multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

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Identification, collection and preprocessing of available data sources and analysis of hazards, exposure, vulnerability and damage under the effects of the global climate change

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2. ABSTRACT

The Spoke VS1-Water is developing a number of outreach products / services for technological transfer of the knowledge developed within the research project. Such products will be demonstrated through the Digital Twin. This report includes sections related to monitoring and data management for two outreach products: ATLAS - nATional fLood informAtion System and NatFIM – National Flood Impact Model.

This report analyses the data structure for the two products, highlighting data sources, coverage, characteristics, possible criticalities.

3. Table of contents

4.INTRODUCTION

The Spoke VS1-Water is developing a number of product / services for technological transfer of the knowledge developed within the research project. Such products will be demonstrated through the Digital Twin.

This report includes sections related to monitoring and data management of two of these products, namely:

- ATLAS - nATional fLood informAtion System
- NatFIM – National Flood Impact Model

An overview of the two products is provided below.

4.1 ATLAS

ATLAS is an information system capable of hosting and managing data in raster, vector, multidimensional matrices and sheet/table formats. ATLAS will host both the data used for the PoCs and produced by the open calls activities. Its structure is expected to host at least the following datasets:

- Maximum annual precipitation values for short and very short durations (sub-daily and sub-hourly) and maximum annual instantaneous and average daily flow values, which are used for research on the statistics of precipitation extremes and floods on small basins and the assessment of the impacts of climate change on extreme events and therefore on flood hazard (paragraphs 4 and 5)
- Spatially distributed precipitation fields with high spatial/temporal resolution, estimated from observations of the national weather radar network combined with ground rainfall observations with high temporal resolution, for the analysis of extreme events on PoCs (par. 2)
- Sheets and maps describing the impacts of extreme hydro-meteorological events, for the analysis of physical processes and damage assessment (paragraphs 3, 5 and 8)
- Geomorphological parameters of river basins, with a specific focus on small-sized basins, for the reconstruction of extreme events and the development and implementation of appropriate modelling
- Parameters for the characterization of soils and the quantification of erosion and runoff in small river basins (par. 6)
- Riverbed descriptors for the reconstruction of flow/debris flow estimates in small basins (par. 3 and 7)
- Cartography for the implementation of models and the evaluation of hazard and hydraulic risk

The ATLAS structure will allow the national scientific community to easily access fundamental information for developing research, overcoming the current main obstacle of data availability. Today the information listed above is often held in scattered databases managed by different bodies or research groups or published in the form of reports such as hydrological annals. Referring to the example of Italian hydrological annals, they are conceived according to a logic that responded to technical and scientific needs of many decades ago, needs that today have evolved towards the request for new information and new types of synthesis processing.

4.2 NatFIM

The product is aimed at developing a model for assessing the impacts (damages) of flood scenarios. The characterization as an "Italian" model refers to both the specific social context and the availability of input data at a national scale.

Specifically, the goal is to propose a tool available in a GIS environment that, once a flood scenario (e.g., water levels, velocities, residence times, etc.) is defined, provides an evaluation of the impacts on various exposed elements as outlined in the Flood Directive. The essential features of the model are as follows:

- Whenever possible, quantitative assessments
- Where feasible and appropriate, assessments in monetary terms
- Primarily focusing on direct damages; indirect/cascading damages are assessed for specific sectors where they are highly relevant
- Results are provided at the meso-scale (census section) and, where feasible, at smaller scales (individual exposed elements)
- In the context of climate change scenarios, the evolution of vulnerability and exposure scenarios is also intended to be considered.

The model primarily assesses the exposed values, and subsequently, appropriate impact/damage functions (vulnerability curves) estimate the expected impacts. Evaluations are carried out separately for different exposed categories. This approach makes the model flexible in both its structure and usage. In particular:

- The global model is composed of independent elements that are easily updatable, modifiable, and replaceable.
- The exposure components can be used independently of the type of hazard (where damage models are hazard-specific).
- Users can choose which categories to evaluate based on their specific objectives.

The intention is to integrate the product as a public service through the Digital Twin platform. Appropriate Proof of Concepts will allow for the assessment of the platform's usability and the significance of the model's results in various contexts, such as risk planning, emergency planning, post-event evaluations, insurance practices, cost-benefit analyses, and more.

A starting point for the product is available, developed within a project funded by the Po River District Authority. The MOVIDA project (sites.google.com/view/movida-project) has provided a model for exposure and damage assessment applicable at the district scale, albeit limited to urban and plain river floods. Within the Return project, the following objectives are set:

- Expand the applicability of MOVIDA to cover the entire national territory.
- Enhance selected impact/damage models based on Return's research activities.
- Add models for specific sectors with characteristics different from those of MOVIDA (e.g., scale of application, input data type, event type, etc.).

Anticipated developments and joint product utilization are expected with other Work Packages within the VS1 Spoke (WP4, related to coastal river flood processes) and other spokes of the project (VS2 for landslide and debris flow damages; VS3 for earthquake and volcanic eruption damages; TS1 for urban environment impacts; TS2 for network damages; TS3 in relation to the cost-benefit analysis (CBA) and multi-criteria analysis (MCA) planned for assessing community resilience

5. ATLAS

ATLAS will be an information system capable of hosting and managing data in raster, vector, multidimensional matrices and sheet/table formats.

The description of the activities reported in the next paragraphs suggests giving ATLAS a structure capable of hosting at least the following datasets:

- Maximum annual precipitation values for short and very short durations (sub-daily and sub-hourly) and maximum annual instantaneous and average daily flow values, which are used for research on the statistics of precipitation extremes and floods on small basins and the assessment of the impacts of climate change on extreme events and therefore on flood hazard
- Spatially distributed precipitation fields with high spatial/temporal resolution, estimated from observations of the national weather radar network combined with ground rainfall observations with high temporal resolution, for the analysis of extreme events on PoCs
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- Cartography for the implementation of models and the evaluation of hazard and hydraulic risk

The ATLAS structure will allow the national scientific community to easily access fundamental information for developing research, overcoming the current main obstacle of data availability. Today the information listed above is often held in scattered databases managed by different bodies or research groups or published in the form of reports such as hydrological annals.

Referring to the example of Italian hydrological annals, they are conceived according to a logic that responded to technical and scientific needs of many decades ago, needs that today have evolved towards the request for new information and new types of synthesis processing.

By way of example, with regards to the observations of raingauge networks, the hydrological annals present summary elaborations of point hydro-meteo-climatological measurements which are affected by the characteristics of the ancient analogue measuring instruments, which made it particularly complex to go below certain temporal resolution. In "traditional" annals the temporal resolution of the summaries never falls below the hour, but it is now well established that, with the latest generation electronic instruments, there is the possibility of analyzing historical series of sub-hourly data, of particular interest for studies on small poorly gauged basins.

The availability in ATLAS of raingauge observations at native resolution, initially on the PoCs, but with the possibility of a future extension to observations of the entire network, will allow us to characterize statistical properties and possible trends over very short durations, with a certain impact on the study of climate changes which appear to be important precisely at these scales, with significant impacts on the overall hydrogeological risk on the Italian territory. Added to this would be a certain improvement in the ability to evaluate the hazard and risk associated with small basins, the triggering of debris flows and urban flooding.

Furthermore, the existence of new sensors cannot be ignored, especially remote sensors, such as weather radar and satellites. The current reports and databases do not allow access to this information, not even in the form of a summary. The integration into ATLAS of synthesis products carefully chosen from the various products derived from these sensors, initially for the PoCs and prospectively for the entire national territory will provide a fundamental contribution to research on hydrometeorological risk.

To populate the database, it cannot be forgotten that there are previous activities that allow both to have examples of systematically collected datasets and to access syntheses already carried out.

In fact, there is consolidated international experience on the creation of databases of hydrometeoclimatic data. ATLAS should interface with these databases, especially those with open access, in order to allow our country to connect to the international hydrometeoclimatic data sharing network, without obviously forgetting the needs of Italian users.

In fact, there is consolidated international experience in the creation of hydrometeoclimatic data databases. ATLAS should interface with these databases, especially those with open access, in order to allow our country to connect to the international hydrometeoclimatic data sharing network, without obviously forgetting the needs of Italian users.

The structure of ATLAS should take into account at least the specifications of the American database CAMELS: (Catchment Attributes and Meteorology for Large-sample Studies):

https://ral.ucar.edu/solutions/products/camels, accessed 18 Sept. 2023

which would allow it to be inserted into the CARAVAN network (Kratzert et al, 2023) or the LAMA-H database (Klingler et al, 2021). This is in order to activate connections with the international scientific and technical community, which would go beyond the duration of the RETURN project. This would contribute to the realization and extension to the international level of one of the main objectives of extended partnerships. The national projects concluded or underway for the digitization of data cannot be ignored either. The results of the FOCA (Claps et al., 2023) and SIREN (Saving Italian hydRological mEasuremeNts):

https://www.diati.polito.it/focus/siren. Accessed 18 Sept. 2023

projects of the Polytechnic of Turin will be considered for integration into ATLAS. Added to these are the datasets owned by the scientific community and the National and Regional Environmental Protection Agencies. For example, the average monthly rainfall and temperature data on a 1 km grid at a national scale from the BIGBANG hydrological balance model (Bilancio Idrologico GIS BAsed a scala Nazionale su Griglia regolare,

https://www.isprambiente.gov.it/pre_meteo/idro/BIGBANG_ISPRA.html . Accessed 6 Oct. 2023

and the national system for the collection, processing and dissemination of climate data (SCIA) of ISPRA (Desiato et al., 2007). It is therefore advisable to carry out a preventive information collection activity on existing data, before starting any project for the digitalisation of historical data.

Below is a preliminary list of the datasets that are expected to be included in ATLAS.

1. Time series of annual maximum of instantaneous and daily flow rates
2. Time series of average daily flow rates
3. Time series of annual maximums of precipitation for the durations 1,3,6,12 and 24 hours
4. Time series of annual maximum of precipitation for periods of several consecutive days

5. Time series of annual maximum of sub-hourly precipitation
6. Time series of daily rainfall
7. Time series of daily min-max temperature
8. Mosaic cartography of flood hazard on a national scale
9. Maps of flooded areas (extent, depth when available) PoCs
10. Surveyed flood extent and/or damage maps for selected events
11. Damage detection sheets
12. Rainfall series of interest for PoCs at the native resolution
13. Hourly radar precipitation product for PoCs merged with raingauge data
14. National High Resolution DTM
15. LIDAR derived high resolution (1m) DTM of the flood-prone areas
16. Geomorphological catchment attributes
17. Soil, land cover and NDVI catchment attributes
18. Climatological catchment attributes

5.1 Flood and sediment cascades in mountain basins

This paragraph introduces the problem of modeling flood and sediment cascades in mountain basins, with a focus on the data necessary for modeling.

The analysis of the most recent flood events in European mountain regions highlighted considerable shortcomings in the current procedures used in natural hazard and risk assessment due to inherent system dynamics. Conventional numerical hydrodynamic and morphodynamic river models are not necessarily reliable for the prediction of process patterns since internal system dynamics, such as changing solids concentration along the flow path, are not sufficiently represented. In particular, the effects of temporally changing channel morphology and the reduction of cross-sectional areas due to clogging were found to significantly amplify process magnitudes and frequencies. To improve hazard and risk analyses and to support decision-making, flood scenarios and hazard assessments need to be re-established based on such processes. Temporal and spatial variations of process characteristics—often as a consequence of the coupling between hillslope and channel processes and interdependencies need to be assessed and included in modelling approaches, namely: the type of flow (e.g. debris flow, debris flood, water flood with bedload transport) occurring along the channel network; the location and magnitude of channel adjustments (e.g. bed and bank erosion, bed aggradation/incision); the volume of sediment transported; and the spatial pattern of inundation (Mazzorana et al., 2011).

Such assessments bring about different sources of uncertainty affecting the predictability of hazard patterns, i.e., those due to an intrinsic variability (aleatory uncertainties), and those stemming from a lack of knowledge (epistemic uncertainties). By including these uncertainty issues in the decision-making of natural hazard management, the nature of the decision to be made will be changed. Concerning uncertainties in natural hazard management, the determination of hazard scenarios for mountain streams has to include (Mazzorana et al. 2009):

1. uncertainties about the main variables describing the flow, i.e., peak discharge as well as flood hydrograph shape and duration, sediment transport rate, volume and concentration (and thus type of flow), rates of wood transport. Overall, this set of variables can be referred to as the loading system variables.

2. uncertainties in the spatial pattern of hazard propagation due to obstructions at critical cross-sections, small-scale topography, and abrupt morphological changes during a flood event. These uncertainties determine the response system scenarios.

3. uncertainties concerning the functionality and effectiveness of the technical protection system (e.g. related to possible failures of levees and check-dams, sediment dosing efficiency of retention basins). Uncertainties of this type may have consequences on both the loading and response system variables.

In order to address the uncertainties outlined above, the explicit use of flood event scenarios is beneficial because it provides a clear, rational method to recognise the inherent stochastic behaviour of natural processes (Figure 1). Scenarios refer both to the possible 'loading' conditions (in terms of water, sediment and wood material) built up in the basin by means of a process routing throughout prevailing one-dimensional process propagation domains (1D domain, hereafter 1DD) as well as to events taking place along stream segments potentially prone to flood areas with prevailing two-dimensional flow characteristics (2D process propagation domains, or 2DD). Therefore, 1DD scenarios are built for the entire drainage network but are most relevant for the valley-confined reaches (i.e. where floodplain surfaces are virtually absent and hillslope-channel processes are tightly coupled), whereas 2DD scenarios are established only for those segments where relevant inundation can occur as in semi- to unconfined reaches (i.e. where valley floor is substantially larger than the channel, as in presence of alluvial fans and floodplains).

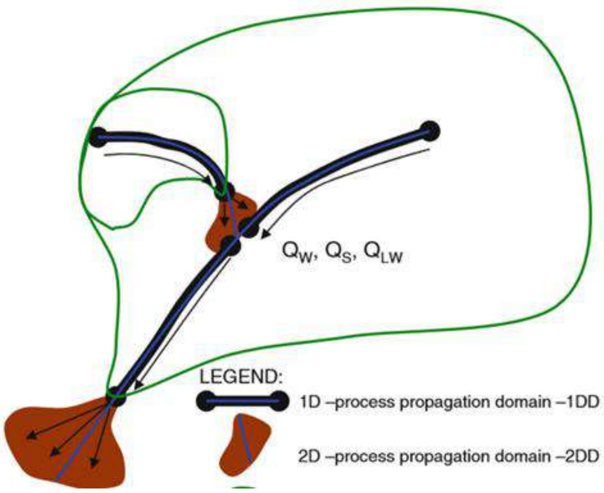

Figure 5.1: flood event scenarios

Hazard scenarios within the 1D domains aim to determine, for any given cross-section along the channel network and for the assigned return interval the expected type of flow (i.e. debris flow, debris flood or bedload-water flows), the flow hydrograph QW, the sediment transport rates QS, and wood transport rates QLW. Such values are the upstream boundary conditions for determining hazard scenarios within the 2D domains. Moreover, such scenarios allow to localise sediment and wood sources and to determine the most likely sites of morphological changes (e.g. bank erosion, bed incision) at multiple scales; thus allowing for an improved design of technical mitigation measures. An appropriate way to analyse channel networks in the 1D domains is to adopt a geomorphologically-based river segmentation as the one proposed in the IDRAIM methodology (Rinaldi et al., 2014), taking advantage of sediment and wood connectivity maps (Cavalli et al., 2013). Hazard scenarios within the 2DD aim to draw, starting from the 1DD output, reliable hazard maps on floodplains, alluvial and debris fans by means of a spatial analysis of the inundation patterns. It is worth noting that more than one 2D domain can be present in a basin, and the larger the basin, the more (and more extended) 2DD are likely to be identified.

Preliminary steps

-Channel segmentation carried out following IDRAIM methodology (based on DTM, geological map, sediment connectivity, presence of artificial structures, channel pattern)

-Delineation of floodplains and alluvial/debris fans based on geomorphological evidence

Required information at the reach scale for events of different recurrence interval:

-Type of process (floods, debris floods or debris flows) at each stream reach, based on geomorphological evidence, historical records, geomorphometric indices

In case of floods/debris foods:

-Water hydrograph (from hydrological models accounting for climate change scenarios)

-Bedload rates and maximum grain size transported (based on the most suitable transport capacity equations for reach characteristics, accounting for form drag correction and possible supply-limitations)

-Total wood transport volumes and maximum log size (based on an integrated geomorphological-forest assessment)

In case of debris flows:

-Initial debris flow hydrograph (based on the most suitable method/model for the specific case)

-Erodible sediment volumes along the channel (based on geomorphological analysis)

-Estimation of debris flow volumes at the outlet

-Debris flow propagation along the channel (based on the most suitable rheology for the specific case)

-Total wood transport volumes and maximum log size transported by the debris flow

-Presence/abundance of large boulders in the flow (based on sedimentological/morphological evidence)

Remote sensing data (from aircrafts or UAV):

-High-resolution DSM and DTM of the catchment (LiDAR, Digital photogrammetry)

-High-resolution orthophotos

-For channels of sufficient width and exposure, grain size distribution based on photo-sieving

Field based data and information

-Channel pattern/morphology at the reach scale (based on IDRAIM)

-Surface grain size based on pebble counts for each reach

-Average channel width (for reaches where this cannot be assessed from remote sensing)

-Assessment of potential sediment supply from channels and lateral sources

-Evidence of sediment and wood connectivity from slopes to channels

-Presence and estimated functionality of artificial structures during events

5.2 Statistics of intense precipitation and floods, spatiotemporal variability and uncertainty: the case of small mountain and urban catchments

Rainfall statistics over the po river basin

In regions with almost flat orography, the evaluation of the statistics of intense precipitation over small basins can be handled with relatively simple approaches, such as interpolation methods that do not require to consider other spatial covariates. A reliable estimation of rainfall statistics and thus high return period rainfall quantiles is instead particularly challenging in data-scarce or orographically complex areas: in regions with significant elevation variability, the interpolation requires methods that can explicitly account for the elevation effect.

Dataset

The Improved Italian – Rainfall Extreme Dataset (or I2-RED; Mazzoglio et al., 2020), a collection of sub-daily (1, 3, 6, 12, and 24h duration) annual maximum rainfall depths measured from 1916 up to the present by more than 5000 rain gauges, allowed to extract about 3800 time series spanning at least 10 years to estimate average sub-daily annual maxima (the so-called "index rainfall") across Italy. Even though an unprecedented rainfall data coverage is now available, the search for algorithms that predict extreme rainfall indices based on local data still faces a marked spatial data heterogeneity in station density due to complex orography, with changes up to half an order of magnitude in different areas of the country.

Methodology

In this work, we approached this topic by exploring the spatial variability of the index rainfall in areas with complex terrain features, considering the influence of local orographic gradients. Our approach incorporated a local georegression model that accounts for elevation-dependent variations in the index rainfall in each 1 km grid cell used to segment Italy.

To estimate the parameters of the local regression in every (x,y) position, a "local" reference sample must be identified with a number n of stations included in an area adequate for a regression. We proceed by selecting n stations available in a circular area of radius r, whose center coincides with the centroid of the grid cell to which the regression is referred. The length of the radius and the minimum number of stations required for reaching a reasonable local estimate are parameters that have to be conveniently tuned. To define the most appropriate radius of the area needed for selecting the local sample, in this work two approaches have been adopted: a) to use a unique, fixed radius r = rfix; b) to use a radius interval, variable from rmin to rmax, that depends on data density.

To prevent the occurrence of anomalously high (positive and negative) rainfall local gradients, we envisaged imposing a minimum elevation range Δz (i.e. the difference between the highest and the lowest rain gauge) to undergo the regression analysis.

We also addressed challenges related to extrapolation difficulties at high and low elevations by testing different model configurations.

Results

The mentioned local regression approach demonstrates to improve the description of the spatial variability of the average annual maximum rainfall depths for short durations (1, 3, 6, 12, and 24 h) over Italy. The proposed method optimizes the interpolation through the selection of small samples that emphasize the value of high local density of stations.

By considering local topographic effects, our model enabled the generation of maps depicting average extreme rainfall patterns at 1 km resolution.

Our findings also revealed a predominantly negative orographic gradient (inverse orographic effect) for 1-hour extremes in large mountainous areas, while 24-hour mean rainfall extremes typically exhibit positive orographic gradients, with a few exceptions in mountainous regions. These results align with prior studies conducted in smaller areas.

The maps and the methodological results presented in this work, which mainly regard the analysis of the spatial variability of the index rainfall, provide a baseline that can be important in view of regional rainfall frequency analyses, aimed to estimate high return period rainfall quantiles. This in-depth investigation will allow us to work on an improved version of the Patched Kriging methodology (Libertino et al., 2018) that incorporates a local-scale regression model between precipitation extremes and elevation. The above-mentioned geostatistical methodology allows the quantification of the spatio-temporal variability of rainfall extremes by reconstructing data in ungauged sites (and missing years). The uncertainty is instead handled by introducing the kriging variance as a weight in evaluating the L-moments of the precipitation extremes. A first application of this new methodology is currently ongoing over the Po river basin.This paragraph introduces the problem of modeling flood and sediment cascades in mountain basins, with a focus on the data necessary for modeling.

Flood uncertainty due to rainfall heterogeneity in the Turin drainage network

In urban areas, drainage networks are usually formed by small subnetworks, hence resulting in small-sized basins with fast times of response. For this reason, prediction of pluvial flood hydrographs in urban basins is hampered by considerable uncertainty due the spatial and temporal variability of rainfall intensity, which is difficult to characterise with the sparse observations from the limited number of rain gauges that is typically available. Information on the response of a drainage network to different spatial patterns of rainfall can be helpful in 1) guiding the design of monitoring networks of rain gauges, and 2) providing indications on the expected uncertainty of modeled flood predictions in ungauged urban basins.

Dataset

The drainage network of Turin is considered as a case study to better understand and quantify the uncertainty of flood hydrographs to different rainfall patterns. Hydraulic models have been developed using the EPA-SWMM software for the different sectors of the stormwater drainage network; the information to build the models were derived from vectorial files of the network structure and conduit materials provided by the city water utility. Additionally, 20 rain gauges have been installed on the network to improve the spatial resolution of rainfall monitoring compared to the available data from the existing rain gauges. Moreover, 11 flow monitoring sensors were deployed on the final sections of some network sectors to measure the response - in terms of flood hydrograph - of the network to different observed rain events.

Methodology

First, the spatial and temporal variability of rainfall intensity over the city of Turin has been assessed using the set of available rain gauges. Then, the sensitivity of flood hydrographs at the network outlets is investigated using both observed and synthetic rainfall hyetographs:

- for the observed rain events, the developed hydraulic models have been used to simulate flood hydrographs using rainfall data from different rain gauges in the same network basin. Both constant hyetographs (derived from each rain gauge and applied to the whole catchment) and spatially distributed hyetographs (derived from spatial interpolation of different rain gauges) were considered, and differences in model performance have been used to infer the true spatial pattern of precipitation.
- for the synthetic rain events, spatial patterns of rainfalls with different peak locations and spatial heterogeneity are being currently generated. The use of synthetic events is aimed to explore how the spatial structure of rainfall can influence the shape and peak flow of flood hydrographs in a systematic way. The spatial structure of the generated rain events is chosen to represent in a simplified way the actual statistical properties of real rain events.

Results

Average rainfall intensity has been found to exhibit spatial variations over the city of Turin. On the one hand, the average intensity of short rain events (e.g., 1 h duration) is slightly higher in the city center than in peripheral areas, suggesting a potential influence of the higher urban temperatures on the intensity of convective rain events. On the other hand, longer rain events (e.g., 24 h duration) tend to be lower on hillside areas in the eastern part of the city compared to the areas with lower elevations of the western parts, possibly reflecting the influence of hill topography on air circulation at the urban scale.

The analysis of real rain events has revealed that the flood hydrograph is sensitive to the location of the peak even in small (4.4 km2) urban basins. This finding indicates that a dense network of rain gauges would be necessary to monitor the spatial rainfall heterogeneity in a way that allows to reliably predict the flood hydrographs. However, in many situations researchers and water managers must rely on information obtained from a single and relatively distant rain gauge. This fact stresses the need to better understand the uncertainty in predicted hydrograph that arises from the limited knowledge of the spatial variability of rainfall intensity. The analysis of this uncertainty is currently under study using synthetic rain events as described in the methodology section.

5.3 Urban catchments: data specifications for modelling of urban floods

Due to the limited extension of the urban catchment areas, with a high density of buildings and largely impervious surfaces, rapidly evolving pluvial floodings are typically experienced in cities resulting from the inefficiency of the urban drainage system in terms of the hydraulic failure of the storm water pipes and/or the insufficient capacity of the storm drain inlets. In the Mediterranean region, this is accompanied by a rainfall climatology characterized by short-duration and high-intensity events, which typically show a quite limited spatial extension and very rapid evolution, therefore hard to be captured by the traditional monitoring networks. Urban areas are also affected by riverine floods, from the overtopping of either large rivers in flat regions or small streams (often covered) in orographically complex and steep areas. This section only focuses on the pluvial flooding phenomena.

Since the storm water drainage in the urban texture is structured in a great number of small-size catchments, usually smaller than the typical spacing of rain gauge stations (although these generally have a higher density than in rural regions), urban catchments are often ungauged. In this section, the case in which a rain gauge station is available within the investigated catchment area is considered, together with the possible alternatives in case of ungauged basins including the integration of the closest rain gauge measurements with information derived from radar maps and opportunistic sensors.

The accuracy and the level of information of each source of data that contribute to the modelling of pluvial flood events (first of all the rainfall intensity measurements) are also examined in this section. For instance, corrected rainfall measurements are essential to estimate the role of the propagation of the instrumental measurement bias affecting rain gauge measurements into the modelling of the pluvial flood scenarios especially because of the typical instrumental bias (see e.g., Cauteruccio et al. 2021) affecting the high rainfall intensity measurements (RI > 100 mm h-1) with underestimation larger than 10%. After appropriate correction the measurement bias may become lower than 5% within the whole measurement range.

The link between the time resolution of rainfall measurements and the extension of the urban catchment to conduct pluvial flood studies is not unique. Radar maps may support in estimating the relationship between the spatial and temporal scales but have the disadvantage to provide rainfall estimation at a spatial resolution comparable with the size of the urban catchment. This means that, in many cases, one or very few pixels of the radar map are overlapped to the investigated area. Moreover, radar estimates provide rainfall intensity values that are smoothed if compared with in-situ measurements. This suggests that the use of radar to estimate the actual rainfall intensity at very fine spatial scale is not applicable. However, the positive contribution regards the potential to observe the dynamic evolution of precipitation events. Despite radars are commonly used to show the real time dynamic evolution of the precipitation event, by exploiting sequences of radar maps for historical rainfall events the predominant combinations of rainfall intensity and duration associated with a specific rainfall climatology can be established.

The development of opportunistic sensors is a recent innovation in the measurement of precipitation intensity (Giannetti and Lanza, 2023), suggesting a high potential for large-scale application due to the low cost of their installation and operation. Already existing, but usually unrelated, microwave (MW) or millimetre wave (mmW) links are used to infer the rainfall amount or intensity by interpreting the extra attenuation induced by the precipitation on the received signal level. Various communication technologies can be exploited, such as commercial MW links (CMLs) of cellular phone networks, satellite MW links (SMLs), including broadcast satellite links (BSLs), but also wireless sensor networks (WSNs), e.g., for Internet of things (IoT) applications, moving vehicles, surveillance cameras, etc.

Further aspects that concur to the estimation of the pluvial flooding risk are related to assessing the exposure, intending the type and numerosity of objects prone to be mobilized by flood water, being damaged themselves and acting as a source of danger for human safety. The work performed in this section aims to extract useful information from available aerial imagery, specifically extracting movable objects from aerial photos of urban areas. These objects encompass a diverse range of items, including vehicles, waste bins, shopping carts, and construction debris. To accomplish this objective, computer vision methods are used by leveraging the power of artificial intelligence to detect and classify these objects within the captured imagery. To accurately identify vehicles within the dataset, advanced vehicle detection algorithms based on deep learning techniques can be employed. These algorithms leverage the power of convolutional neural networks (CNNs) to extract and analyze complex features from the aerial images, enabling precise vehicle detection even in challenging conditions.

As a proof of concept for this section, a densely built urban catchment was chosen within the Metropolitan area of Genova (Italy), that was recently affected by a pluvial flooding even associated with a rainfall event characterized by a low return period (T from 1.5 to 3 years). The investigated urban catchment has an extension of about 1.5 km2 and is in the West part of Genova, in the Sampierdarena district. The area is characterized by a flat zone of about 1 km2 confined to the North by hills and to the South by the seaport. The investigated urban catchment is equipped with a traditional tipping-bucket rain gauge station and covered by the meteorological radar (a doppler and polarimetric GPM250C radar in the C band) positioned on the Settepani mountain, both managed by the environmental protection agency of the Liguria region (ARPAL). Within the investigated urban area, one Smart Rainfall System (SRS) – an opportunistic sensor used to estimate rainfall intensity in real time by processing the attenuation of microwave satellite link signal measured by low-cost devices – is also positioned and other two sensors are available close to the investigated area: in Borzoli at 2.5 km to the West and in Castelletto at 3.7 km to the East. About thirty years of rainfall intensity measurements (from January 1st, 1988, to December 31st, 2021) from a tipping bucket rain gauge are available from the meteorological station of the department of Civil, Chemical and Environmental engineering (DICCA) at the University of Genova (at about 7 km to the Est), for statistical and accuracy analysis of the rainfall information.

A detailed database of the surface drainage system, from both in-situ survey and manual digital images interpretation, is available from the previous project "RUN – Urban Resilience: Now-casting of flood risk using IoT sensors and Open Data" funded under the POR FESR 2014-2020 programme. A total of 3045 inlets were categorized in terms of type, size, and maintenance condition (degree of clogging).

Digital Terrain Models at the spatial resolution of 1 and 5 m, available from the regional and municipal cartographic repositories are used to perform morphological analysis of the area and to identify the depressed areas where the probability of pluvial flooding is the highest. From the same repositories, aerial photographs at the resolution of 25, 10 and 5 cm were obtained.

The flat area of the investigated urban catchment was subject to pluvial flooding during the rainfall event occurred on September 24th, 2022. In figure 8.1 rainfall intensity measurements at five-minutes resolution as provided by the ARPAL rain gauge are compared with those derived from the SRSs. These sensors measure the received power along a microwave link crossed by precipitation, sampled at one-second resolution, and provide rainfall intensity estimation at one-minute resolution. The cumulative rainfall depth measured by the ARPAL rain gauge is equal to 75 mm, in agreement with those provided by the three sensors, equal to 79, 78 and 74 mm from West to Est, respectively. The peak ratio between the SRS-Borzoli and the SRS-Sampierdarena is equal to 0.80, while it is equal to 0.68 between SRS-Castelletto and SRS-Sampierdarena. Finally, the peak ratio between SRS-Sampierdarena and the ARPAL rain gauge is 0.60 meaning that the SRS allows an approximate characterization of the rainfall event responsible for the urban flooding, especially when it is not positioned within the investigated urban catchment.

The return period of the investigated rainfall event was estimated using Depth–Duration– Frequency (DDF) relationships derived from the DICCA rainfall time series from one-minute raw and corrected rainfall data (obtained after applying suitable calibration curves derived in the laboratory as requested by the European norm EN 17277/2019). In the right-hand panel of Figure 5.2, the derived DDF curves are shown to highlight that uncorrected measurements produce an underestimation of the rainfall depth, per each duration, with any given return period. This underestimation increases with the return period. Since ARPAL rain gauge measurements are not corrected for the instrumental bias (personal communication from the ARPAL staff), the comparison with the corrected DDF curves leads to some underestimation of the return period that would affect the design of potential structural adjustments of the drainage network

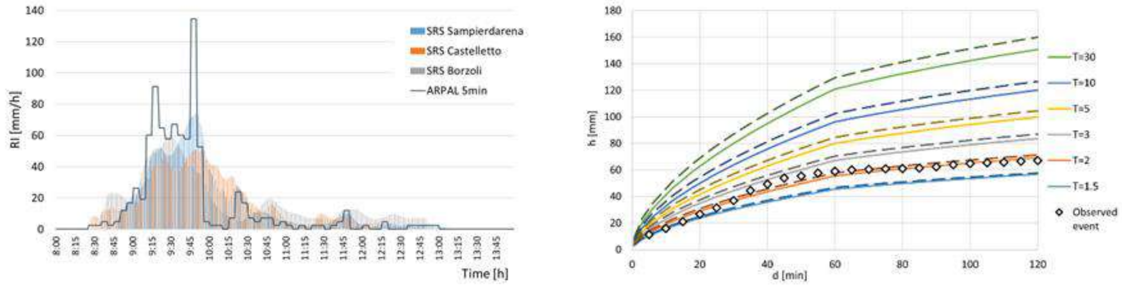

Figure 5.2: left-hand panel: comparison between rainfall intensity measurements provided by the three SRSs at one-minute resolution and ARPAL rain gauge measurements at five-minutes resolution for the September 24th, 2022, event. Right-hand panel: DDF curves for various return periods (T expressed in years) as derived by one-minute raw (continuous lines) and corrected (dashed lines) rainfall intensity measurements from the DICCA rain gauge with overlapped the observed event measured by the ARPAL rain gauge in terms of the maximum depth recorded per each duration (white diamonds).

The dynamic evolution of the investigated rainfall event is shown in Figure 5.3, in terms of rainfall intensity maps as provided by the meteorological radar. In each map, the black square indicates the position of the investigated urban catchment area. The analysis shows that the rainfall event crosses the investigated area in about forty minutes. At 9:15 the rainfall intensity is about 20 mm/h and in just five minutes this value is doubled and persists for further fifteen minutes. At 9:45 the rainfall intensity value drops to about zero and the maximum peak measured by the rain gauge is not detected. The rainfall intensity values provided by the radar are about a half of those measured by the rain gauge. This means that a stand-alone adoption of radar maps for pluvial flood studies is not encouraged, while rain gauge measurements at a resolution equal to five minutes or finer (e.g., one minute) allow to capture the main features of the rainfall event. A lower time resolution, up to fifteen minutes, can provide intermediate results while data at a time resolution larger than this value can only support pluvial flood studies with some approximation.

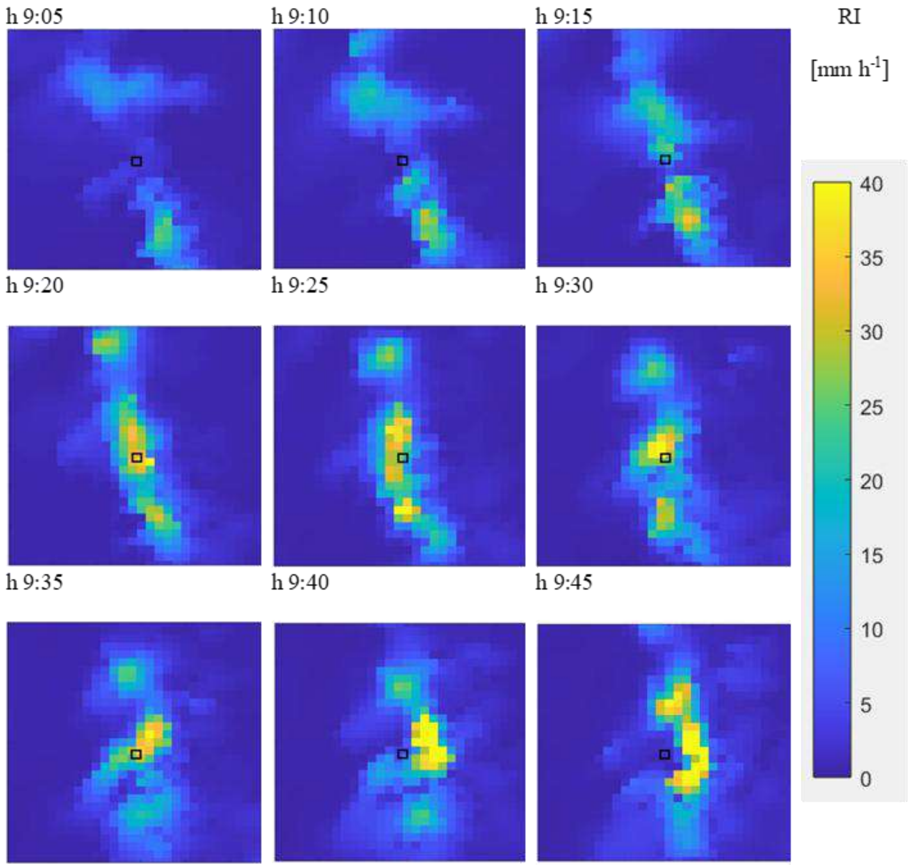

Figure 5.1: dynamic evolution of the rainfall event occurred on September 24th, 2022, as measured by the ARPAL meteorological radar. The pixel size is equal to 1 km in both directions. The black square indicates the position of the investigated catchment area.

Some real-world challenges that should be considered in aerial photo object detection and that are relevant in the present work are as follows. 1. Shadow in photos: In aerial images, due to tall buildings and sunlight, numerous shadows are present in the photos. It is worthwhile to employ shadow removal methods before applying object detection techniques. 2. Small vehicle size: Considering a spatial resolution of 10 cm and average vehicle size of 3 by 5 meters, each vehicle occupies approximately 30 x 50 pixels which is very small in comparison with the total pixels of the images and with the size of target objects in most of the object recognition tasks in remote sensing. 3. Limited spectral variability: Vehicle objects in aerial images often have a limited spectral variability, making them difficult to distinguish from other objects in the scene, such as structures on the roof. 4. Lack of large-scale and well-annotated dataset: Deep learning methods have achieved remarkable results in object detection tasks, but training these models effectively requires a large-scale and well-annotated dataset. To address this challenge, this study leverages pre-trained models and other previously published datasets to develop a new dataset.

An accurate analysis of the scientific literature has been conducted, the deep learning-based approach has been adopted to address shadow-related issues. For vehicle detection in aerial images, first, a high-quality annotated dataset is being developed for the Sampierdarena site, combining pre-trained deep networks and visual photointerpretation. For this purpose, the initial stage involves fine-tuning pre-trained object detection networks like YOLO and Faster R-CNN (Ammar et al., 2021) using readily available annotated aerial image datasets. This fine-tuning process ensures that the networks are better equipped to handle the specific characteristics of aerial imagery. Following this, images from our custom dataset are introduced into the fine-tuned network to be classified. The final step involves manual examination of the network's outputs to rectify any errors in the results. This manual refinement process ensures the accuracy and reliability of the annotated dataset.

The resulting high-quality annotated dataset can then be employed for training and evaluating customized networks tailored to our specific object detection needs. To achieve this objective, various strategies can be employed and are being methodologically considered, including the implementation of feature pyramid networks (FPNs) and attention mechanisms (Shen et al., 2022). While previous works on vehicle detection in aerial imagery have not been directly utilized for pluvial flood studies, a major novelty of this study lies also in incorporating the enhanced mapping results into pluvial flood modeling.

5.4 Characterization of soil, runoff and soil loss in small catchments

Development of innovative techniques of soil hydraulic characterization in the perspective to obtain a relevant parameterization of runoff simulation models, also with reference to fire-affected soils

The developed activity was oriented towards the study of the infiltration process and the hydrodynamic characterization with reference to soils with an upper altered layer or in the case of a reduced experimental information. In particular, experimental, numerical and theoretical investigations were carried out with the following specific objectives: i) experimentally testing water pouring height effects on soil hydrodynamic characterization performed by beerkan infiltration runs; ii) experimentally testing the hydrodynamic response of a soil subjected to a spatially variable wetting; iii) numerically exploring a three-dimensional infiltration process in the case of a layered soil with a more compacted and less conductive upper soil layer overlying a less compacted and more conductive subsoil; and iv) theoretically developing a new BEST (Beerkan Estimation of Soil Transfer parameters) algorithm yielding estimates of soil sorptivity and saturated hydraulic conductivity even in the absence of soil water content data.

Water pouring height effects

Performing beerkan infiltration runs with different heights of water pouring could help to obtain saturated soil sorptivity, S, and hydraulic conductivity, Ks, data usable to explain and simulate hydrological processes but the soil response can vary during the year. Therefore, water pouring height effects on the S and Ks values were tested in different sampling dates in a loam soil.

Soil alteration due to the mechanical impact of the applied water appeared almost completed by the end of the runs in all cases but in a more advanced stage when the soil was initially more sorptive and conductive. Overall, the H (high; height of water pouring = 1.5 m) runs yielded 2.3-2.8 times smaller S values and 8.5-14.5 times smaller Ks values than the L (low; heigh of water pouring = 0.03 m) runs but differences between the L and H methodologies varied during the sampling period. In particular, these differences were smallest when the soil was initially relatively wet and little sorptive and conductive and largest in the opposite conditions. Overall, the H runs described a soil that was less sorptive, less conductive, more spatially homogeneous and more temporally stable than the L runs.

The L-H methodology should be further tested in the perspective to develop simple field methods to determine the hydrodynamic properties of both nearly undisturbed and intensively disturbed soils.

Spatially variable wetting

Different points in a field can be wetted with different natural or artificial rainfall amounts and intensities. Therefore, a non-uniform soil wetting could occur during short-term monitoring of soil hydrodynamic parameters and its global effect on soil characterization is not easily predictable.

For an initially dry loam soil, a sequence of three beerkan infiltration runs was performed at fixed sampling points in a period of two weeks. Immediately after the first beerkan run, the soil was perturbed by adding an additional water volume differing with the sampling point by the amount of water (from 0 to 227 mm) and the application methodology (rainfall simulation, another beerkan run).

As compared with the initial conditions, the soil infiltration parameters (mean, initial and final infiltration rates; constant of the Horton's infiltration model) decreased by 2.9-4.3 times after wetting. A decrease of these parameters by 1.6-2.3 times remained detectable at the end of the sampling period, even if the soil likely returned to wetness conditions close to the initial ones. A link was recognized between the infiltration parameters determined in the subsequent runs of the sequence. The correlation was stronger when the initial runs were compared with the last runs than with those performed immediately after the intermediate wetting.

The hydrodynamic response of a disturbed soil appears overall related to that of the initially undisturbed soil even if the disturbing agent is not exactly the same over the sampled area.

Layered soils

With reference to a more compacted and less conductive upper soil layer overlying a less compacted and more conductive subsoil, a simple three-dimensional (3D) infiltration run is expected to yield more representative results of the upper layer than the subsoil. However, there is the need to quantitatively establish what is meant by more representativeness.

Numerically simulated infiltration was investigated for a theoretically unconfined process under a null ponded head of water. The considered layered soils differed by both the layering degree (from weak to strong; subsoil more conductive than the upper soil layer by 2.3 to 32.4 times, depending on the layering degree) and the thickness of the upper soil layer (0.5-3 cm).

It was confirmed that water infiltration should be expected to be more representative of the upper soil layer when this layer is the less permeable since, for a 2-h experiment, the instantaneous infiltration rates for the layered soil were 1.0-2.1 times greater than those of the homogeneous low permeable soil and 1.3-20.7 smaller than those of the homogeneous coarser soil that constituted the subsoil. Similarity with the homogeneous fine soil increased as expected as the upper layer became thicker. For a weak layering condition, the layered soil yielded an intermediate infiltration as compared with that of the two homogeneous soils forming the layered system. For a strong layering degree, the layered soil was more similar to the homogeneous fine soil than to the homogeneous coarse soil. A sequential analysis procedure appeared usable to detect layering conditions but with some modifications as compared with the originally proposed procedure.

This investigation contributed to better interpret 3D infiltration processes in soils composed of a less conductive upper soil layer overlying a more conductive subsoil and it also confirmed that the infiltration data contain a signal of the time when layering starts to influence the process.

New BEST algorithm

The BEST algorithms allow estimation of soil sorptivity and saturated soil hydraulic conductivity, using the transient and steady-state stages of a three-dimensional infiltration process. However, these algorithms can only be applied to the cases that the initial and the saturated water content values are known. A new BEST algorithm yielding estimates of soil sorptivity and saturated hydraulic conductivity even in absence of soil water content data was theoretically developed. By applying the existing and the new BEST algorithms to infiltration curves simulated by an analytical model, the accuracy of estimated S and Ks parameters was determined. Both the existing and the new algorithms allowed estimation of these hydrodynamic parameters with a good degree of accuracy.

Measurement of runoff, soil loss and sediment yield at the Sparacia experimental station at both the plot and small watershed scale

The developed activity concerned the contribution to the compilation of a European open-access database of water discharge and sediment yield using data collected in the experimental basin named SPA1. The latter is located at the Sparacia experimental station for soil erosion measurement of the Department of Agricultural, Food and Forestry Sciences- University of Palermo. The experimental station is located in western Sicily, Italy, approximately 100 km south of Palermo. The area has a typical Mediterranean semi-arid climate with an average annual rainfall of approximately 700 mm. The wet period of the year extends from October to March.

The basin area is about 4 ha, with a maximum elevation of 455 a.s.l. and slopes ranging from 0 to 30%. A Vertic Xerochrept soil covers the whole basin; the A horizon is 30 cm deep with a clay texture and a massive/blocky structure.

At the basin outlet, a 16 m-long measurement channel, with a rectangular cross-section (width of 0.12 m and height of 0.3 m) and a horizontal bottom is equipped. The channel ends with a sedimentation tank. A Khafagi-Venturi (KV) meter (Hendress and Hauser), having a contracted cross-section width of 0.048 m, was installed 4 m apart from the end of the measurement channel.

For each rainfall event producing sediment transport, sediment yield was measured by sampling the suspension or by weighing all solid materials stored in the tank. Sampling was used for suspensions having sediment concentration values less than or equal to 15–20 g/l. The suspension was well mixed before the sampling of 15 samples in five cross-sections of the tank, used for calculating the mean concentration. For each event, the sediment yield was calculated as the product of the mean concentration and the measured suspension volume. For higher values of the mean concentration, the total weight (liquid and solid fractions) of the stored suspension was measured, and a representative sample was collected to be oven-dried to determine the dry solid fraction of the suspension. Upstream of the KV meter, an ultrasonic probe measured the water depth with 1 min resolution. The use of the latter and the stage-discharge relationship allowed runoff measurement.

The research group responded to a call of interest for participation in the EUropean SEDiments collaboration (EUSEDcollab) database (Matthews et al., 2023), issued by the Joint Research Centre (JRC) as part of the erosion working group within the EU Soil Observatory (EUSO). The EUSEDcollab is a multi-source platform containing over 1600 catchment years of water discharge and sediment yield time series measurements collected in small to medium-sized catchments across ten European countries (Figure 4) (catchment area: median = 43 km2, min = 0.04 km2, max = 817 km2). The EUSEDcollab was compiled to overcome the scarcity of open access data at relevant spatial scales for studies on runoff, soil loss by water erosion, and sediment delivery.

A dataset consisting of sediment yield and runoff volume, measured at the event scale from 1997 to 2020 at the SPA1 basin, was compiled and shared to a centralized data repository for harmonization and quality-checking efforts aimed at creating a standardized database from the multiple data contributors. Data processing provided the first data release (EUSEDcollab.v1) of a continuing collaboration and data collation campaign through the EUSO, with the broad objective of converging scientific knowledge, people, and data for research and policy-related objectives in Europe

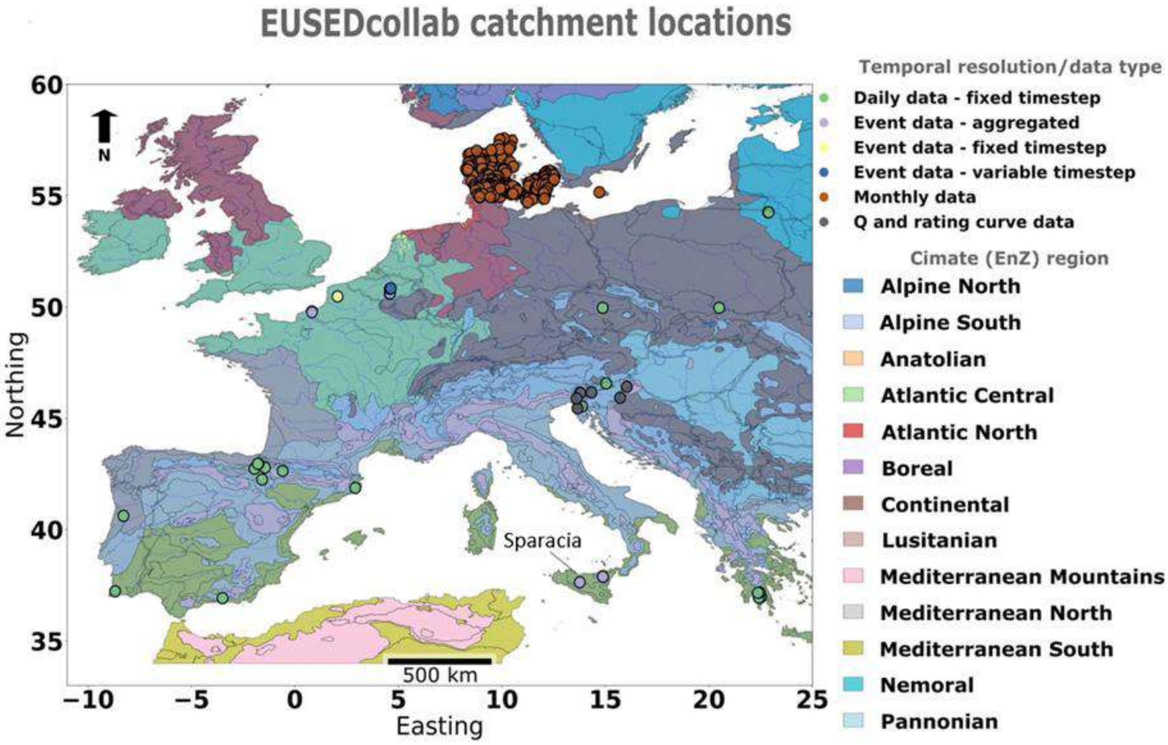

Figure 5.4: - A geographical overview of EUSEDcollab.v1 data entries per climate (EnZ) region in Europe (from Matthews et al., 2023)

5.5 Riverbed descriptors: techniques for field survey of 'easy to measure' hydraulic, morphologic and material parameters.

Monitoring and data collection

Measuring the flow characteristics in rivers is a key factor for the hydrologic cycle, flood forecasting, water resources management and climate change issues. Traditional flow velocity measurement techniques are costly, time-consuming, difficult to use and not safe for operators especially during high flows, when flow depth can significantly change and high flow velocities might occur.

In this context, the aim of the activities conducted in the context of the present DV2.1 is the identification of suitable techniques for field survey allowing us to easily measure hydraulic and morphologic parameters, as well as the development and the application of reverse flow routing techniques for the discharge estimation in ungauged and/or poorly observed basins.

To this aim, image-based techniques are applied to estimate the free surface flow velocity distribution.

In particular, on the contrary to classical LSPIV procedures, only moving grains and natural tracers are used in the proposed image-based technique (Termini and Di Leonardo, 2018). One of the challenges in the application of this technique is the determination of the error in estimating surface velocity and the error quantification is complex because it depends on many factors (Termini and Di Leonardo, 2018). A preliminary calibration has been operated in a channelized reach in the Oreto River (in Sicily) by comparing the values of the free surface velocity estimated by the image-based technique in a selected cross-section of the river reach with those measured with ADCP measurement instrument (Figure 5.5). Further sensitivity analyses will be conducted to estimate the influence of specific parameters (such as the number of frames to be processed or the dimension of the interrogation area) on the velocity estimated values examining the efficiency of the digital image-technique for remote monitoring of surface velocity and flow discharge.

The data collected will be then used for the application of a 1-D model (Termini, 2011) to estimate the sediment transport process.

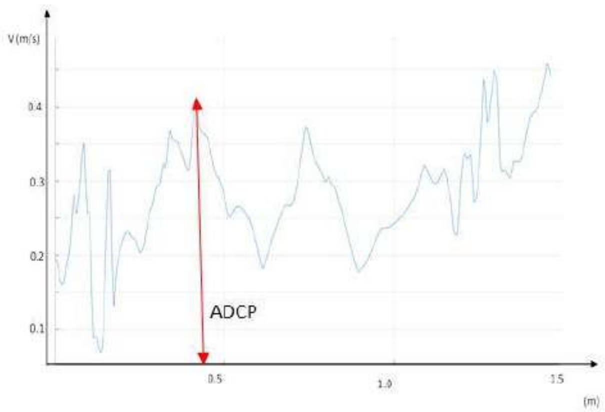

Figure 5-5: Flow velocity estimated by the image-based technique (in blue) and the measure by ADCP (in red)

Selection of the river site

The watercourse under study is located in Sicily, is called Fiume Torto and it is a torrential river, dry for several months of the year. The choice of this river is due to the frequent flooding during the year, which should guarantee its validation inside the period of the project. The area under study is shown below (Figure 5.6). The stretch under study was chosen because it has several flood – prone areas, where allocation of measurement instruments (stadias, cameras, radar and ultrasonic level sensors) is relatively easy

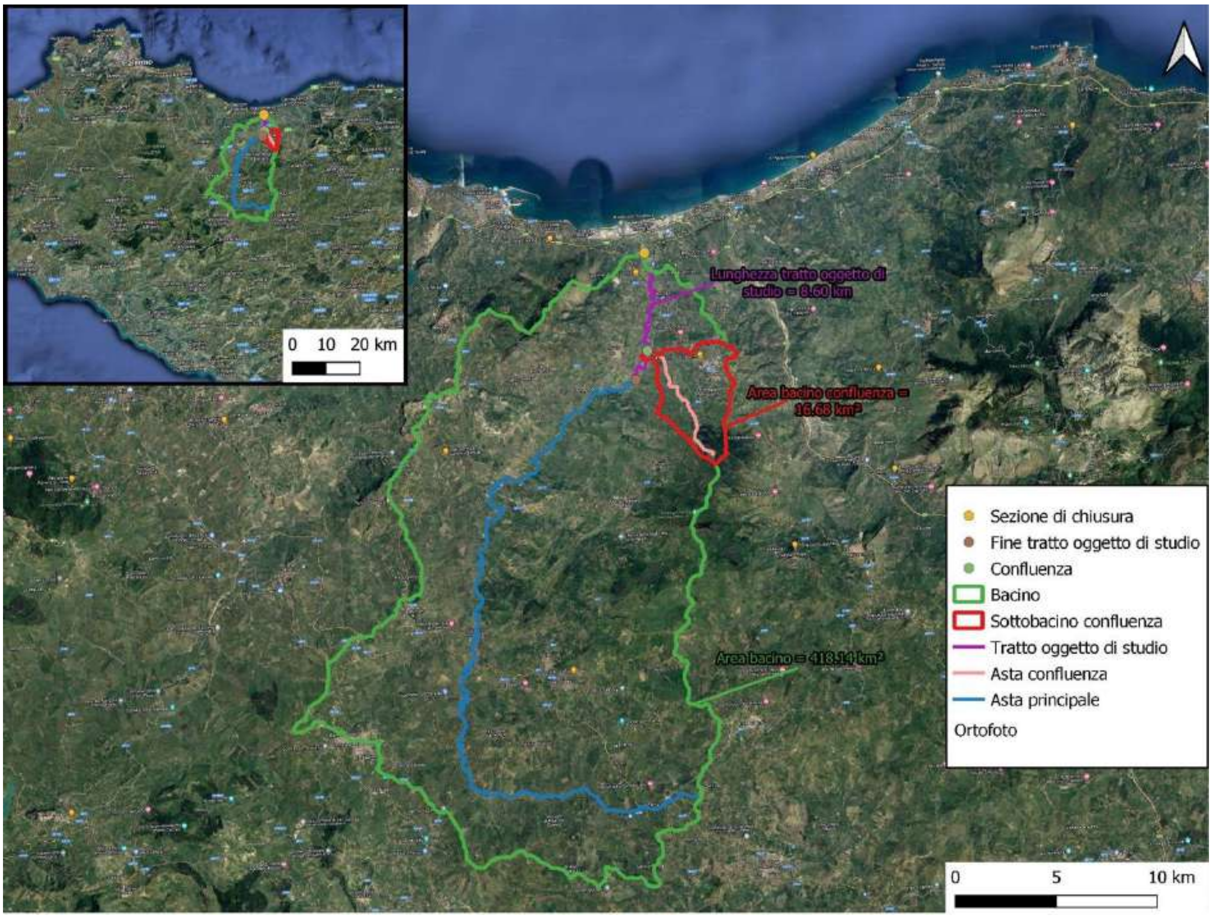

Figure 5. 6:-Area under study

Definition of procedure for the optimal peak estimation

We look for the optimal estimation of the flow rate hydrograph in a river reach with torrential regime, by solving the reverse engineering problem for given governing equations.

The methodology relies on the synchronous and continuous measurement of water level data in two river sections located few kilometers apart. The governing equations are solved according to the diffusive hypothesis, in order to minimize the sensitivity of the results to the topographic error. The methodology will be applied using a combination of 1-D and 2-D models, according to the expected flooded areas.

As can be seen from the image above, there are no significant lateral inflow contributions inside the reach and this makes the method particularly robust (Spada et al. 2017). The project 1D sections were traced in a 2x2 DTM (digital terrain model) which presented some artificial irregularities, corrected using the methodology proposed by Sinagra et al. (2020). The preliminary 1D flood wave simulations have been carried out using the 1D model proposed by Aricò et al. (2016).

Preliminary simulations have been run with a direct solution of the governing equations, using a Manning coefficient of 0.05 sm-1/3, in order to estimate the potentially flooded areas. Using steady-state inlet flow rates, flooding started at about 30 m3/s. Setting and initial water depth of 3 m, flooded occurred in several sections. In the initial part of the stretch under study, no flooding is computed, while in the central part flooding is computed along different sections as can be seen in the following Figure 5.7. For this reason, future developments will include the coupling of the 2D model along the sections where flooding has been computed using the 1D model.

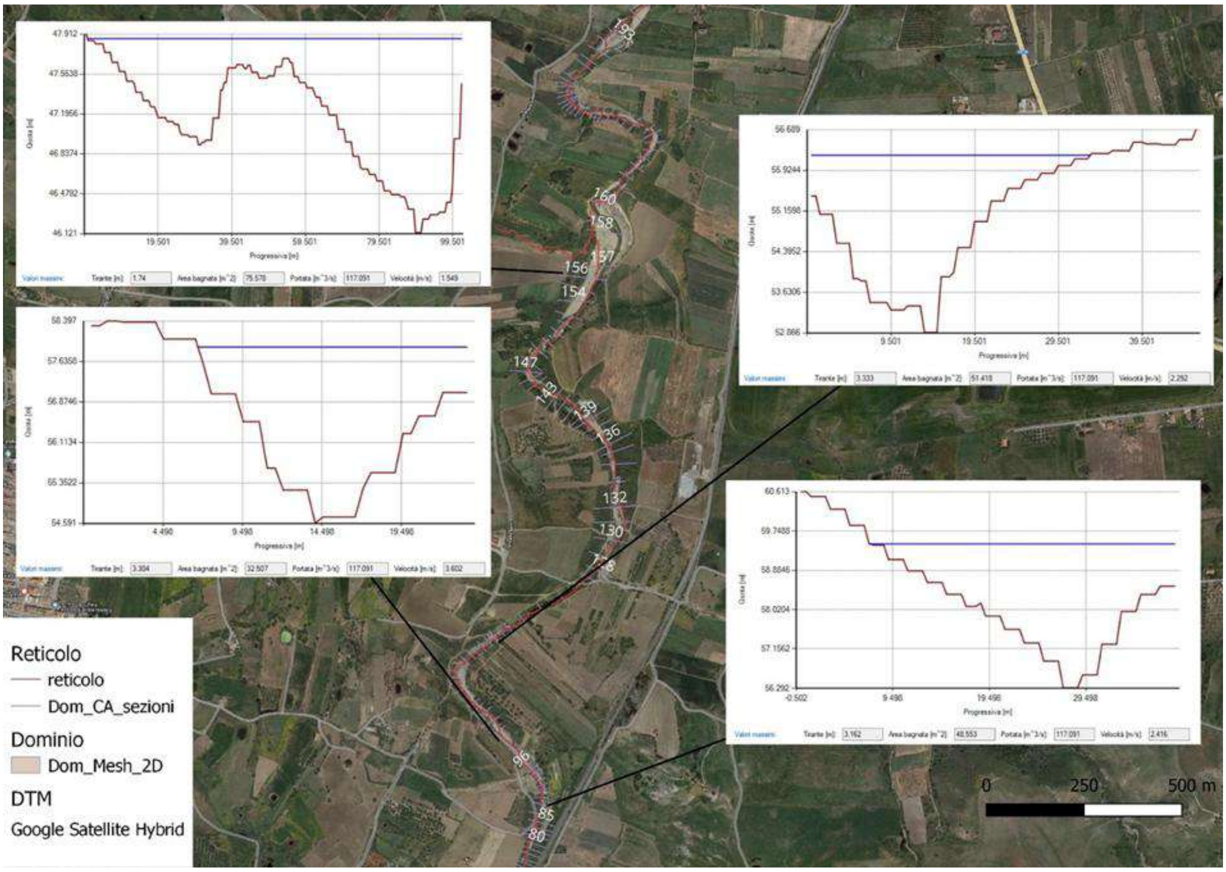

Figure 5.7: Flooded area

6. NatFIM

In the following sections the main sources for the data are described for each kind of exposed element. The description includes:

- Spatial resolution
- Type of data
- Vulnerability variables related to the element
- Criticalities connected to data availability and treatment

6.1-Population

Starting point

Source	**ISTAT's Population census (2021)**
Spatial resolution	ISTAT Census block (meso-scale)
Type of data	Vector – polygon (.shp) for the census blocks and text (.csv) for attributes
Description	ISTAT provides the number of residents and their distribution by age groups in the census blocks. The number of unhoused people is provided at the municipality level.
Vulnerability variables	Age group (children and elderly). Number of people in homelessness status.

Criticalities and developments

Spatial distribution of the population. Assuming the population to be distributed uniformly within the census block may lead to a wrong spatial distribution of the exposed population, particularly for large census blocks.

Latest version of the census. The latest version of the census is still some years behind the implementation of the project, which mainly affects the quantification of the population groups considered to be the most vulnerable (i.e., children and elderly).

Discrepancies in the spatial scale. The spatial scale considered by ISTAT for the number of unhoused people (municipality) differs from the way in which are presented the census results (census block). This may lead to wrong estimations of this population group.

6.2-Cultural Heritage

Starting point

Source	**[1] MOVIDA Cultural Heritage Geodatabase and ISTAT's census blocks (2021)**
Spatial resolution	Single asset (micro-scale)
Type of data	Vector – point (.shp) for the single assets and text (.xls) for attributes
Description	MOVIDA's database was created ad hoc by merging data from international, national, and regional open cartographic data repositories. It provides a unified classification according to the same taxonomy. Each asset is associated to a typological class (e.g., religious architecture, monument, museum, etc.) and to a level of protection (e.g. UNESCO asset, asset of national importance, asset of regional importance). For further information on the database refer to MOVIDA's report annex available in the Po River District's website [2].
Vulnerability variables	Typological class Level of protection

Criticalities and developments

Possible errors in the database. Some criticalities arise from the methodology adopted in the creation of the database in MOVIDA. These include: the errors in the sources used to unify the data (e.g., georeferencing problems, overlapping and duplications) and the lack of attributes that allow the type of asset to be classified.

Limited coverage. The database is limited to the Po River district.

Works of art. The methodology does not consider the possible works of art contained in some assets.

Strategy for improvement. The analysis of exposure of Cultural Heritage can be carried out at different spatial scales, thus also the supporting geospatial data change in topological representation and attributes. At national level the database of the ministry of Culture represents cultural heritage with points (Vincoli in rete, VIR). The Vincoli in Rete project, carried out by the Istituto Superiore per la Conservazione ed il Restauro (Higher Institute for Conservation and Restoration), brings together several databases including the "Risk Map" Information System containing all the constraint decrees on buildings issued from 1909 to 2003 (ex leges 364/1909, 1089/1939, 490/1999). In order to obtain a more representative dataset of the cultural heritage at regional or local level, the databases and map portals of the agencies responsible for cataloging and georeferencing cultural property can be used. Both at national and regional scales, Cultural Heritage geospatial data does not have a taxonomy or classification of items, which should be addressed by reserchers based on the characteristics of the proof of concept analysed (Arrighi et al., 2023). Moreover, exposed values are difficult to estimate due to the significant intangible components (e.g., spiritual, aesthetic, historical, values etc.). Notice that these aspects are addressed specifically in Spoke TS3.

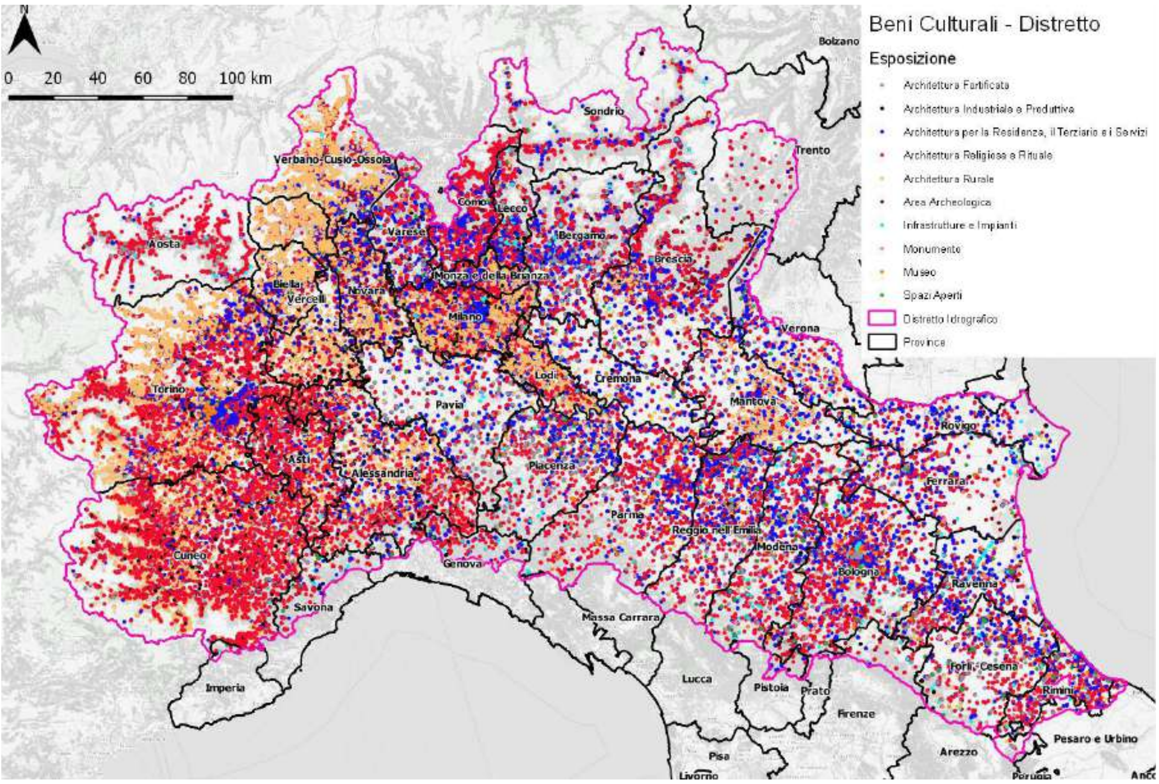

Figure 6.1 Cultural heritage in the Hydrographic District of Po River

6.3-Environment

Starting point

Source	**MOVIDA's Environmental Heritage Geodatabase**
Spatial resolution	Single exposed asset (Micro-scale)
Type of data	Vector – polygon (.shp) for the single assets and text (.xls) for attributes
Description	MOVIDA's database was created ad hoc by merging data from international, national, and regional open cartographic data repositories. It provides a unified classification according to the same taxonomy. Each asset (represented by a polygon) is characterized by the typology of ecosystem service provided (e.g., supply, regulation and conservation, cultural value). These services refer to the relationships between the environment and human communities. They describe the direct and indirect contributions of the ecosystem to human well-being. In addition, the database contains the institution (at regional, national, or international scale) in charge of each protected area. For further information on the database refer to MOVIDA's report annex available in the Po River District's website [3].

Vulnerability variables	Typology of ecosystem service provided

Criticalities and developments

Classification procedure. The wide variety of databases considered for the unification of the final MOVIDA's database does not allow for a univocal classification procedure. Very few works have addressed or collected data on flood damage to the environment following a flood. In this project, the information related to environmental consequences of the flood event has been analysed and preliminary discussed in the work "Brief Communication: On the environmental impacts of 2023 flood in Emilia-Romagna (Italy)". The manuscript identifies types of environmental damages and most affected environmental areas.

Limited coverage. The database is limited to the Po River district.

Limited coverage. The database is limited to the Po River district. Possible sources of information to be analysed for Italian coverage are provided by the Ministry of Environment (PCN – Portale cartografico nazionale) or ISPRA (Institute for the Environment Protection). The available data include:

- Important Bird Areas http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/IBA.map
- Sites of European importance (SIC) including Special Conservation/Protection zones (ZSC-ZPS) http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/SIC_ZSC_ZPS.map
- Environmetally protected areas (EUAP) http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/EUAP.map
- Wetlands of international importance http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/RAMSAR.map
- Lakes http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/Specchi_Acqua.map
- Rivers http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/wfs/Aste_fluviali.map
- Geosites: https://sgi2.isprambiente.it/arcgis/rest/services/Geositi/Mappa_reader/MapServer?Request=GetCapabilities&service=WMS https://sgi2.isprambiente.it/arcgis/rest/services/Geositi

6.4-Residential Buildings

Starting point

Source	**Regional Topographic Databases (DBTR), ISTAT's Population census (2021), CRESME (2020)**
Spatial resolution	Single building (micro-scale) for the DBTRs Census block level (meso-scale) for ISTAT
Type of data	[DBTR]: Vector – polygon (.shp) for the single buildings and text (.xls) for attributes

	[ISTAT]: Vector – polygon (.shp) for the census blocks and text (.xls) for attributes [CRESME]: Text (.xls)
Description	DBTRs supply the location and the characterization of the physical exposure (area in plan, height, and number of floors, etc.) as well as some vulnerability features, depending on the investigated region, at the micro scale (single building). ISTAT supplies the number of residential buildings along with some vulnerability features (structural type, age, number of floors and level of material) at the census block scale. CRESME supply reconstruction costs at the national/regional level.
Vulnerability variables	Structural type (reinforced concrete, masonry, etc.). Level of maintenance/state of conservation (excellent, good, mediocre, terrible). Number of floors

Criticalities and developments

Misclassification within the DBTRs. Poor or absent data in the DBTRs lead, in some cases, to buildings mistakenly categorized as residential, especially in the case of large buildings.

6.5-Commercial and industrial activities

Starting point

Source	**ISTAT's Industry census and National accounts (2021)**
Spatial resolution	ISTAT Census block (Meso-scale)
Type of data	[Industry census]: Vector – polygon (.shp) for the census blocks and text (.xls) for attributes [National accounts]: Text (.xls)
Description	For each ATECO/NACE macro-sector (B to N), ISTAT supplies the number of employees and the number of units at the census block level. Moreover, ISTAT supplies national values of the net capital, for both structure (buildings) and the contents (machinery, tools, and equipment) for different ATECO/NACE sector.
Vulnerability variables	ATECO/NACE sector Number of employees

Criticalities and developments

Use of aggregate data by ATECO macro-sectors. The unitary net capital is given at the national scale for each macro-sector (B to N), which implies a lack of representativity at the local level. Furthermore, the aggregation by macro-sector creates heterogeneous groups for which the same exposure value is assumed despite the differences in the economic activities.

Spatial distribution of the companies. The companies are assumed to be distributed uniformly over the census block, which is not always representative of reality.

Lack of availability of the stocks value. The net capital of stocks is not available (i.e., raw materials, products in progress, finished products and goods for resale).

6.6-Agriculture

Starting point

Source	**Cadastre, CAP (Common Agricultural Policy) farmers declarations, SIAN (National Agricultural Information System), ISMEA (Institute of Services for the Agricultural and Food Market), Regional Website (EU subsidies), contractors pricelist.**
Spatial resolution	Cadastral parcel (meso-scale)
Type of data	[Cadastre]: Vector – polygon (.shp) for the cadastral parcels and text (.xls) for attributes [CAP and ISMEA]: Text (.xls) [SIAN]: Available online for each region
Description	The cadastral parcels are supplied by the Agricultural Land Register. Agricultural uses can be derived from the farmers' declarations for reward system before CAP. Yields, prices and production costs can be obtained from the SIAN benchmark yields, the ISMEA prices and the contractor tariffs available for each region.
Vulnerability variables	Crop typology.

Criticalities and developments

Declarations by farmers. The lack of detailing in the answers provided by the farmers for some of the parcels impede the proper assignment of the PLV value.

Regionalization of the prices. The costs are available at the regional level, which may prevent from capturing significant local particularities.

6.7- Livestocks

Starting point

Source	**National Zootechnical Registry Database**

Spatial resolution	Single farm (micro-scale)
Type of data	Vector – polygon (.shp) for the single farm and text (.xls) for attributes
Description	The localization, typology (poultry, cattle-buffalo, pigs, sheep, and goats) and consistency (number of animals) come from the database.
Vulnerability variables	Livestock typology

Criticalities and developments
Criticalities are yet to be identified due to the lack of literature on this asset

6.8.Na-tech sites

Starting point

Source	**MOVIDA's Na-tech database**
Scale of analysis	Individual installation (micro-scale)
Type of data	Vector – point (.shp) for the single assets and text (.xls) for attributes
Description	MOVIDA's database was created ad hoc by merging data from international, national, and regional open cartographic data repositories. It provides a unified classification according to the same taxonomy. Each installation is characterized by the substances treated and the regulatory references (international, national, and regional) that classify that plant as dangerous. For further information on the database refer to MOVIDA's report annex available in the Po River District's website [3].
Vulnerability variables	Substances Level of classification

Criticalities and developments

State of art. Criticalities are yet to be identified due to the lack of literature on the dynamics of potential contamination of neighbouring areas applicable at a district scale.

Limited coverage. The database is limited to the Po River district.

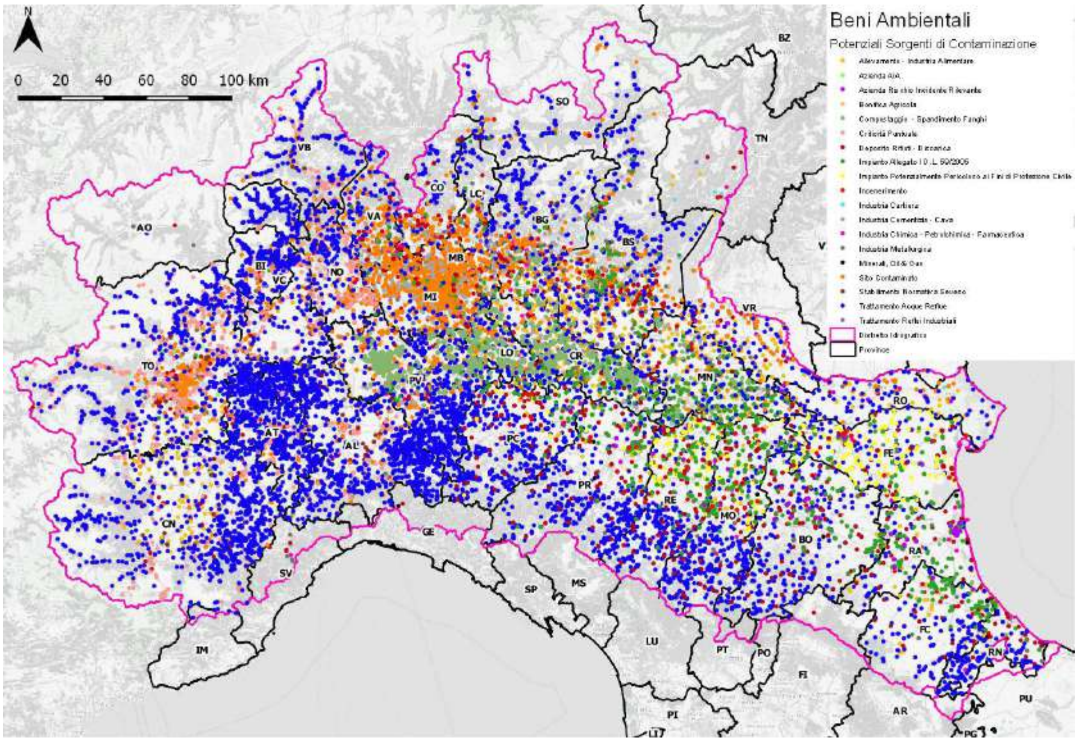

Figure 6.2 Potential contaminating sources in the Hydrographic District of Po River4

6.9-Strategic Buildings

Starting point

Source	**MOVIDA's Strategic buildings database**
Spatial resolution	Single building (micro-scale)
Type of data	Vector – point (.shp) for the single assets and text (.xls) for attributes
Description	MOVIDA's database was created ad hoc by merging data from international, national, and regional open cartographic data repositories. It provides a unified classification according to the same taxonomy. The buildings are of two types: buildings with a strategic function for civil protection purposes and buildings housing vulnerable population groups. For further information on the database refer to MOVIDA's report annex available in the Po River District's website [3].
Vulnerability variables	Type of building

Criticalities and developments

Quality of the original base data. The heterogeneity of the data available in the different regions and their lack of completeness and accuracy in some cases may lead to georeferencing problems, overestimation of building counts and wrong classification of the buildings.

Lack of categorization of the buildings. The database allows to distinguish between the types of buildings mentioned before but it does not assign a level of importance or relevance.

Limited coverage. The database is limited to the Po River district.

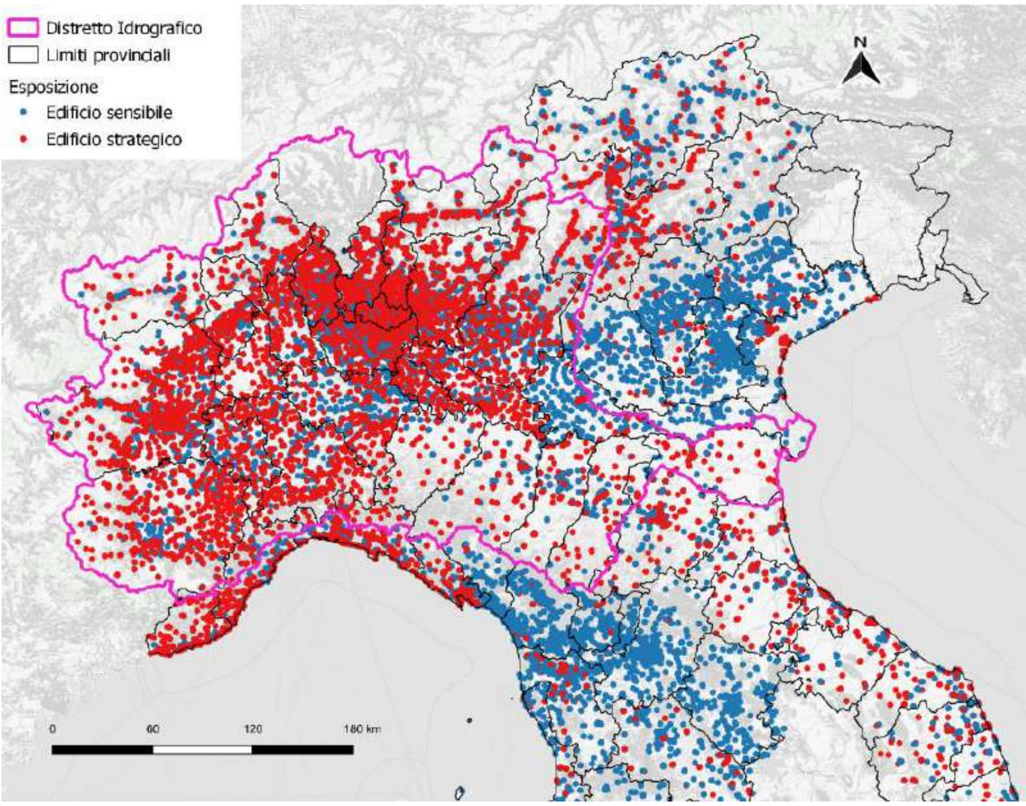

Figure 6.2 Strategic buildings in the Hydrographic District of Po River (MOVIDA)**Errore. Il segnalibro non è definito.**

6.10-Roads and Railways

Starting point

Source	**Open Street Map (OSM), Centro Interregionale, Topographic Database – Lombardy Region**
Spatial resolution	Individual track (micro-scale)
Type of data	Vector – polygon (.shp) for the single assets and text (.xls) for attributes
Description	The roads and railways typology (category and elevation) and location are supplied by OpenStreetMap. In the case of railway stations, information can be obtained by the intersection between OSM and the Region's Topographic Database/Centro Interregionale database.
Vulnerability variables	Tracks typology (secondary, tertiary, highway, etc.).

Tracks elevation (bridge, tunnels, viaduct).

Criticalities and developments

Poor information for railways. The lack of characterization of the railways impedes a more in-depth analysis of their vulnerability conditions such as routes redundancy and regional or interregional importance

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