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Assessing flood risk at regional scale: the KULTURisk Assessment methodology applied in Zurich

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INTRODUCTION

Nowadays, extreme weather and climate dynamics, the physical contributors to disaster risk, interacting with exposed and vulnerable human and natural systems, can lead to severe catastrophes. Some types of extreme weather and climate events have increased in frequency or magnitude in recent years along with increase development in natural areas and assets exposed at risk, exacerbating consequences for water related disaster risks. The major expected climate change impacts include sea-level rise, coastal erosion, alteration in water quality and increase of flooding (Hirabayashi et al., 2013). Recent river flooding events occurred in Europe have caused huge damages for people, their properties and the environment underlining the importance of better flood risk management as well as proper prevention measures in order to avoid these dramatic consequences. Particularly, in Switzerland severe flood events have occurred in many catchments in the last decade, while periods with frequent floods alternated with quieter periods have occurred during the last 150 years (Bründl et al., 2009). A research conducted by Hilker et al. (2009) in Switzerland has estimated an approximate 8 billion Euros of total monetary loss due to floods, debris flows, landslides and rockfall, with 56% of this damage caused by six single flood events from 1978 to 2005. In this context, the European Flood Directive (FD) 2007/60/EC represents an ad-hoc legislative framework which specifically supports the development of proper flood management strategies, in order to reduce the adverse consequences for human health, the environment, cultural heritage and economic activities. Generally, the risk assessment process encompasses the identification, characterization and evaluation of risks, associated with a specific context and/or system. The outcomes of the risk assessment can be used in a wide variety of decision making processes, such as the realization of new infrastructures (e.g. a new tunnel, early warning systems), or the acceptability of safety levels and the need for improvement in existing systems (e.g. a flood defence system) (Jonkman, 2008). Overall, the risk assessment provides a rational basis for flood management decision-making at national scale, as well as at regional and local scale (Hall et al., 2003; Apostolakis, 2004). Recently, Cirella et al. (2014) presented a comprehensive review and classification of current approaches and methodologies for the assessment of risks posed by several water-related natural hazards (coastal storms, tsunamis, river floods, avalanches, landslides, etc.). The review underlined that there are very few examples of methodologies that consider the complete suite of elements at risk (receptors) pointed out by the FD through an integrated

and multidisciplinary approach, encompassing the entire varieties of risk dimensions (i.e. physical/environmental, social and economic). In fact the elements at risk are mostly buildings, infrastructures and population (e.g. Forte et al., 2005; Kubal et al., 2009), that are usually analysed separately, in monetary terms and related to damages only. Moreover, flood risk assessments methodology were mainly developed for very specific contexts at a very local scale, with an high level of complexity and data demanding (e.g. Forte et al., 2005; Meyer et al., 2009; Kubal et al., 2009,Forster et al., 2008), and they can hardly be employed for a wide range of case studies.
In this study, the application of the specific KR-RRA methodology, developed through the integration of these (three) different dimensions of risk, have been performed by tailoring the hazard, exposure and susceptibility analysis of flood risk to the specific characteristic of the Sihl river valley, in a local-stakeholder participative manner. In this sense, the application provided GIS-based relative risk maps and statistics related to different receptors to support the (local) decision makers in (knowledge-based) land planning and decision making processes.

THE SIHL RIVER VALLEY: DESCRIPTION AND HYDROLOGICAL REGIME

The Sihl is a 68 km long alpine river located in the foothills of the Alps of Switzerland. Its sources (total basin coverage: 336 km^2) are located at Drusberg in the Canton of Schwyz. Downstream it flows through the artificial Sihl lake regulated by a concrete dam (upstream basin: 156 km^2) entering the Canton of Zurich (ZH) through the Sihl valley and flowing parallel with Zurich lake. At the end, the Sihl river joins the Limmat river at Platzspitz in the Zurich city centre (downstream basin: 180 km^2.).
The Sihl river valley is extensively wooded; the forest lying on the hills is classified as coniferous and mixed forest (CORINE Land Cover classification, 2006) and the valley is also cultivated mainly as arable land and with pastures. The analysed area (77.97 km^2) refers only to the lower part of the valley and in particular to the city of Zurich with its 21 districts and 5 municipalities (see Fig. 1).

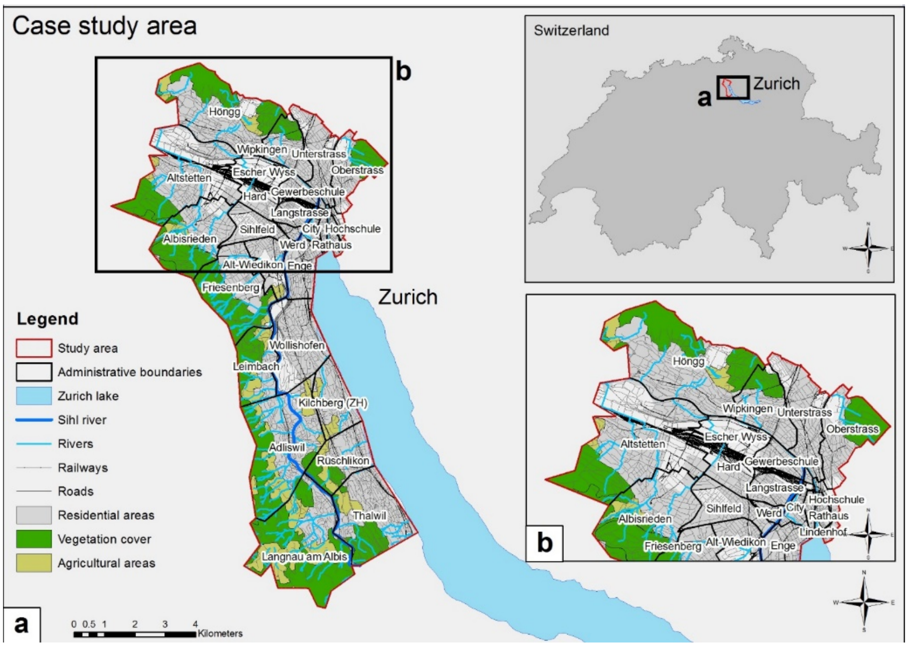

Figure 1. The case study area: a) its location in Switzerland and b) focus on the city centre (from: Ronco et al., 2014b).

The area is densely populated especially close to the city of Zurich, the residential area covers 41.28 km^2 (more than half of the case study area) and the total population is 289'029 (Statistical Office of Canton of Zurich, 2011); 20.19 km^2 are covered by forest and just 7.67 km^2 are devoted to agriculture. Several cultural heritage hotspots are present in the valley and especially in Zurich city centre. The valley is also characterized by a complex network of infrastructures including railways, road and pathway, deeply concentrated in the lower part of the valley where the city of Zurich is located.
The Sihl river basin is quite often prone to flash floods (Addor et al., 2011). In the lower part of the basin the Sihl river flows through Zurich, for which it represents the largest flood threat (Addor et al., 2011) because, just before joining the Limmat river, it flows beneath the main railway station of Zurich (Zürich Hauptbahnhof HB). During the past, several flood events affected this area and the more recent ones (2005 and 2007) confirm the need to design a proper flood risk management strategy, that include among others, effective prevention measures to reduce the risk of flood for different critical receptors of the area, such as the infrastructures.

KR-RRA METHODOLOGY: THEORY AND APPLICATION

Framework and background

Within the KULTURisk Project "Knowledge-based approach to develop a cULTUre of Risk prevention" funded by the 7th Framework Program of the European Commission, a water risk-based methodology for the evaluation and accounting of risk prevention measures has been developed. The Conceptual Framework has been built upon the consolidated formalization of risk being a function of hazard, exposure, and vulnerability. These elements are combined to calculate the Risk delineated as the combination of the probability of a certain hazard to occur and of its consequences (Giupponi et al., 2014).
Accordingly, the Physical-Environmental cluster of the risk assessment methodology addressed by this paper and based on the Regional Risk Assessment (RRA) approach proposed by Landis et al. (2005), integrates four steps of analysis: hazard assessment, characterizing the flood pattern by means of relevant metrics according to different scenarios to be investigated; exposure assessment identifying the elements at risk that could be adversely affected; susceptibility assessment evaluating the degree to which the receptors could be affected; and risk assessment combining the information about a certain flood hazard scenario with the exposure and susceptibility of the examined receptors, providing a first evaluation of risks related to each receptor through the computation of a relative risk. After the normalization of the receptor-related risk, a total (integrated) risk index is calculated by means of Multi Criteria Decision Analysis (MCDA) function).

Setting of scenario and data characterization

The proposed methodological framework requires the preliminary analysis of different flood scenarios (baseline and alternative) considering possible alternative situations and structural and non-structural solutions which could mitigate the risk in the analysed area. As far as the Sihl case study is concerned, the available flood hazard maps, referring to the three classes of hazards, as required by the FD, where flood-prone areas are classified according to different classes of frequency levels (high, medium and low) based on the concept of return period of the hazardous event (30, 100 and 300 years of return period), have been collected and analysed. The 300 years return period scenario has been considered to be the most relevant one for the purpose of this study. The other two scenarios (30 and 100 years) in fact, are characterized by a flood extension that only marginally affects the Sihl typical prone area without any consideration of the area around the main railway station of Zurich, that, typically, is a very critical hot spot in case of a flood event. Finally, by assessing the most catastrophic configuration, the selected scenario gives the opportunity to plan the mitigation, adaptive, response and preparedness actions in a precautionary framework, also without considering the mitigation measure of the Early Warning System, activated in 2008.

Relative Risk to relevant receptors

The following paragraphs describe in summary the method and the results of its application to the Sihl river valley, also presented in a companion paper Ronco et al. 2014b.

People

The approach proposed for the people is based on the methodology developed by the UK Department for Environment, Food and Rural Affairs (DEFRA, 2006). Here, the (flood) hazard assessment identifies water depth and flow velocity as relevant flood metrics considered in a linear relation with the flood hazard (i.e. when water depth and flow velocity increase, the flood hazard increase linearly). Moreover, the presence of debris factor floating material is also considered since it can increase the hazard in relation to depth values.
The exposure assessment considered the presence of the people potentially affected by the hazard by referring to residential areas only. Here, the assumption is that all the people are present in their homes at the low ground where they do not have safer areas to refuge.
The susceptibility assessment step has been performed by considering the percentage of resident aged over 75 years and the percentage of residents with disability that are considered as factors that could increase the susceptibility of resident people (aged people can be more prone to health and stability problems during flood events).
Hazard, exposure and susceptibility have been aggregated in the risk assessment phase in order to provide the number of people injured or dead during a flood event.
The risk to people (injured) with classes are reported in Figure 2. The forecasted number of total injuries is estimated in 1000, while the number of total (potential) fatalities is estimated in 29. Among the affected areas, Albisrieden and Altstetten districts (densely populated districts with medium scores for susceptibility) are subject of higher values of casualties with 223 and 155 injuries and 5 fatalities each, respectively. It should be underlined that these two districts are normally flooded by other tributary rivers to the Limmat river. The rate of injured people considering the total population of the study area is 0.35% and the percentage of dead people is 0.01%. These rates suggest that risk to people is generally low, despite not negligible, if we consider the high density of population that actually rely on the residential area (Ronco et al., 2014b).

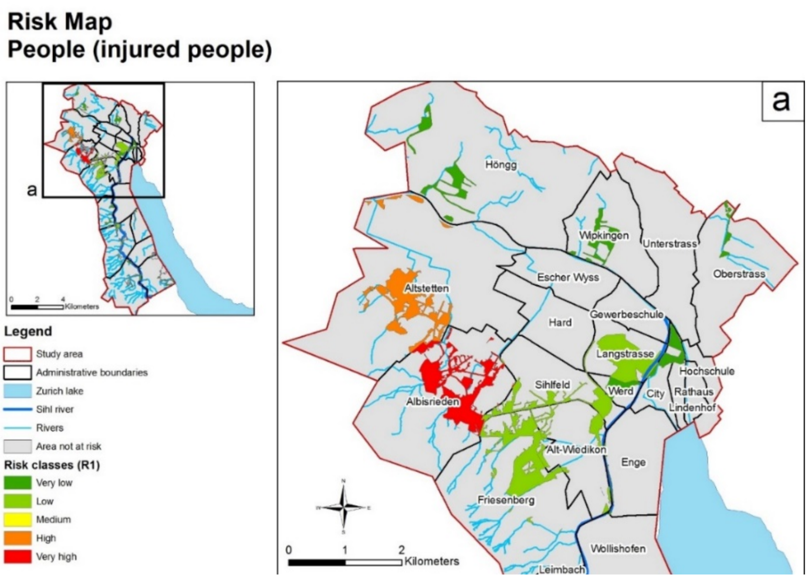

Figure 2. Risk map for people for the entire case study area and in particular for the city of Zurich (box a). From Ronco et al., 2014b.

Buildings
For the sake of simplicity, it has been assumed that all the buildings present in the study area are characterized by the same structure (i.e. susceptibility = k), so it is possible to evaluate risks directly considering the relationship between flood hazard classes and potential structural damages, as proposed by Clausen and Clark (1990).This method provides three risk classes (inundation, partial damage, total destruction) differentiating the potential consequences of floods for buildings, in a qualitative way, based on thresholds determined by flow velocity values and by the product between water depth and flow velocity. The GIS-based risk map points out the spatial distribution of the risk to building along the studied area. Being the intensity of phenomena lower than the fixed threshold, all the buildings affected by the flood event would be only inundated and would not suffer from dramatic structural damages. The total number of buildings at risk is 3,267 and the related surface area is 2.2 km^2. The percentage of flooded buildings is around 17% while the percentage of flooded areas is almost 20%.

Infrastructures
The flood hazard assessment step has considered the flood extension related to the 300 years return period scenario as representative flood metric for the identification of flooded areas and the target infrastructures. No other flood metrics have been considered since the analysis is not oriented to the evaluation of direct structural damages for infrastructures, but rather to the loss of service. For this reason the susceptibility has been considered constant. The exposure assessment has addressed the localization of the infrastructures (including railways, road and pathways present in the study area) using the Roads (Strasse_CH_line) and Railways (Eisenbahn_CH_line) TLM3D shapefiles. The infrastructure-related risk has been calculated from the intersection between the flood extension map and the map of infrastructures in order to identify the length (in km) and the percentage of infrastructures inundated by the flood event of reference. The total extent of roads, railways and pathways at risk is around 209 km out of 1,540 km of infrastructures that currently rely on the study area (less than 14% of infrastructures are at risk). In particular, around 54 km refers to railways network and 155 km to roads and pathways. The infrastructures receptor is one of the most relevant one if we consider that the Sihl river flows underneath Zurich main station and many railways lines are located just beside of the river.

Agriculture
The aim of the KR-RRA methodology when assessing the risk to agriculture at the meso-scale is to define the percentage of the harvest loss due to a flood event. The hazard assessment step requires the identification of water depth and flow velocity as relevant flood metrics specifically pointing out thresholds for several agricultural typologies characterized by different susceptibility to flood. Since none of the most vulnerable agricultural typologies are actually present in the Sihl valley (namely: vegetables, vineyards, fruit trees and olive groves), it has been assumed that arable lands and pastures should be classified as vegetables, with similar thresholds. Moreover, for the sake of simplification and according to the overall scope of the analysis, it has been assumed that these agricultural typologies have similar growing pattern (low growing plants) and, therefore, the same susceptibility score. The agriculture-related risk has been calculated starting from the flood hazard thresholds identified and considering that below the hazard thresholds there is only field inundation and over the hazard thresholds there is the destruction of the harvest. Finally the risk for the agricultural cluster is very limited: the destructed agricultural area only amounts to 0.59 km^2 (around 8% of the total agricultural area). Out of this, 0.53 km^2 belongs to the non-irrigated arable land class and 0.07 km^2 to the pastures class. The total surface at risk is probably underestimated because the exposure classification have been performed according to the

CLC resolution that could have missed out some small agricultural areas that might be important for cash crop cultivation.

Natural Systems

The flood hazard assessment step to natural and semi-natural systems considers the extension of the flooded area as flood metric. Moreover, to perform the susceptibility assessment step is necessary to characterize the environmental pattern of the area in order to evaluate the degree to which the receptor could be affected by the 300 years flood event scenario. The valley is characterized by two different kind of forest systems: coniferous forest (0.21 km^2) which covers the area only for very small part, and mixed forest (19.98 km^2) which occupied most of the natural environment along the Zurich Lake. The risk for natural and semi-natural systems has been calculated by considering vegetation cover, slope and soil permeability as susceptibility factors. Each susceptibility indicator has been classified and scored by expert judgment considering the class most susceptible to the flood event. The susceptibility indicators were then aggregated through a Multi-Criteria Decision Analysis (MCDA) function, in order to provide a single normalized score of susceptibility for homogeneous areas (Ronco et al., 2014a). Finally, the hazard and the susceptibility scores have been aggregated in a relative risk score in order to identify and prioritize natural and semi-natural systems at risk. The application to the Sihl area pointed out that only a limited portion of forest is at risk of inundation and two classes of risk have been identified: a very small part (625 m^2) belongs to the high class of risk while the rest (around 289,000 m^2) belongs to the very high class of risk.

Cultural Heritage

The flood hazard assessment step identifies the flood extension as relevant flood metric. The exposure assessment step requires the localization of the cultural heritages in the case study area. In the Sihl valley 416 cultural assets are currently present, mainly classified as ancient buildings. They include different churches such as Fraumuster and Grossmunster in Zurich city centre, the Swiss National Museum, the central library of Zurich, the Rathaus (the municipal building), the Synagogue, the Operahaus, several ancient residential buildings and villas in the centre as well as along the Zurich lake etc. The susceptibility assessment assumes a score equal to 1 for all the receptor (this means that all the cultural heritages are impacted in the same way). Accordingly, the cultural heritage-related risk has been calculated from the intersection between the flood extension map related to the 300 years return period scenario and the localization of identified cultural assets. As a result, 40 items are at risk, corresponding to the 9.13%of the total within the area (416 items).

Total Risk

The total risk has been calculated by aggregating the different receptor-related risks, by means of MCDA weighted average methods that allow identifying and classifying areas and hotspots at risk in the entire study area. The weighting process has been implemented during a roundtable-meeting organized with several experts involved in the project. The total risk map shows the spatial pattern of flood risk within the analysed area (Fig. 2). The total surface at risk is 7.98 km^2 and the total risk index ranges between $0.6 \cdot 10^{-5}$ and 0.24 that represents mostly the lower class of risk. The total risk map (final output of the total risk analysis) points out that Langstrasse district and part of the city of Zurich present the relative highest values of risk; areas within the districts of Werd, Sihlfeld, Alt-Wiedikon and Friesenberg, that rely next to the Sihl river course, also present relative higher risk levels. Despite being very dependent on weights assigned to each receptor, the results are plausible because they demonstrate that the overall risk for the study area, considering the receptor of importance, is higher in areas around the main station of Zurich (lot of infrastructures and railway lines and buildings will be possibly flooded) and on the left side area of the Sihl river before it joins the Limmat river.

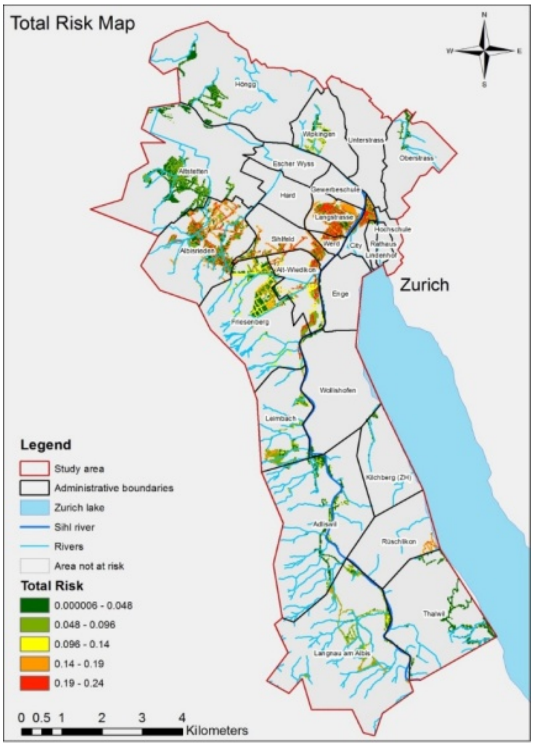

Figure 4. Total risk map for the Sihl river valley considering the 300 years return period scenario, from Ronco et al., 2014b.

CONCLUSIONS

This study addressed the application of the KR-RRA methodology to a very site-specific case, the flood risk of the Sihl river in Zurich, Switzerland. The methodology allows to identify and to rank the relevant receptors, areas and hot spots at risk, not attempting to provide absolute predictions about flood impact; rather, providing a relative analysis and ranking of the sub-areas that are more vulnerable and possibly more dramatically affected by the flood risk in the investigated region. However, a more detailed analysis (at the micro-scale) could be required in the areas considered at risk or where more specific information are available. The methodology represents a very useful tool to identify and to rank the relevant receptors, areas and hot spots at risk in a urbanized area among people, economic activities, natural and semi-natural systems and cultural heritage and moreover, it can be applicable in different problem contexts, case studies and spatial scales with the aim to provide a benchmark for the implementation of the Floods Directive at the European level. In addition, GIS-based maps and outcomes result useful to communicate the potential implications of floods in non-monetary terms to stakeholders and administrations and can be a basis for an appropriate management of flood risks as they can provide information about the indicative number of inhabitants, the type of economic activities, natural systems and cultural heritages potentially affected by flooding (Ronco et al., 2014a). Moreover, it is worth to notice that the final total risk index aggregates scores coming from multiple heterogeneous parameters. The final decision-making process should therefore consider not only the final values of the index, but also the factors that contributed in determining that value (i.e. susceptibility indicators, hazard metrics). A correct interpretation of these factors is particularly relevant for the analysis of the potential prevention measures that could be suitable for reducing the risk for current hot spot areas (Torresan et al., 2012).

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