**Abstract code: DP3**

**Rainstorm height and flooding effect analysis as a tool for pluvial flood emergency management**

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**Keywords**:
Pluvial flood, Civil Protection, urban areas, climate change risk assessment

## Introduction

During the last 10 years, worldwide urban areas are experiencing the effects of climate change, in terms of increase in the number and frequency of extreme rainfall events (Bates et al., 2008). To date, the study of urban flooding, caused by extreme rainfalls is one of the major challenge of urban drainage, especially because the hydraulic performance of urban drainage infrastructure is often not adequate for these impacts. The anthropic modifications of hydrological system, as well as the extension of impervious surfaces, sealing of stream beds, stream channelized into sewer network, reduce infiltration and increase runoff. This may causes ponding of rainwater into the topographic depressions when the sewer network is overwhelmed. Furthermore, the anthropic modifications particularly affect urban areas because of the high population density, high concentration of economic and social activities, as well as the cultural and artistic heritage.

While fluvial flood risk assessment is characterised by well-established and tested procedures for several years (e.g., Dawson et al., 2008; Morita, 2008; FLOODSite, 2009; European Flood Risk Management Directive - EC 2007/60), however, the application of this methodology on the issue of pluvial floods caused by extreme rainfall runoff is still at the beginning (Niemann and Illgen, 2011; Zhou et al., 2012).

Since pluvial flooding is influenced by many local factors (e.g., sewer and manholes maintenance, type and extension of impervious surfaces over the basin, presence of underground structures, etc.), the common approach is to use hydrologic numerical models which simulate the water height over urban surface as a function of many variables.

However, the construction of hydrologic models of large urban areas may constitute a difficult challenge because it requires a deep knowledge of the urban system (e.g., sewer network, land use, soil type) at a proper scale, as well as a detailed and hydrologically correct Surface Terrain Model. Furthermore, being a very time-consuming procedure, it also requires an expert modeller able to run different models with updated parameters (i.e., changes in land use, manholes maintenance conditions, etc.) not always available in public administration or local Civil Protection offices. In recent years, reliable tools for a detailed flooding risk analysis are available within geographic information systems (GIS) (i.e., 1D/2D-simulation of surface runoff, sewer network simulations, Djordjevic et al., 1999, 2005 and 2007; Schmitt et al., 2005; Obermayer et al., 2010).

This paper presents preliminary results obtained in the framework of the Urban Georisk Project, carried by the Institute of Environmental Geology and Geoengineering (IGAG) of the National Research Council of Italy, and financed by the Italian Civil Protection National Service. The project is aimed to the analysis, definition and prevention of the hydrogeological and hydrological geohazard in urban areas. In particular, it consists in the development of a fast procedure for mapping the susceptibility to pluvial flood in urban areas through the elaboration of easy-to-find data. This methodology provides on one hand an important contribution in understanding the causes of past flood events; on the other hand it supports the development of a comprehensive approach to risk management by the recognition of potential pluvial flood hazard in the urban area. The procedure has been applied to the case of Rome urban area and has to be intended as a useful tool for the Civil Protection in the planning and emergency phases.

## Methodology

The presented methodology consists of a four-part workflow:

1. Data collection and storing, DCS
2. Rainfall Analysis, RA
3. Terrain Analysis, TA
4. Flood Hazard Analysis, FHA
5. Vulnerability Assessment, VA.

1. **Data Collection and Storing, DCS.** Documentation regarding emergency calls caused by extreme rainfalls and observed floodings collected by Municipal Civil Protection and Firefighters have been acquired and integrated with data from online newspapers and reporting blogs. All these information consist of vector data (points and polygons); the

attribute table contains the coordinates, the date of occurrence and the address. Sub-hourly rainfall data, registered by up to 51 rain gauge stations have been provided by Instituto Idrografico e Mareografico Regione Lazio. All collected data were stored in a geodatabase build specifically for the project.

2. **Rainfall Analysis, RA.** The rainfall analysis was performed over 36 storm events occurred over Rome's municipality exceeding 20 mm/1h from 2001 to 2014. Maximum rain heights in 30 minutes, 1 hr, 2 hrs and 3 hrs were derived for each storm and for the 51 rain gauges.
3. **Terrain Analysis, TA**. This analysis was aimed to detect areas of topographic lows (depressions), which are zones more susceptible to flood, by means of ArcHydro tool installed in the ArcGIS environment. The analysis has been performed on a DTM constructed by using geostatistical technique (i.e. kriging). Then, the map of the main hydrological basins was reconstructed on the basis of data reported in Ventriglia (2002).
4. **Flood Hazard Analysis, FHA.** The analysis of the potential flood hazard is essential to investigate all possible influencing factors directly related to the specific local conditions, i.e., extention of hydrological basins and the rainfall height measured at the rain gauge. In particular, the aim of this analysis consists of the individuation of a critical rain height necessary to fill a depression and originate a flooding.
5. **Vulnerability Assessment, VA.** Objects that may be affected and damaged during heavy rainfall events and pluvial flooding (e.g. buildings, municipal infrastructure, facilities, industrial plants, networks and other protected goods and assets) are examined and evaluated in terms of their vulnerability. The analysis was performed once defined the critical rain height for each area or basin.

All processing steps are implemented within GIS environment and a subsequent step of validation based on selected extreme rainfall events is performed. The proposed methodology is also focused on an optimal implementation of the available municipal and spatial data sources by the construction of a dedicated geodatabase and WebGIS.

## Results

*Data Collection and Storing, DCS*

Obeserved floodings provided by Municipal Civil Protection and Firefighters have been georeferenced and/or geocoded in vector layers within ArcGIS software. Calls obtained from the Fire Department have been examined and filtered only for the flooding that affected the road network. These data were geocoded in a point layer as they often lacked information concerning the extension of the flooded area. However, in the following steps of the analysis they have been buffered to simulate a floded area.

Rainfall data, registered by up to 51 rain gauge stations have been provided by Instituto Idrografico e Mareografico Regione Lazio. All collected data were stored in a geodatabase build specifically for the project. Data were elaborated in order to obtain sub-hourly rainfall.All collected data, as well as results obtained by further eleborations, have been stored in a geodatabase specifically constructed for the project and available in a preliminary WebGIS.

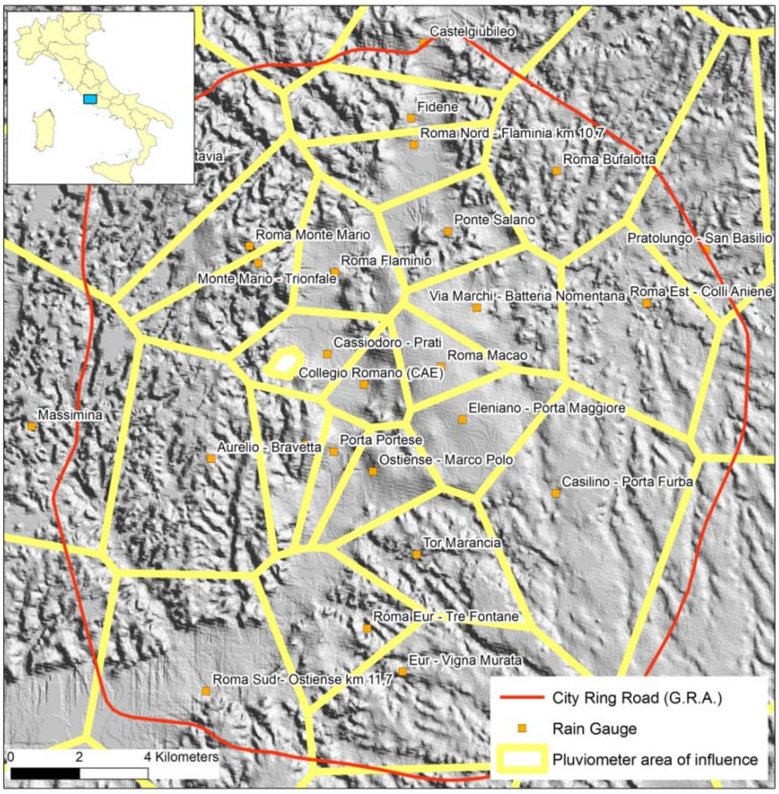


*Figure 1: Rain gauge stations and influence areas.*

*Rainfall Analysis (RA)*

Rainfall data sheets were elaborated to obtain sub-hourly and total rainfall for each rain gauge, and used to produce graphs showing distribution of rainfalls vs time (Fig.1).

Two main types of storm trends have been recognized in the graphs: high-intensity single event storm (type A) and medium-intensity prolonged storm (type B). Type A storms consist in one-peak event lasting 1-3 hours; type B storms are characterised by intermittent peaks lasting from 24 to 60 hours. Total rain heights were used to produce maps of total rainfall distribution by means of kriging algorithm (Fig.2).

*Terrain Analysis, TA*

A high resolution (2x2m) DTM was built by means of kriging algorithm using elevation points obtained by the Technical Map of Regione Lazio at the 1:5000 scale. In order to obtain a hydrological corrected DTM, a sensitivity analysis consisting in sink prescreening was performed in order to fill small depressions and pits by the definition of a threshold for the minimum drainage area or sink depth. Quantification of the threshold has to take into account all elevation inaccuracies and fault tolerances of the DTM. Then, the depression evaluation tool available in ArcHydro was used to elaborate the map of depressions; only depressions having fill volume > 0.1 $m^3$ were considered as hazardous areas and then selected for further elaboration. Furthermore, as point observed floodings represent flooded areas (Fig.3), a buffer of 100 meters was created around each point in order to simulate a flooded area. Then, the shapefile of the depressions and the buffered floods were merged together, in order to represent all highly susceptible areas (Fig.4).

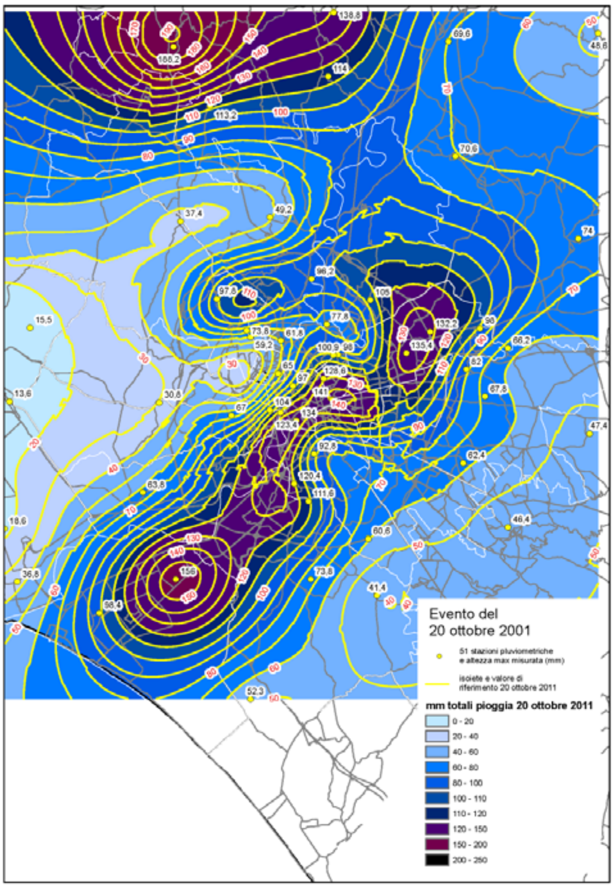


*Figure 2: Map of total rainfall (date of storm: 20th October 2011)*

*Flood Hazard Analysis, FHA*

The result of this step provides a map of the "influence areas" for each rain gauge by using the Voronoi method (Fig. 1). Since each influence area may be overlaied by more than one hydrological basin, the map of the influence areas was intersected with the map of the hydrological basins by using "Intersect" tool in ArcGIS. This operation is aimed to calculate and consider the rainfall contribution of each rain gauge to the hydrological basin. The total rainfall over one basin has been calculated as the weighted sum of the minimum values measured in all the influence areas intersecting the basin; a weight has been assigned to each rain value proportional to the overlay percentage between the influence area and the basin. Then, observed floodings were selected within each basin in order to link the measured rainfall to the floodings observed therein.

The occurrence (location and date) of floodings for each considered storm allows to define if the rainfall may be considered "critical" for flood occurrence. On the contrary, rainfall height of storms that did not originate floodings, is considered not critical for pluvial flood.

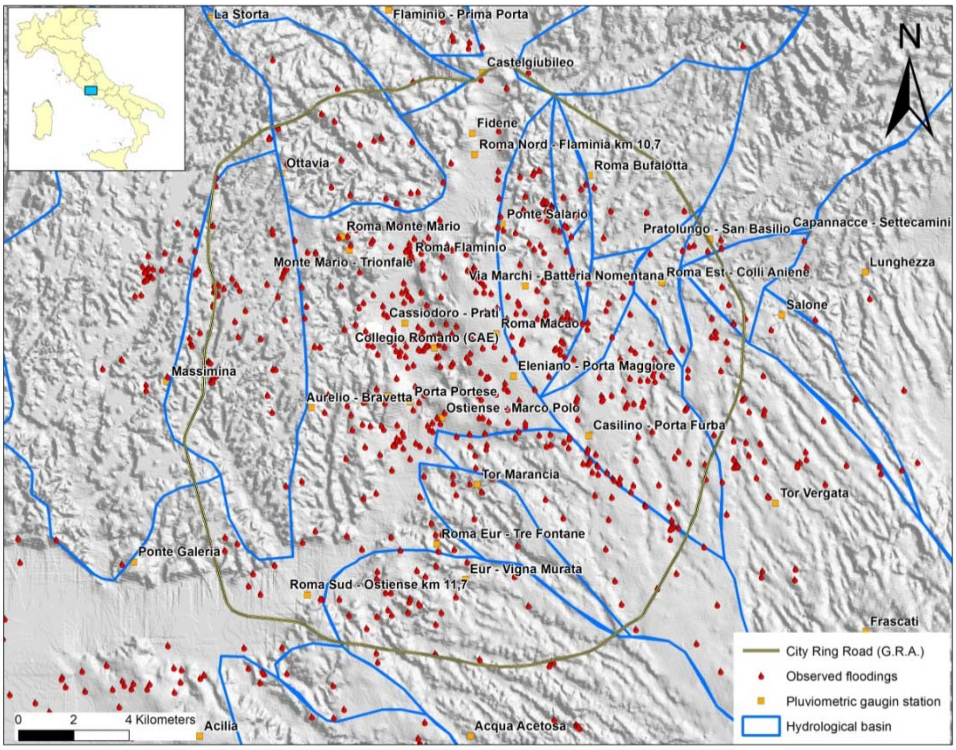


*Figure 3: Pluvial floodings observed in the study area between 2001 and 2014*.

Analysed data recognised two different critical rain heights, depending on the previous defined storm types: critical rain heights for type A are higher than critical rain heights of type B storms. This is in agreement with the assumption that previous conditions of soil and sewer affect the critical rain height. For example, type A storms, occurring over originally dry soil and sewer, need a higher critical rain height to originate floodings; on the contrary, type B storms, occurring in conditions of sewer overwhelm and soil saturation, results in a lower critical rain height. This analysis highlights that area most susceptible to flood are characterized by minimum critical rain height. A flood hazard map is then obtained by assigning a score proportional to the critical rain height in 1hr: <=10 mm (score 3), 10<mm<17 (score 2), mm>=17 (score 1).

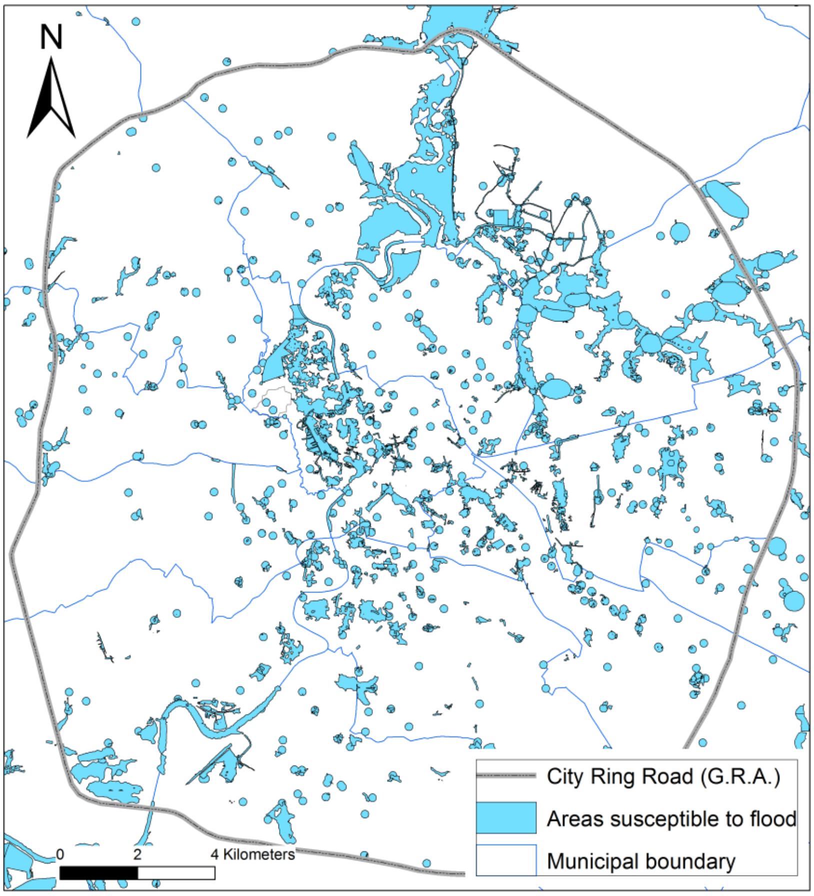


*Figure 4: Map of areas susceptible to flood*

*Vulnerabilty Assessment (VA)*

The vulnerability analysis was performed once defined the hourly critical rainfall for each basin. The strategic buildings, administrative office, industrial plants and networks were intersected with the map of susceptible areas. Then, a score number corresponding to the degree of vulnerability was assigned to the considered goods and assets according to the following classification:

- Primary public buildings (i.e., school, hospitals, etc.), score 4;

- Networks and strategic buildings (i.e., streets, railways, wastewater treatment plants, airports, etc.), score 3;
- Public and private plants (i.e., industrial plants), score 2;
- Secondary public and private buildings (i.e., residential buildings), score 1.
- Areas with no goods or structures, score 0.

## Final Flood risk analysis

The methodology of flood risk assessment due to extreme rainfall events is based on a superposition of the potential flood hazard (susceptibility) and vulnerability that are combined in risk levels according to a defined risk matrix. (see Leitao et al., 2012; Niemann and Illgen, 2011). The risk matrix is defined by the four classes of vulnerability and the three classes of susceptibility (Fig.5).

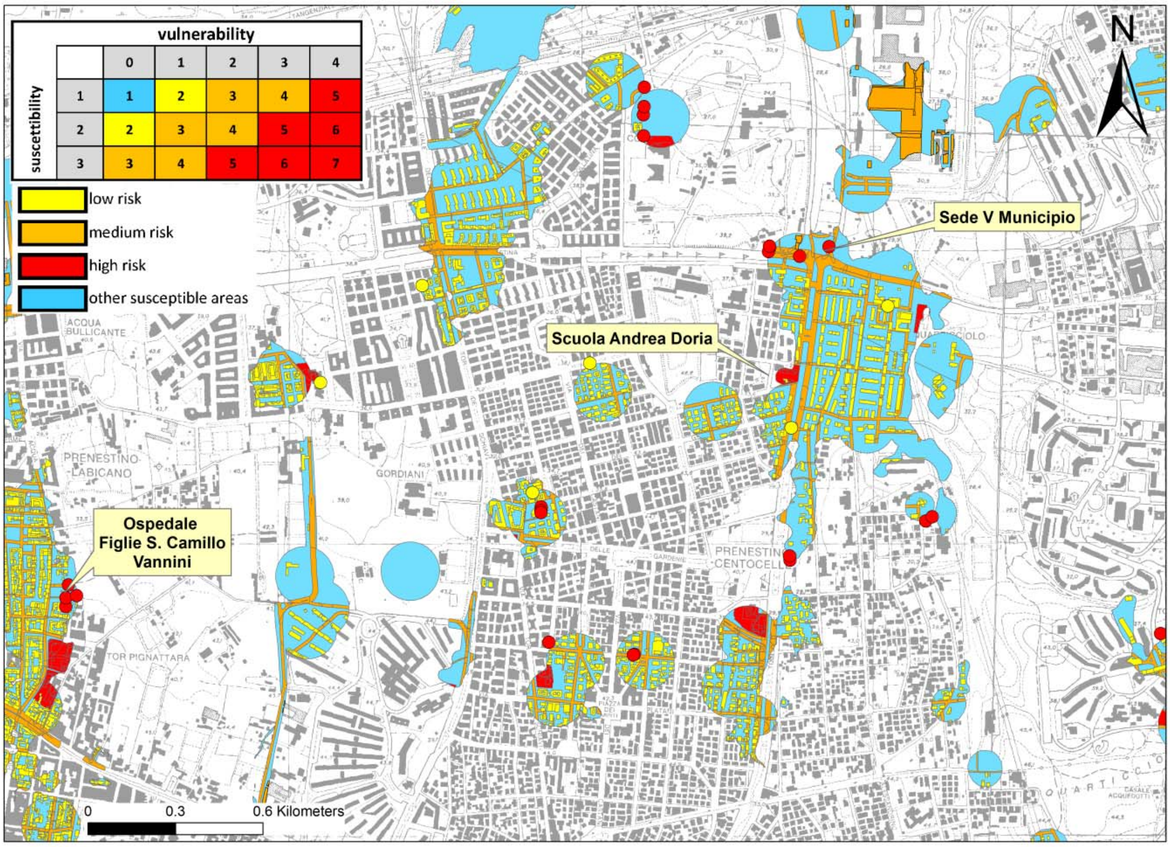


*Figure 5: A detail of flood risk analysis map and risk matrix*

## Conclusions

This study provides a fast GIS-based methodology for flood hazard analysis and risk assessment of the urban area of Rome. The developed procedure needs data about rainfall heights and observed floodings easy to find in the local administration office. It is suitable for a comprehensive, largely automatic initial analysis of pluvial flood risk in urban areas and it is easily replicable. The final flood risk map can provide a useful tool for the Civil Protection in evaluating and planning emergencies.

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