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Multi-hazard risk assessment of two Hong Kong districts

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SUMMARY The assessment of multi-hazard risks in urban areas poses particular difficulties due to the different temporal and spatial scales of hazardous events in urban contexts, and the potential interactions between single hazards and between hazards and different socio-economic fragilities. Yet this exercise is important, as identifying the spatial distribution and concentration of risks in urban areas helps determine where and how preventive and corrective actions can reduce levels of vulnerability and exposure of urban populations. This article presents the results of a GIS-based assessment of present day risks to socio-natural hazards in two districts of Hong Kong (PRC) by utilizing indicators to describe the hazards and vulnerabilities. Mapping composite indicators facilitates the communication of complex concepts like vulnerability and multi-hazard risk, allowing for the visual representation of concentrations of hazard intensities and vulnerabilities. Mapping indicators operationalizes the concept of vulnerability at the urban level, and supports the detection of potentially risk prone areas at the sub-urban scale. This approach has the potential of providing city planners and policy makers with visual guidance in focusing and prioritizing risk management and adaptation actions with respect to current and future risks existing in specific parts of the city, taking into account more than one hazard at the time. Under a climate change prospective, the assessment of the present day risk is relevant to highlight how the capacity of communities to cope with potentially intensifying hazards could be strengthened.

Keywords: Urban areas,Hazard,Vulnerability,Risk,Climate change,GIS, urban adaptation

Urban Adaptation

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INTRODUCTION

Natural hazards in the Asia-Pacific region affected 6 billion people and caused over 2 million casualties between 1970 and 2014 (ESCAP, 2015). These fatalities and the number of persons affected represent a significant portion of the worldwide totals: according to the Economic and Social Commission for Asia and the Pacific, 56.6 percent of deaths due to disasters and 87.6 percent of people affected by natural hazards are located in this region. While the total number of fatalities per disaster has actually decreased over the past several decades, economic damages have increased (ESCAP, 2015). Disaster risk reduction activities have helped to lower the number of deaths, yet factors including population growth, development of cities in coastal areas, and climate change contribute to increased exposure and damages. Since 1980 the number of people exposed to hydro-meteorological hazards, like floods and storms (cyclones), has increased by 70 percent (UNISDR, 2015c), and this number is likely to rise with population growth and climate change. Indeed, Asia's urban population is projected to increase from 2.06 billion in 2014 to 3.31 billion in 2050 (United Nations and Department of Economic and Social Affairs, 2014) further increasing the number of people exposed to natural hazards. Urban centres in the Asia-Pacific region are often located in geographically vulnerable areas, and development, especially of land occupied by the urban poor, is increasingly occurring in hazard-prone areas (ESCAP, 2015). A large portion of Asia's urban population (238 million in 2000) lives less than 10 meters above sea level (Nicholls and Small, 2002; McGranahan et al., 2007; Nicholls and Cazenave, 2010; IPCC, 2014b), highly exposed to storm surges and sea level rise.

This paper proposes an indicator based approach for the spatial assessment of the risk to heat waves, landslides, and storm surges in two socio-economically diverse districts of Hong Kong Special Administrative Region of the People's Republic of China (herein referred to as Hong Kong). It addresses strategies that can improve the knowledge needed for managing and reducing disaster risks in urban areas, with some consideration in the case of future climates. Section 2 provides the state of the art concepts, methods and background information on risk assessment. Section 3 presents the case study areas and the features of several hazards for Hong Kong; section 4, the methodology used; section 5, the results; section 6, the final discussion; and section 7 the conclusions.

RISK, VULNERABILITY, AND HAZARD: CONCEPTS AND METHODS

The term hazard refers to a potentially damaging physical *event*, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or *environmental degradation* (UNISDR, 2015a, p.19 emphasis made by the authors). Risk to natural hazards is the combination of the probability or likelihood of a natural hazard to occur and the vulnerability of the system potentially affected (UNISDR, 2015a). In contrast to this definition provided by the disaster risk reduction community, the climate change community puts less emphasis on the likelihood aspects and defines risk as the result of the interaction of hazard, exposure, and vulnerability (Parry et al., 2007). The traditional approach of natural sciences (such as geophysics) to risk has mainly been engineering based with the aim of reducing the exposure of potentially affected communities to a seemingly unavoidable event (Cardona, 2004). Risk can concretise in a disaster[1] when severe consequences and disruption occurs. More recently, the disaster risk reduction community modified this perspective that focused mainly on the characteristics of the hazard, including the likelihood of occurrence, to take increasingly into account the features of the system exposed as key drivers of the entity of potential damages (Bankoff et al. 2004; Birkmann, 2006; Wisner et al. 2004). The concept that the fragilities of the exposed and eventually impacted social-ecological system also contribute to risk is made evident, for instance, in the case where one hazard unevenly impacts distinct parts of the same city due to the socio-economic and governance failures or disparities (Collins, 2010).This "vulnerability" perspective in risk reduction originated from social sciences. It takes into account the socio-economic conditions of people, or their capacity to prevent and cope with a hazard (Cardona, 2004; Bankoff et al. 2004; Birkmann, 2006; Wisner et al. 2004). This perspective has extensively framed the concept and analysis of vulnerability also in the climate change community (Füssel and Klein, 2006; IPCC, 2014c; IPCC, 2012). In this area, vulnerability is generally defined as the "propensity of exposed elements such as physical or capital assets, as well as human beings and their livelihoods, to experience harm and suffer damage and loss when impacted by single or compound hazard events" (Birkmann et al., 2013). The IPCC Glossary of terms[2] more simply defines vulnerability as the "propensity or predisposition to be adversely affected". It encompasses, further to the character, magnitude, and rate of climate change and variation to which a system is exposed, aspects like sensitivity and capacity to cope. In the disaster risk reduction community, vulnerability is described through three components: exposure, or "the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected;" susceptibility or sensitivity, namely the "predisposition of elements at risk (social and ecological) to suffer harm;" and lack of resilience or coping capacity "determined by limitations in terms of access to and mobilization of the resources of a community or a social-ecological system in responding to an identified hazard," (Birkmann et al., 2013). In the long run, the capacity of the system to reduce risk to hazards is called adaptive capacity, which governs "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences", (Parry et al., 2007). In this sense, adaptive capacity is an element modifying vulnerability for instance by enhancing the capacity to cope or by reducing exposure to climate change impacts in the long term. As mentioned, the vulnerability perspective presents hazards not as inevitable events "naturally" affecting socio-ecologic systems, but as the result of the interaction between the features of the affected system and the event. The interaction that takes place between the natural and the social systems, determining a particular configuration of risk, develops not only on the characteristics of the hazard itself, but also on the conditions of the social-ecological system impacted. Some features of the transformed social-ecological system can magnify the impacts of a hazard on the system itself and can therefore be addressed to reduce the risk of damages. Further to hazards with a mere natural component, UNISDR defines socio-natural hazards as those where "the causes are a combination of natural and anthropogenic factors, including environmental degradation, climate change and others", (UNISDR, 2015a). Also according to the definition used by the IPCC (2014a), socio-natural hazards are originating in the human degradation or transformation of the physical environment. For example, this is the case with the concentration of air pollution or the urban heat island effect, both increasing the impacts of heat waves in cities (Clarke, 1972; Fischer et al., 2004; Gabriel and Endlicher, 2011; Laaidi et al., 2011; Rainham, 2003; Tan et al., 2010; Weng and Yang, 2006). Similarly, soil sealing can increase the impacts of heavy precipitation leading to floods in urban areas by limiting drainage and accelerating run-off (Scalenghe and Marsan, 2009). Damages and casualties of storm surges following cyclones are also amplified due to the concentration of urban areas and sealed surfaces along coasts (Hanson et al., 2010). The vulnerability of coastal settlements is in many cases accentuated by natural and anthropogenic subsidence, by artificial coastlines increasing erosion, and deforestation which might increase erosion or intensify landslides (Smyth and Royle, 2000). In most cities, the poor live in those areas that are more exposed to disaster risks, like river and coastal flood plains or steep slopes and areas at risk of landslides. This holds for cities in the developing world as well as for those in developed countries (Preston et al., 2014; Satterthwaite et al., 2007). Distinguishing between natural hazards, which occur independently from human action but may be enhanced by anthropogenic climate change, and socionatural hazards, which lie at the interface between hazardous natural events and socio-economic vulnerabilities, helps to contextualize the potential effects of disaster risk reduction policies and climate change adaptation strategies. Climate change is one, but not in all cases the most important, driver of disaster risk (Kelman, 2015).

MULTI-HAZARD RISK IN URBAN AREAS

Hazards of different kinds can impact urban areas and create different types of damages and disasters, often acting on the same parts of the territory, creating, from a spatial point of view, multiple risks. Already in the early nineties, the consideration of multiple risks was proposed as part of the requirements for the definition of strategies for sustainable urban development. In fact, the need for multirisk assessment is part of Agenda 21 for sustainable development, formulated during the UN Summit in Rio in 1992, which requests a “complete multihazard research” as part of human settlement planning and management in disaster-prone areas (UNEP, 1992). The importance of considering multiple risks was reconfirmed in the Johannesburg Declaration of Sustainable Development in 2002, which required, as a prerequisite of the protection and management of natural resource base of safe economic and social development, “[a]n integrated, multihazard, inclusive approach to address vulnerability, risk assessment and disaster management, including prevention, mitigation, preparedness, response and recovery,” (UN, 2002, p.20).

The consideration of multiple risks and of their potential interactions has also been developed within the risk management community. The Hyogo Framework of Action for instance pledged for the introduction of “integrated, multi-hazard approach[es] for disaster risk reduction [. . .] into policies, planning and programming related to sustainable development, relief, rehabilitation, and recovery activities in post-disaster and postconflict situations in disasterprone countries” (UNISDR, 2005). The importance of creating comprehensive views on hazards is underlined further in the subsequent framework agreement, established in Sendai in 2015: “Disaster risk reduction practices need to be multihazard and multisectoral, inclusive and accessible in order to be efficient and effective”. Among the strategic actions to be undertaken, the framework explicitly calls for researchers “[t]o promote the conduct of comprehensive surveys on multi-hazard disaster risks," (UNISDR, 2015b, p.13). The concentration of risks in urban areas derives from a set of different and often overlapping kinds of vulnerabilities and hazards. This variety of hazards concentrated in a relatively small space makes multihazard assessment an increasingly important yet challenging task for disaster risk reduction in cities for several reasons. First, various hazards in urban areas have different characteristics, their impacts on structures and buildings are diverse, and they can potentially act at various scales in space and time (e.g. frequencies, times of onset, as well as durations). Second, the socioeconomic conditions determining vulnerabilities are not distributed evenly in urban areas, and the dense and interconnected structures of urban areas create strong spatial differentiations. Third, different types of impacts can interact in different ways amongst each other, depending both on causal and spatial relationships, creating a challenge for the analysis of interactions or overlay of different types of hazard impacts, sometimes described as hazard chains, cascades, etc. (Tarvainen et al., 2006; Marzocchi et al., 2009; Kappes et al., 2010). These three factors represent a challenge for the analysis and assessment of urban disaster risks, as they impose the use of diversified approaches (Carpignano et al., 2009; Hufschmidt and Glade, 2010; Kappes, Keiler, et al., 2012; Papathoma-Köhle et al., 2011). In particular, the methods available for the description and quantification of single risks needs to be adapted carefully to the contemporary or comparative assessment of multiple risks (Marzocchi et al., 2012; Marzocchi et al., 2009). A basic approach to multi hazard mapping consists in the mapping of "the totality of relevant hazards in a defined area", (Kappes, Papathoma-Köhle, et al., 2012). This implies to define the urban areas potentially exposed to hazards and the spatial extent of different hazards potentially impacting those areas. Such an approach allows for the identification of potential hotspots of vulnerability, where more than one potential hazard can have impacts, providing specific indications for disaster preparedness [see for instance 52]. Under this perspective, the effects of hazards are considered simply additive, with overlapping and equally severe impacts. A more sophisticated approach would consist in relating the spatial or causal interactions between different hazards and analysing the relative importance of single impacts (Kappes, Keiler, et al., 2012). Another issue worth considering is that of interrelated hazards, as hazards frequently occur as consequences of other types of hazards (e.g. landslides provoked by seismic events or chemical incidents by flooding), or alongside them as in the case of cloud burst events causing both flooding and landslides in the same or contiguous urban areas (Greiving et al., 2006). We will limit our analysis here to natural hazards corresponding to impacts which are, in most cases, spatially defined and differentiated, like impacts on flood prone, coastal, or densely constructed urban areas. Potential interactions between hazards can be based on spatial concentrations of different risks, which can transform multi-hazard risks into factors that expose some urban areas to higher risk levels than others. Under traditional approaches, hazards are analyzed separately, considering also that in most cases these do not occur contemporarily and can, from a risk management point of view, be addressed separately. However, a joint analysis of different hazard impacts can provide substantial improvements for the design of risk mitigation and management strategies, especially in dense urban areas. In fact, from an urban vulnerability point of view, further to temporal interaction of hazard impacts, the spatial concentration or interaction of impacts can also cause particular challenges for peoples' coping capacities. Interacting hazards can be compound hazards: under a spatial approach, the simple fact that two different hazards impact the same people or the same elements of the urban system can cause effects which go beyond the sum of single independent impacts (Kappes, Keiler, et al., 2012). Impacts acting on the same parts of the territory, without interacting causally or coinciding contemporaneously, nevertheless may need to be considered jointly as measures mitigating risks for one impact can potentially enhance vulnerabilities towards other hazards, thereby accentuating hotspots of vulnerability. In this sense, Kappes et al. (2012) focus on vulnerabilities of single buildings, distinguishing between four different types of interactions. The four different options for spatial and temporal interaction as presented by Kappes et al. (2012) have diverse implications in terms of potential forms of action. In the case of spatial but not temporal coincidence of impacts, measures for risk reduction need to be in place aiming at mitigating risks from each of the single hazards, taking into account the co-presence of all hazards (e.g. measures attenuating the impact of heat which need not to compromise the safety in cases of flood or land-slide). In the case of neither spatial nor temporal coincidence between hazards, a differentiated profile for the mitigation of different types of hazards in different parts of the city is suggested. In the case of spatially and temporally coinciding hazards, further to impacts from single hazards, results from interaction and cascading effects need to be taken into account. Finally, the case of simultaneous but not spatially coinciding hazards represents a challenge in terms of risk and emergency management, as in different parts of the city, different types of emergency situations will require different types of management intervention at the same time [following Kappes, Papathoma-Köhle, et al., 2012]. From an assessment point of view, the consideration of multiple hazards requires the creation of complex spatial indices, which provide useful information about risks from different hazards alongside with exposure and aspects of sensitivity and coping capacity for single parts of the urban area. In this sense, single indicators and aggregated indices represent a synthetisation of a complex reality and represent phenomena that, as for instance with vulnerability, are difficult or impossible to measure. Spatial interactions can be captured by simply summing up single hazard indices to create an overall urban multiple hazards map for each spatial unit considered. Using an additive approach for the aggregation of spatial indices for hazards has the disadvantage of potential compensation between high and low risk levels across different hazards. In this way, problematic situations with respect to one hazard can be "hidden" by low risk levels with respect to other hazards considered in the index. Furthermore, additive approaches do not detect (eventual non-linear) interaction between the hazards and the system, which can cause changes in the characterization of the hazards themselves (e.g. cloud bursts or inundation can combine in unforeseen ways with coastal flooding and slope instability) and in changes in the state of the urban system. The changes can cause new and different types or forms of risk which are different from the sum of single hazards. Thus, considering single hazards separately can lead to an important underestimation of risk (Marzocchi et al., 2012), although interactions between more than one hazard are still not well understood (Greiving et al., 2006; Kappes, Papathoma-Köhle, et al., 2012). Aggregation strategies for the single indicators based on multiplicative techniques have been used in some approaches to multi-hazard mapping in order to avoid the compensation problem, like geometric aggregation of weighted indicators (El Morjani et al., 2007; Lung et al., 2013). Weighting of single hazard indicators has been made based on expert knowledge (Lung et al., 2013) or according to the relevance of socio-economic damages (El Morjani et al., 2007). The way forward thus begins with an accurate analysis of all single hazards and their impacts, with special attention given to potential interactions with contemporaneous or sequential hazards: those in which one process triggers the next or those in which the disposition of one hazard is altered by another (e.g. earthquake induced landslide; floods and landslides triggered by extreme rainfall or coinciding with river or coastal flooding) (Delmonaco et al. 2006 p.15; Hewitt and Burton 1971, p. 30, cited by Kappes, Keiler, et al., 2012, p.1935). For each of the single hazards considered, indicators that could be mapped using the available information have been chosen. It is worth mentioning that there are other types of interactions between hazard impacts, including the domino effect or cascading effect. According to Delmonaco et al. (2006 a, cited by Kappes, Keiler, et al., 2012), the "domino effect or cascading failure" is a "failure in a system of interconnected parts, where the service provided depends on the operation of a preceding part, and the failure of a preceding part can trigger the failure of successive parts".

In urban areas this is particularly the case as the accumulation small or everyday hazards can cause widespread impacts, especially in developing countries due to unplanned urban expansion in hazard prone areas (Bull-Kamanga et al., 2003). For a more in-depth review of multi-hazard assessment methods refer to Kappes et al. (2012). With regards to interactions, the spatial overlay of these single indicators in multiple hazard maps can provide a first idea on the existence of eventual interactions.

The second step is to examine, one by one, the sensitivities of the single elements exposed to the multiple hazards and determine degrees of risk. Degrees of risk are comparable across different hazards that are not expressed by a common metric system, provided that hazards are analyzed on the same spatio-temporal scale and on the same risk metric (economic, ecological or social, etc.) (Marzocchi et al., 2012). Classification offers a simple approach to compare risk (Kappes, Keiler, et al., 2012) and semi-quantitative index based approaches by Dilley et al. (2005), Greiving (2006) and Greiving et al. (2006). Dilley et al. (2005) compute hazard and vulnerability as described above and weight the hazard with the vulnerability index to calculate risk.

The third step involves creating an aggregation procedure. Greiving (2006) presents a qualitative Integrated Risk Index (IRI) as basis for spatial planning decisions, which is based on the aggregation of single components of risk. The intensity of single hazards (or hazard impacts) relevant for spatial planning are classified into five intensity classes and aggregated into an integrated hazard risk component. The weight, representing the importance of each of these single hazards is determined based on expert knowledge, whereas the weight of indicators contributing to vulnerability (exposure and coping capacity) are assumed to equally contribute to the overall index. The two composite indicators for hazard risk and vulnerability are then equally weighted for the creation of the integrated risk maps (Greiving et al., 2006, p.215). Qualitative approaches have also been applied by Granger et al. (1999) and Middelmann and Granger (2000), and spatial multi-hazard assessment is presented in El Morjani et. al. (2007). In their health risk oriented study Morjani et al. weighted, different hazards according to the damages caused. In this case the regional averages of damages (persons killed or affected and economic damages) are expressed in monetary terms

(El Morjani et al., 2007, p.6). Kappes et. al. (Kappes, Papathoma-Köhle, et al., 2012) propose a weighting procedure that is able to take into account the different importance of single elements of risk and vulnerability for different types of hazards. The final aggregation of hazard risk indicators is made from the perspective of different activities for disaster risk reduction (emergency management and risk mitigation).

HONG KONG

[Figure 1 about here.]

Hong Kong is situated on the southern coast of China, close to the Pearl River Estuary and shares its northern border with Guangdong Province of Mainland China. The territory consists of Hong Kong Island, the southern part of Kowloon Peninsula, Stonecutters Island and the New Territories, which include the mainland area lying largely to the north, together with 230 large and small offshore islands. The territory of Hong Kong had been leased by the British Empire from China for 99 years, from 1898 to 1997. It is currently classified as a Special Administrative Region of the People's Republic of China. It is part of the coastal region crossed by the Pearl River delta, extending over more than 1,100 square kilometres. Less than 25 percent of its territory is developed, and about 40 percent of the undeveloped land is dedicated to parks or natural reserves as a result of difficult orography and of a long tradition in environmental forestry in the region (Corlett, 1999). Due to the particular socio-political position held by the city throughout the second half of the 20th century, Hong Kong has become one of the most densely populated areas in the world with around 6,300 people per square kilometre. Most of the current population of Hong Kong are descendants of immigrants from mainland China. In 1841 the area only had about 7,450 inhabitants (Ching, 1974), whereas in 1941 population was 1.64 million, dropping to 600,000 after World War II, growing to 3 million in 1960 (Ching, 1974), and finally reaching approximately 7.3 million inhabitants in 2015.[3] The population is projected to increase at a rate of 0.6 percent to reach 8.47 million in 2041, and to continue ageing (HKGOV, 2012). The population aged 65 and over is projected to grow from 13 percent in 2011 to 30 percent in 2030 (HKGOV, 2012). The territory of Hong Kong is subdivided in eighteen districts, each of which consists of a variable number of constituencies. There are pronounced differences in terms of socio-economic conditions throughout different areas of the city in terms of income and living conditions. Further to statistical income levels, these differences are visible also with respect to the percentage of green areas and the environmental conditions across the city. The high percentage of green in the Victorian urban fabric gradually ceded in favour of a high-density and high-rise mode of development, which nowadays pervades most of the city until its peripheries (Jim, 1998), transforming the availability of private green areas into a privilege, available only for the most affluent population in areas close to the center (1998).

CENTRAL AND WESTERN DISTRICT AND KWUN TONG DISTRICT

To perform a detailed analysis of multi-hazard risk at the very local level of the constituency, two of Hong Kong's eighteen districts have been considered: Central and Western District and Kwun Tong District. They were chosen to capture a range of distinct socio-economic and environmental characteristics in coastal areas that are currently experiencing the hazards of storm surge, heat waves, and landslides. Specifically, the Central and Western District features a high income level and low densities of residential population, and the Kwun Tong District represents a lower income level and a high number of inhabitants and population density. According to the 2011 Hong Kong Population Census, Kwun Tong District has the second largest population and the highest population density of all Hong Kong districts. Central and Western District is the third least populated and the eight densest district. Kwun Tong has the sixth highest median age, and Central and Western the twelfth highest. Extensive waterfronts characterize both districts. The Central and Western District, which has a dense central business district situated along the coast, covers an area of about 1,255 hectares and is broken down into 15 constituencies in the 2011 census. Kwun Tong District is slightly smaller at around 1,130 hectares, and is divided into 35 constituencies according to the 2011 census.

NATURAL HAZARDS

Hong Kong is situated along the southeast rim of the Asian Pacific region, in an area that is especially exposed to strong typhoons (wind and heavy precipitation) causing storms and floods.[4] Tsunamis triggered by earthquakes are a second potential trigger for coastal flooding. As a densely urbanized area situated in a humid subtropical climate, Hong Kong is also affected by heat stress (Goggins et al., 2012). Landslides often occur due to the steep slopes in mountainous parts of the city, triggered by heavy precipitation, for instance during cyclones.

HEAT WAVES

The Hong Kong Observatory (HKO) has been recording the occurrence of very hot days and hot nights since 1884 (excluding the period of 1940-1946). Over this period, a total of 1031 days with a maximum temperature greater than or equal to 33°C,[5] and 894 nights with a minimum temperature greater than or equal to 28°Chave been recorded.[6] The climatological normal for very hot days observed from 1961-1990 is 13.37°C, from 1971-2000 is 9.83°C, and from 1981-2010 is 10.20°C. The climatological normal of hot nights from 1961-1990 is 8.73, from 1971-2000 is 13.1°C, and from 1981-2010 is 17.8°C. Since 2000, the HKO has also been issuing Very Hot Weather Warnings (VHWW) to alert the population in the event of a heatwave. Warnings are generally issued when temperature reaches 34°C, or exceeds 30°Ctogether with a certain humidity level, wind speed and direction. Between January 2000 and October 2015, the VHWW was issued 203 times; the average duration of each very hot weather event was about 1.5 days.[7] These hot conditions represent a particular risk, especially for elderly people living alone, and particularly during long spells (Lam, 2004). Currently there are 14 heat shelters in Hong Kong managed by the Home Affairs Department that opened in the summer 2007 (Chau et al., 2009). The city around the delta is also affected by high levels of air pollution favoured by the high density of tall buildings. Daily mortality connected to air pollution seem to be high in the cooler season in correspondence of northeast monsoons, than in the warm one (Huang et al., 2009; Lam et al., 2005; Wong et al., 2001). Episodes of high Ozone (O^3) and Particulate Matter (PM) concentrations have however been recorded during the hot season linked to the presence of tropical cyclones and due to sources of pollution located at the regional level (Huang et al., 2009; Lam et al., 2005). These might further contribute to the number of excess deaths in extreme hot weather conditions, as suggested by Chau et al. (2009).

Table 1
Socio economic indices of the study areas

	Hong Kong	Central and Western	Kwun Tong
Surface (km2)	1,104	12.52	11.05
Population	7,071,576	251,519	622,152
Population density (people/km2)	6,405	20,089	56,303
Median age	41.7	41.3	42.8
Median monthly income (HKD)	11,000	15,000	10,000
Population change 2001 - 2011 (%)	5.4	- 4	10.6

Hong Kong Population Census, 2011http://www.census2011.gov.hk/en/index.html,(retrieved on 12/11/2015)

LANDSLIDES

A landslide is a geological phenomenon that occurs due to the movement or rock, earth, or debris down a slope. These occur mainly on bare land and shrub-covered areas (Zhou, Lee, J. Li, et al., 2002) and occur frequently under heavy rainfall conditions (Dai and Lee, 2002). Landslides in Hong Kong have been studied in particular on the little inhabited Lantau Island (Dai et al., 2004; Dai et al., 2001; Dai and Lee, 2002; Zhou, Lee, J Li, et al., 2002). Other researchers have looked at the New Territories district (Yao et al., 2008), and Hong Kong Island (Chau and Chan, 2005). Research on Hong Kong Island has found that elevation to be the most dominant factor in explaining landslide occurrence in the area, whereas other research shows that the other factors, like slope angle, soil characteristics, and coverage have a more important role (Evans et al., 1997; Chau et al., 2004). Hong Kong Island is also more affected by landslides than the other parts of the city, as it is the most populated area with high rates of soil sealing and high building densities (Chau and Chan, 2005). Since 1983, the HKO and Geotechnical Engineering Office has been issuing landslip warnings when there is a high risk of many landslips as a result of persistent heavy rainfall. Warnings are intended to encourage the public to take precautionary measures to reduce their vulnerability to the hazard posed by landslips. Furthermore, they are intended to assist engineers, contractors and others who may suffer losses from landslips. Relevant government departments and organisations are prompted by warnings to take appropriate actions, including opening temporary shelters, standing by for search and rescue operations, and closing individual schools and relief work projects. From January 1983 to October 2015, a total of 103 landslip warnings were issued in Hong Kong.[8]

TYPHOONS

Hong Kong's typhoon season spans from May to November, with the peak season occurring during the summer months of June, July, and August. These tropical cyclones often result in flooding and landslides (Dai et al., 2001). In the past, the greatest death toll and economic losses have been inflicted by typhoon-induced storm surges (Lam, 2004; Yim, 1996). According to the HKO's database on Storm Surge Records in Hong Kong during the Passage of Tropical Cyclones from 1949 to 2015, tide gauges nearby the case study areas have recorded water levels as high as 1.77 meters above the astronomical tide. In the city's history, typhoons are the hazards that have caused the most casualties and damages in Hong Kong (Lam, 2004). According to the EM-DAT,[9] in 1906 a tropical storm hit the city causing 10,000 deaths while another typhoon caused 11,000 deaths in 1937. In 1947, 2000 people died in a storm. In June 1960, Typhoon Mary hit the city affecting more than 15,000 people. Since then, the city's vulnerability has been reduced drastically, as only minor damages were registered in Hong Kong[10] when a similar situation reoccurred in October 2010 when typhoon Megi made landfall over Mainland China, approximately 400 kilometres north of Hong Kong in Fujian. However, according to EM-DAT, floods too are at the origin of high numbers of people affected in Hong Kong, and together with storms cause the highest amount of economic damages. On the other hand, typhoons also bring benefits to Hong Kong. Cyclones are responsible for at least 30 percent of annual rainfall in the area, and are therefore important for the water balance of the city, also by breaking drought periods and cooling the environment (Lam et al., 2012). The downside is that these precipitation events are often concentrated in relatively short time periods. May, June, July, August, and September each have monthly rainfall levels exceeding 300 millimetres; about 80 percent of the yearly rainfall occurs in these 5 months. HKO monthly mean precipitation data from 1981-2010 indicates that June is the rainiest month in terms of both total and duration of rainfall.[11] The HKO issues Tropical Cyclone Warning Signals in the event of a typhoon. Warnings to the public are issued in case of persisting strong winds, storms and cyclones and in case of tropical cyclones centered within 800 km of Hong Kong which may affect the city. From January 1964 to October 2015, 1028 cyclone warnings of signal 1 or higher were issued with an average duration of nearly 17 hours. The climatological average from 1951-1980 was 492 warnings, 499 from 1961 to 1990, 475 from 1971to 2000, 413 from 1981 to 2010, and 359 have been issued since 1991.[12]

RISK ASSESSMENT METHODOLOGY

Risk is defined by the likelihood to be affected and is generally obtained by aggregating vulnerability indices with those describing hazard. Several approaches for the aggregation of single indices exist: for example, Greiving (2006) proposes an integrated risk matrix with 10 degrees of risk obtained by summing vulnerability and hazards classes. The Global risk index is also calculated as the product of exposure (the hazard sphere) per susceptibility, coping capacity, and adaptive capacity (Welle and Birkmann, 2015). Others have defined vulnerability spatially as the product of hazards features, sensitivity, and adaptive capacity (Kienberger et al., 2009), what has been referred to as risk herein. Carreño et al. (2007) also assessed the risk to multiple hazards spatially in an urban context as a product of the potential physical damage (D) based on the exposure and an impact factor (I) based on the susceptibility and lack of resilience of the exposed population. By multiplying D and I Carreño et al. (2007) obtained a spatially explicit map of different risk at the district level. The methodology applied in this spatially explicit multi-hazard risk assessment has been informed by the multi-risk assessment of Europe's regions described in Greiving (2006), opting for a linear aggregation rather than a multiplicative approach. The methodology consists of four steps: 1) developing intensity maps for each socio-natural hazard based on a set of clearly identified indicators using normalized indices in order to keep values based on different dimensions and metrics comparable (see Table 2); 2) deriving an integrated hazard map encompassing and overlaying all the hazards considered; 3) developing a vulnerability map based on the indicators of exposure, sensitivity and adaptive capacity (see Table 3), relevant for the hazards considered; and 4) obtaining an integrated risk map as a product of the values of the multi-hazards map and of the vulnerability map. Each step is detailed in the next sections. All mapping was done using QGIS software (QGIS Development Team, 2009).

SOCIO-NATURAL HAZARD ASSESSMENT

The heatwave hazard is estimated using the indicator for the urban heat island effect. As a hazard determined by socio-economic factors like urban density that exacerbate the impacts of natural hazards like heat waves, a combined index based on the percentage of sealed surface area and building volume is used. As mentioned, it is assumed that heatwaves impacts the entire city; rather the intensity of the hazard is a function of the UHI phenomena. The landslide hazard is estimated using the percentage of the constituency with a slope greater than 45 degrees. A forty-five degree threshold is chosen as landslides generally occur on steeply sloped lands. Due to lack of data on soil characteristics and soil coverage, only the slope inclination could be used for this assessment. Landslide distribution data for 428 cut-slope failures on Hong Kong Island shows that most landslides occurred in areas with an inclination from 55° to 60° ; other landslide data distributed around this value in a form of normal distribution (Chau et al., 2004). Floodable area is the most relevant factor composing the storm surge hazard, so the percentage of the constituency area between sea level and the highest observed storm surge water level from 1949 to 2015 is used to estimate the storm surge hazard. For both districts, the intensity of impacts from hazards are assessed spatially, while the time dimension is excluded due to lack of available information. The magnitudes of the three hazards considered are aggravated by the features as well as by the activities of the urban system. The urban heat island magnifies the impacts of heat waves; soil sealing is an aggravating factor for flooding; and deforestation increases the risk of landslides. These factors directly affect the spatial magnitude of hazards and can be thus addressed to reduce risk. It is assumed that heat waves intensified by the Urban Heat Island (UHI) effect and heavy precipitation potentially triggering landslides affect all areas in the assessment, but with different intensities due to different spatial characteristics as urban density or slope characteristics, where areas with a slope greater than 45°are considered to be most at risk (Chau et al., 2004). Maps of coastal storm surge are created based on land elevation and historical flood data.

The integrated hazard is the average of the three individual hazards:

$$H = (1/3HW) + (1/3L) + (1/3SS) \qquad (1)$$

Where H is integrated hazard, HW is heat wave, L is landslide, and SS is storm surge.

$$HW = UHI = (1/2SSA) + (1/2BV) \qquad (2)$$

Were SSA is the sealed surface area and BV is the building volume.

$$L = (1/2SA) \qquad (3)$$

Were SA is the percent of land area with a slope greater than or equal to 45 degrees.

$$SS = \text{percent of land area below the highest observed storm surge water level} \qquad (4)$$

An indicator of hazard from 1 to 5 is calculated to classify areas in the districts in terms

Table 2
List of descriptors of spatial intensity of the socio-natural hazard considered

Hazard (H)	Indicator or parameter	References
Heat waves (HW	UHI: sealed surface area (excluding buildings, SSA) plus building volume (BV)	(Depietri et al., 2013; Haase et al., 2012; Larondelle et al., 2014)
Landslides (L)	Slope area: percent of land area with steep slope (SA)	(Chau et al., 2004; Evans et al., 1997)
Storm surges/coastal floods (SS)	Floodable area: percent of land area below highest observed storm surge water level	(Damm, 2010; Welle et al., 2014)

of heat waves, landslides, storm surges, and integrated hazard. The classes were defined based on the equal interval method, and implemented in QGIS. The primary source of land use data is the Hong Kong Survey and Mapping Office. The iB5000 Digital Topographic Map provides information on building footprint, land cover, and places of interest. This data is supplemented with Open Street Map data on leisure and natural areas in order to develop a more complete view of land use, particularly green areas. High resolution LiDAR Digital Elevation Model (DEM) and Digital Surface Model (DSM) data are used in the assessment to derive information on elevation, slope, and building height. Data for Central and Western and Kwun Tong districts were provided by the Civil Engineering and Development Department. DEM and DSM data have a vertical accuracy specification of $\pm 0.10m$ standard error (95 percent confidence level or 2σ) and a horizontal accuracy specification of $\pm 0.30m$ standard error. DEM and DSM LiDAR data were collected from December 2010 to January 2011. Tide gauge data is taken from the Hong Kong Observatory's database on Storm Surge Records in Hong Kong during the passage of tropical cyclones. Data from both Quarry Bay, collected from 1986 to 2015, and North Point, from 1949 to 1985, are considered as they are the tide gauges located closest to Central and Western District and Kwun Tong District.

VULNERABILITY ASSESSMENT

Based on the literature and on data availability, a range of indicators has been chosen to characterize vulnerability to the different hazards. All indicators describe some aspects of the social-ecological system regarding its susceptibility or coping capacity with respect to the potential hazards impacts. The indicators selected are presented in Table 3. Socio-economic data used in the assessment has been obtained from the 2011 Hong Kong population census. Specifically, data on population, age, education, employment, income, people per household, and gender are considered for the 15 constituency areas within the Central and Western District on Hong Kong Island, and the 35 constituency areas within the Kwun Tong District in Kowloon. Although overall hazard preparedness has improved in Hong Kong in the last decades (Lam, 2004), there are substantial differences among age groups: a 2012 study revealed, for instance, that only 22.4 percent of the elderly were prepared for disasters (Loke et al., 2012).

Table 3
List of indicators describing the multi-hazard vulnerability of Hong Kong

Vulnerability component	Indicator	References
Exposure (E)	Constituency population (as a percent of Hong Kong's total population)	(Birkmann et al., 2013)
Susceptibility (S)	Young people (percent population< 5) (Y) and Elderly (percent population >65) (A)	(Gabriel et al. 2011,92-95) Loke et. al. 2012; Brückner 2006; Kosatsky, 2003
	Unemployed (percent) (U)	(Yardley et al., 2011)
	Income (median monthly domestic household income) (I)	(Lin et al., 2008; O'Hare and Rivas, 2005)
	Education (percent of population over 15 with max primary level of education) (P)	(Frankenberg et al., 2013; Harlan et al., 2012; Lee, 2014; Ni et al., 2015)
Lack of coping capacity (LCC)	One person households (percent of households)	(Bouchama, 2007; Fouillet et al., 2006; Kosatsky, 2005; Naughton et al., 2002)

CALCULATING VULNERABILITY

Based on the definition of vulnerability, which is a function of exposure, susceptibility and lack of coping capacity, socio-economic data has been normalized in order to assess relative differences in vulnerability between the districts and across constituencies. For population and income, normalization is done relative to all Hong Kong constituencies, whereas for the other variables it is done across the constituencies included within the two case study districts.

Vulnerability, which exists only in areas where the population is exposed to hazards (Bankoff et al., 2004), is calculated as follows:

$$V = E * (S + LCC)Eq.(5) \tag{5}$$

Where E is exposure, S is susceptibility, and LCC is lack of coping capacity.

$$E = \text{constituency area population as percentage of Hong Kong population} \tag{6}$$

$$S = (1/5Y)+(1/5A)+(1/5U)+(1/5I)+(1/5P) \tag{7}$$

Where Y is the percentage of the population under age 5, A is the percentage of the population over age 65, U is the percentage of the population that is unemployed, I is income, and P is the percentage of the population over 15 years old with a maximum level of primary education.

$$LCC = \text{percent one person households} \tag{8}$$

RESULTS

Figures 4 to 11 report the results of the procedure depicting single hazards, integrated hazards, the components of vulnerability, vulnerability, and risk. Risk (R) is the product of hazard (H) and vulnerability (V):

$$R = H * V \tag{9}$$

[Figure 2 about here.]

[Figure 3 about here.]

For a visual representation of the indicators, the levels of hazard, vulnerability, and risk are categorized into 5 classes based on the equal interval method of classification. Figures 2 and 3 serve as a reference for the codes and names associated with each constituency area in Central and Western District and Kwun Tong District.

UHI, STORM SURGE, AND LANDSLIDE HAZARDS

[Figure 4 about here.]

The UHI hazard, according to this analysis, is most intense in constituency KT21 in Kwun Tong, while CW14 has the highest UHI hazard in Central and Western constituency, and ranks second highest among all constituencies considered.

[Figure 5 about here.]

[Figure 6 about here.]

The coastal constituencies of both districts are those where the storm surge hazard is highest, particularly in northwest Central and Western and southern Kwun Tong. The highest level of storm surge hazard exists for constituency CW8 in Central and Western District; constituency KT22 has the highest storm surge hazard in Kwun Tong and second highest storm surge hazard among all constituencies. Constituency CW3 in Central and Western District has the highest landslide hazard of all constituencies considered, while the highest in Kwun Tong and second highest landslide hazard overall is in constituency KT7.

INTEGRATED HAZARDS

[Figure 7 about here.]

The highest overall integrated hazard level exists for constituency CW8 in Central and Western District, while the highest hazard index in Kwun Tong is constituency KT22, which ranks third highest overall. Based on the use of the equal interval ranking method, 13.3 percent (2 constituencies) of Central and Western District's 15 constituencies face the highest multi-hazard level of 5, while 33.3 percent (5 constituencies) are at level 4; 26.6 percent (4 constituencies) are in both categories 3 and 2, and none have a hazard index of 1. As for Kwun Tong District, 5.9 percent (2 constituencies) of the 34 constituencies have a hazard index of 5; 11.7 percent (4 constituencies) have a hazard level of 4; 8.8 percent (3) constituencies have a hazard level of 3; 47 percent (16 constituencies) have a hazard index of 2; and 26.4 percent (9) constituencies have a hazard level of 1. Central Western has significantly higher hazard levels when compared with Kwun Tong.

VULNERABILITY

[Figure 8 about here.]

[Figure 9 about here.]

[Figure 10 about here.]

The most exposed constituency is KT12 in Kwun Tong, whereas the most exposed constituency in Central and Western is CW9, which ranks fifth most vulnerable overall. Constituency KT10 has the highest overall susceptibility, while CW11 is the most susceptible constituency in Central and Western but only nineteenth most susceptible overall. The constituency with the lowest coping capacity, according to the socio economic vulnerability indicators used, is CW1 in Central and Western District; constituency KT31 has the lowest coping capacity in Kwun Tong. The overall most vulnerable constituency is KT12 in Kwun Tong; CW9 is most vulnerable in Central and Western and tenth most vulnerable overall. Generally, Kwun Tong shows higher vulnerability levels than Central and Western District.

[Figure 11 about here.]

Using the equal interval ranking method to place the 49 constituencies within vulnerability categories, all of Central and Western District's 15 constituencies face the lowest vulnerability level of 1. As for Kwun Tong District's 34 constituencies, only 1 constituency has a vulnerability index of 5. 23.5 percent (8 constituencies) have a vulnerability level of 2, and 73.5 percent (25 constituencies) have a vulnerability index of 1.

MULTI-HAZARD RISK

[Figure 12 about here.]

Relative to all other constituencies in Central and Western District and Kwun Tong District, constituency KT12 (Sau Mau Ping Central) in Kwun Tong faces the greatest multi-hazard risk; the most at risk constituency in Central and Western is CW3 (Castle Road), which has the fourth highest risk level overall. Based on classifications using the equal interval ranking method, none of Central and Western District's 15 constituencies face a risk level of 5 or 4. 33.3 percent (5 constituencies) face a risk level of 3, while 46.7 percent (7 constituencies) are at level 2, and 20 percent (3 constituencies) have a level 1 risk. As for the 34 Kwun Tong Districts, 5.9 percent (2 constituencies) have a risk index of 5, and 2.9 percent (1 constituency) is at level 4. 11.8 percent (4 constituencies) face a risk level of 3, while 35.3 percent (12 constituencies) are at level 2, and 44.1 percent (15 constituencies) have a level 1 risk. Although the levels of vulnerability are low for Central and Western District, the multi-hazard risk map shows a more distributed level of risk between the two districts.

However, if we look at the constituencies ranking highest in terms of risk, three with the highest risk levels are located in Kwun Tong District, while two are in Central and Western District. For hazard level, two constituencies from Central and Western District have the highest hazard levels. The top five most vulnerable constituencies are all located in Kwun Tong District; in fact, the nine constituencies ranking highest are all located in Kwun Tong, with number 10 being constituency CW9 (Belcher) in Central and Western District.

DISCUSSION

By performing a multi-hazard risk assessment using indicators, we identified particular areas within the two districts that show higher vulnerability levels than others; these areas are characterised mainly by higher population densities and lower socio-economic indices in Kwun Tong. Integrating the multihazard index with the vulnerability score we find that the two districts have more comparable and distributed levels of risk. Despite this finding, results of the multi-hazard risk assessment show that although

Table 4
Ranking of constituencies

	Storm surge	Heat wave	Landslide	Hazard	Exposure	Susceptibility	Lack of coping capacity	Vulnerability	Risk
1	CW8	KT21	CW3	CW8	KT12	KT10	CW1	KT12	KT12
2	KT22	CW14	KT7	CW3	KT11	KT31	CW13	KT15	KT22
3	CW10	CW15	KT29	KT22	KT23	KT5	CW2	KT11	KT7
4	KT1	KT32	CW4	KT21	KT15	KT3	KT31	KT22	CW3
5	CW6	KT14	KT6	CW10	CW9	KT25	CW12	KT25	CW2

both study areas are significantly exposed to multiple hazards, the most affected communities are located in the less wealthy parts of the two districts. This suggests that Central and Western District, despite being wealthier, less dense, and thus less vulnerable, is nevertheless at risk as it is exposed to significantly high hazard levels. The highest risk area in Kwun Tong is the constituency of Sau Mau Ping Central (KT12) due to its high level of vulnerability. In this relatively small area, high residential density alongside with medium to low incomes and education levels contribute to a high index of vulnerability. On the other side, a wealthy constituency in Central and Western District shows a high percentage of single households, eventually due not only to more singles but also to non-Chinese household assistants serving with wealthy families. Assessment of results shows that local knowledge can contribute to a better interpretation of these vulnerability and hazard factors, which nevertheless indicate potential vulnerabilities that are recognized in the international scientific debate. For example, closer investigation on the landslide hazard shows that the risk to landslides is highest in constituency CW4 (Peak) in Central and Western District, which is actually covered to a great extent by forest, meaning that the type of soil coverage is able to mitigate risk of landslides. This does not however distort the assessment of vulnerability, as this area is scarcely inhabited and low susceptibility levels keep the overall risk index low.

CLIMATE CHANGE AND SOCIO-ECONOMIC CHANGE IMPLICATIONS FOR MULTI-HAZARD RISK

Climate change scenarios for the region depict increasing impacts from heatwaves, extreme rainfall events, and droughts (Hong Kong Environment Bureau, 2015). In addition, the coastal areas of the city will be progressively impacted by rising sea levels (Yim, 1996; Hong Kong Environment Bureau, 2015), which will worsen coastal flooding from typhoons and storm surges. According to the 2015 Hong Kong Climate Change Report, climate change will lead to more very hot days and hot nights, fewer rainy days but increased average rainfall intensity, more extreme rainfall events, more extremely wet years with risk of extremely dry years, global sea level rise will leading to coastal changes, and increased threat of storm surges associated with tropical cyclones (Hong Kong Environment Bureau, 2015). According to tide gauge data maintained by the HKO, mean sea level in Victoria Harbor has increased at a rate of 30 mm per decade from 1954 to 2014. Sea level rise is projected to increase the risk to storm surges and tsunamis, and to a limited extent, increase the risk of inundation of some low-lying coastal areas. Projected changes in mean sea level in Hong Kong by 2100, relative to the 1986-2005 average, range from 62 to 70 to 73 to 91 cm for the IPCC's RCP2.6, RCP 4.5, RCP 6.0, and RCP 8.5 scenarios respectively. These projections from the HKO are slightly higher than the IPCC's global sea level rise projections to 2100, which are 44, 53, 55, and 74 cm for RCP2.6, RCP 4.5, RCP 6.0, and RCP 8.5 scenarios respectively (Church et al., 2013). Sea level rise is an important factor to be considered in assessing the future development of hazard intensities. This might lead to increasing hazard impacts also in the wealthiest parts of the city, which occupy some of the low-lying areas. As it is for other coastal cities, such as New York, New Orleans, and London, hard infrastructures or mixed green and grey approaches could provide the necessary protection, which would furthermore have the benefit of mitigating the urban heat island effect. These climatic changes nevertheless would not modify the distribution of risk across the city in a significant way (spatial patterns do not change with exception of the risk of coastal flooding), so that in absence of spatially explicit projections of changes in the distribution of socio-economic characteristics of the population, an additional mapping exercise would not yield new insights. On the demographic side, the fertility rate in Hong Kong has been consistently below the replacement rate of 2.1, reaching approximately 1.2 in 2011 (CSD, 2012). In contrast, life expectancy has increased and the proportion of the population aged 65 and over is projected to rise markedly, from 13 percent in 2011 to 30 percent in 2041, as also shown by the projected rising median age (CSD, 2012). The ageing process of the society resulting from these phenomena will cause additional concerns for vulnerability reduction.

INDICATIONS FOR ADAPTATION ACTION

The spatial mapping of single and composite indicators is a powerful tool for directing future investigation of particularly at risk areas. Policy action will need to address inequalities, which have become evident both in the sense of reducing exposure in higher income neighborhoods and focussing more attentively in improving susceptibility and coping capacities of populations in lower income and more densely inhabited areas of the city. Furthermore, this method allows for the identification of hotspots of risk where green or grey infrastructures might be needed most. Mapping indicators indicates potentially problematic areas where further investigation and policy action is needed in order to reduce vulnerabilities. Assessing vulnerabilities on a spatial level, rather than sector or impact wise, opens the way to more holistic planning of urban adaptation. Planning may correspond with the spatial extension of potentially integrated and focussed policy actions aiming at improving living conditions, which take place at a suburban/neighbourhood level, or tackle the connections between neighbourhoods and other parts of the city.

CONCLUSIONS

The level of multi-hazard risk for both districts considered in the assessment is comparable. A deeper analysis of the data obtained however reveals that Kwun Tong contains most of the constituencies with the highest levels of vulnerability, due primarily to higher levels of susceptibility, whereas both districts have a similar distribution of hazard intensities. However, this also translates in higher levels of risk to multiple hazards for Kwun Tong District.

Based on the methods of assessment employed herein, the integrated risk is highest where spatial intensity of hazards and vulnerability coincide. This is the case in some constituencies of Kwun Tong, where population density and susceptibility due to socio-economic factors are high, alongside with some medium to high hazard indices. A similar risk due to hazards does not in all cases correspond to identical integrated risk levels in some constituencies in Central and Western District where lower levels of vulnerability are encountered. As this analysis focuses essentially on the residential population, a specific vulnerability assessment with regards to working populations might suggest differentiated measures with respect to those targeting the residential population.

It should be noted that these results are dependent on the weighting and aggregation techniques used. Whereas equal weights were utilized in this assessment, a more comprehensive weighting of hazards and aspects of vulnerability would require collaboration with stakeholders in order to define relations between the single hazard and vulnerability levels as they relate also to specific policy goals. An approach based on equal weighting nevertheless provides useful information for a comparative assessment of risk to multiple hazards in different areas of a coastal city, as it highlights local concentration of those physical and socio-economic conditions that can determine elevated levels of risk.

In summary, our analysis shows that under a multi-hazard approach, no part of the city is significantly less exposed to hazards than others. Nevertheless, elements contributing to higher or lower risk levels are not equally distributed across the city. In those areas where socio-economic factors drive or accentuate the overall risk level, improvements specifically addressing the socio-economic conditions of the population (like in most of the constituencies of Kwun Tong) and providing targeted services to improve coping capacity may be appropriate, whereas in others (like Central and Western) exposure reduction would be a more effective strategy. This leads to the conclusion that a multi-hazard assessment at the sub-urban scale is effective in identifying spatial distribution of principle drivers of risk that might change within a city. It helps prioritize interventions within different districts, at the very local level, which will be increasingly required under climate change conditions.

Notes

[1] Disaster is defined as “A serious disruption of the functioning of a community or a society due to hazardous events interacting with conditions of vulnerability and exposure, leading to widespread human, material, economic and environmental losses and impacts”, (UNISDR, 2015a)

[2] http://www.ipcc-data.org/guidelines/pages/glossary/glossary_uv.html (retrieved on 08/01/2016)

[3] http://www.censtatd.gov.hk/home/ (retrieved on 4/03/2016)

[4] http://www.preventionweb.net/countries/hkg/data/ (retrieved on 31/03/2016)

[5] http://www.hko.gov.hk/cis/statistic/vhotday_statistic_e.htm (retrieved on 22/10/2015)

[6] http://www.hko.gov.hk/cis/statistic/hngtday_statistic_e.htm (retrieved on 22/10/2015)

[7] http://www.hko.gov.hk/wxinfo/climat/warndb/warndb13_e.shtml (retrieved on 22/10/2015)

[8] http://www.hko.gov.hk/wxinfo/climat/warndb/warndb4_e.shtml (retrieved on 22/10/2015)

[9] http://www.emdat.be

[10] http://www.hko.gov.hk/informtc/megi/report.htm: According to the report provided by the Hong Kong observatory, damages were registered mainly on the Philippines, and in Fujian. According to press reports, Megi caused the death of at least 36 people in the Philippines. It also triggered landslides and destroyed some 1,000 houses. The damage to rice crops amounted to 1.5 billion paso (around 270 million HKD). Megi brought heavy rain to Taiwan, triggering landslides and causing the deaths of at least 13 people and another 26 missing. In Fujian, more than 640,000 people were affected and the direct economic losses were around 1.6 billion yuan. Damages in Hong Kong were limited and no casualties have been registered.

[11] http://www.hko.gov.hk/cis/normal/1981_2010/normals_e.htm#table2 (retrieved on 31/03/2016)

[12] http://www.hko.gov.hk/wxinfo/climat/warndb/warndb1_e.shtml (retrieved on 31/03/2016)

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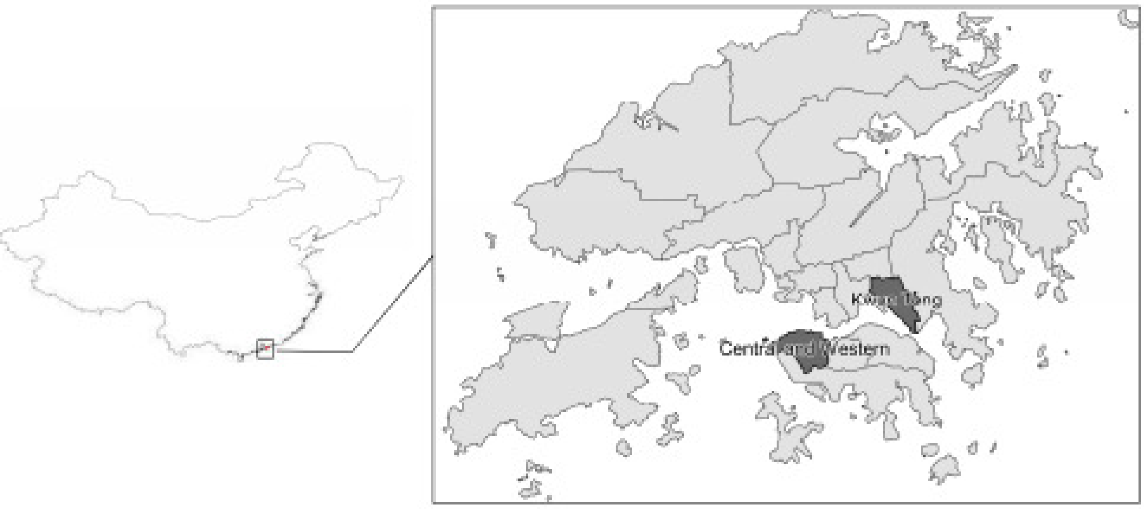

Figure 1:
Map of China and of Hong Kong

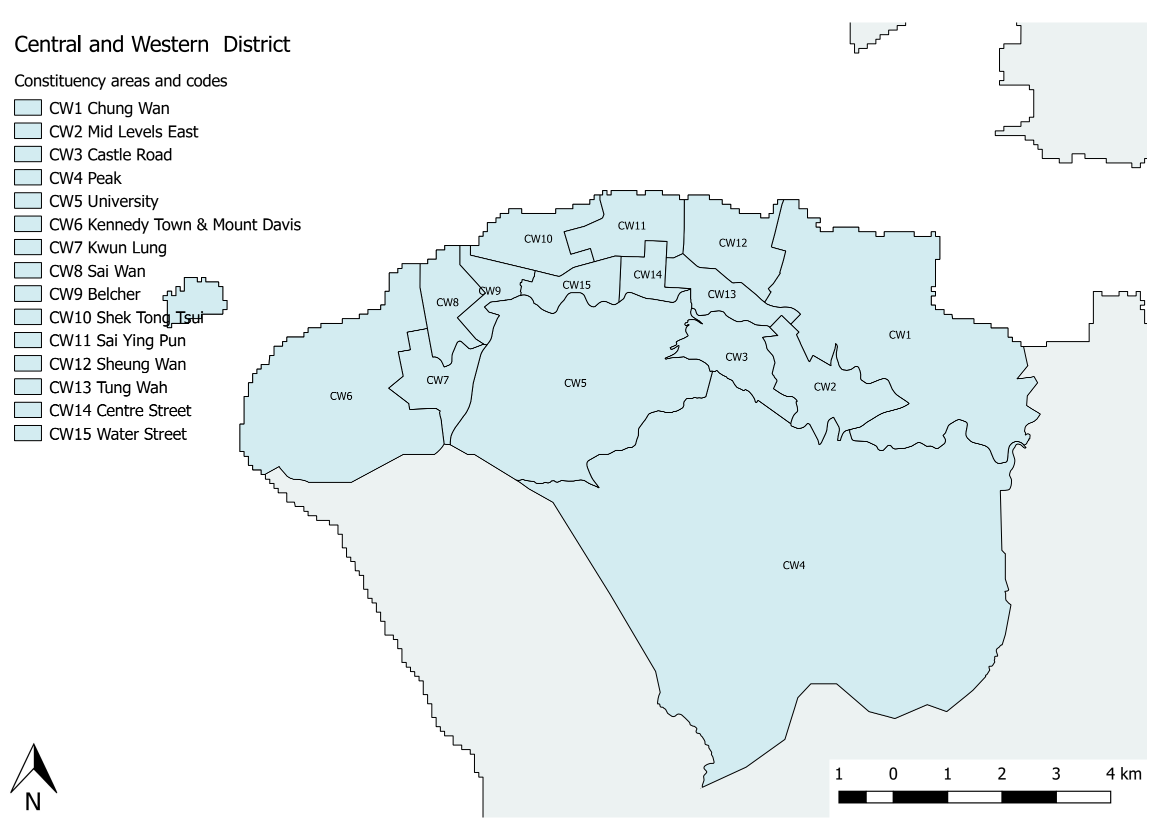

Figure 2:
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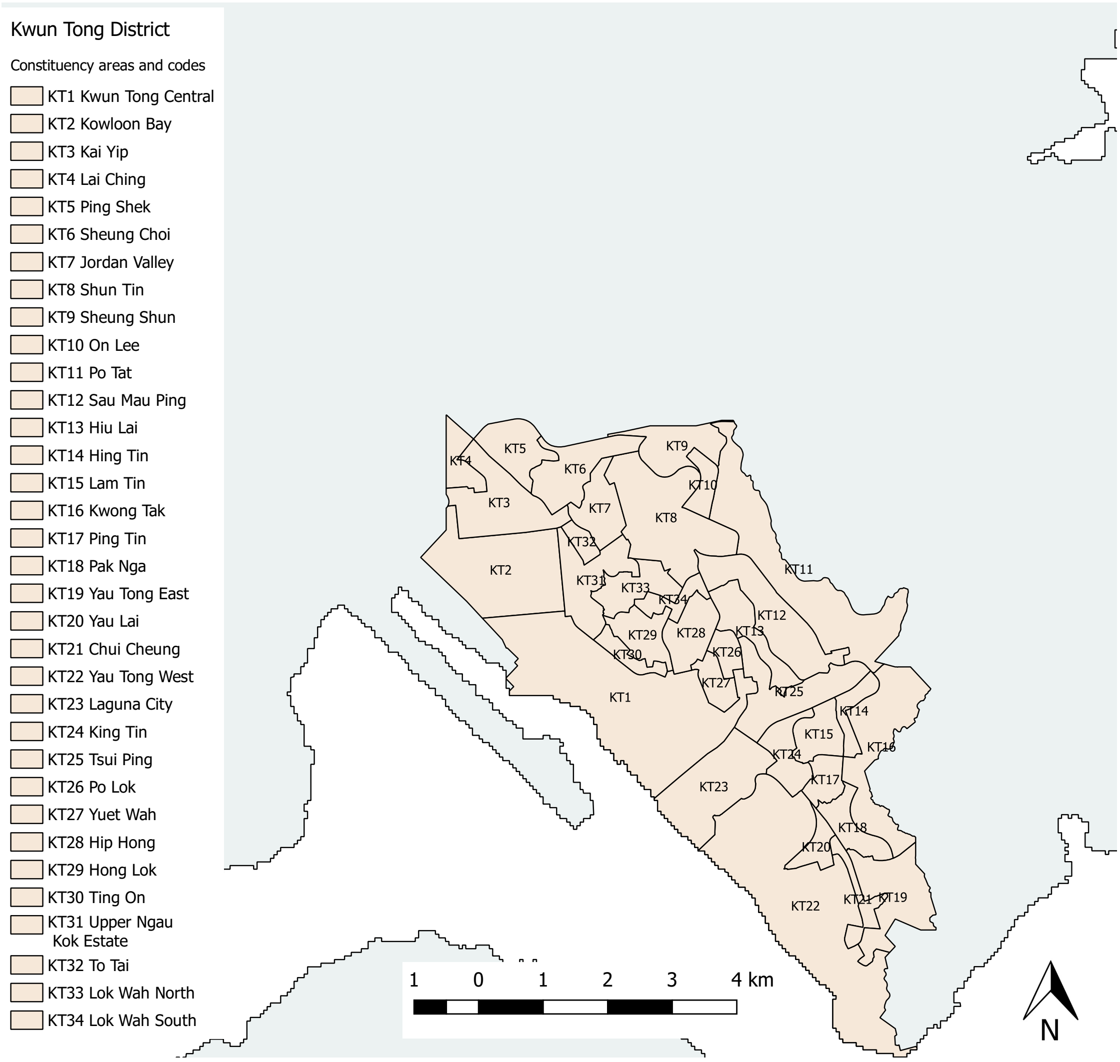

Figure 3:
Kwun Tong District constituency area names

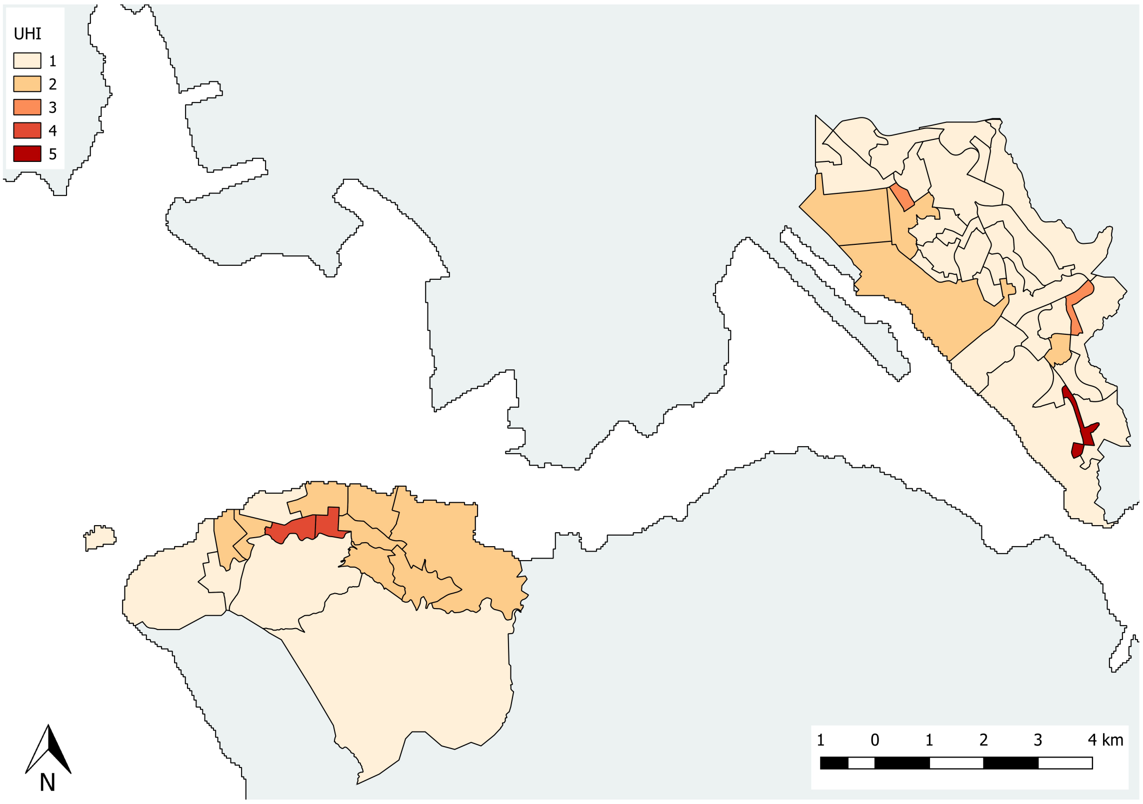

Figure 4:
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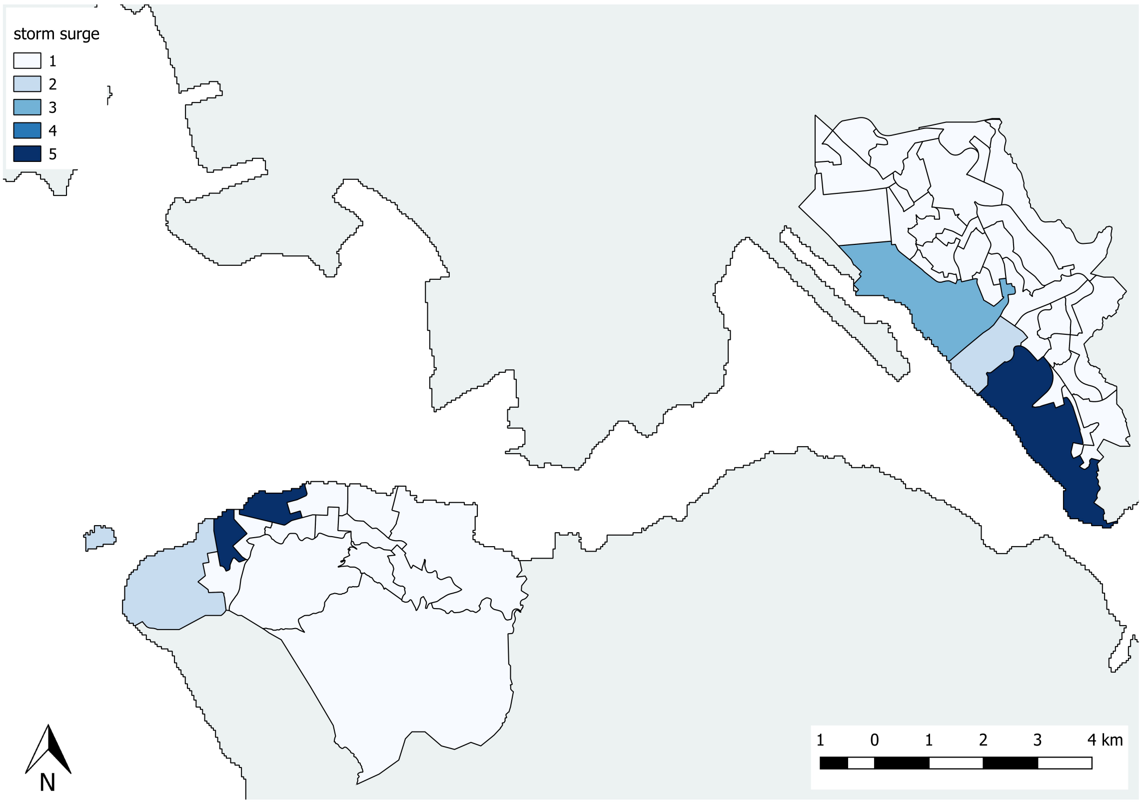

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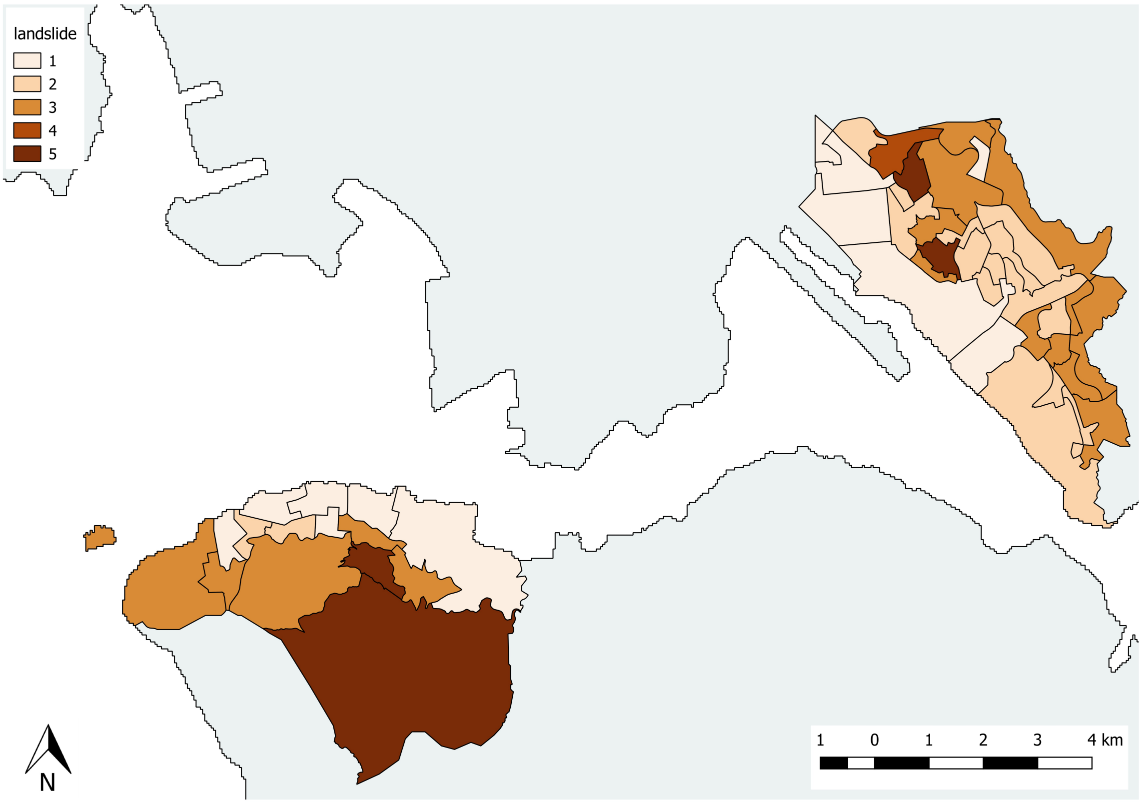

Figure 6:
Landslide hazards map for Central and Western District (left) and Kwun Tong District (right)

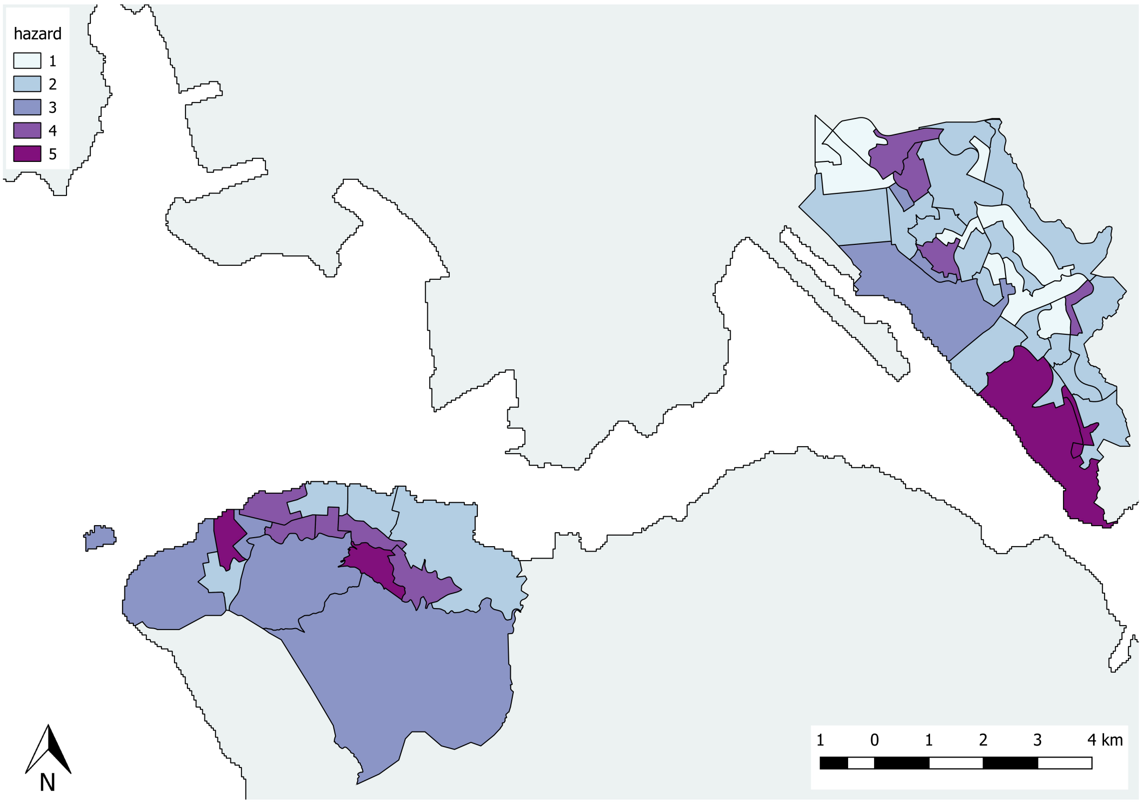

Figure 7:
Integrated hazards map for Central and Western District (left) and Kwun Tong District (right)

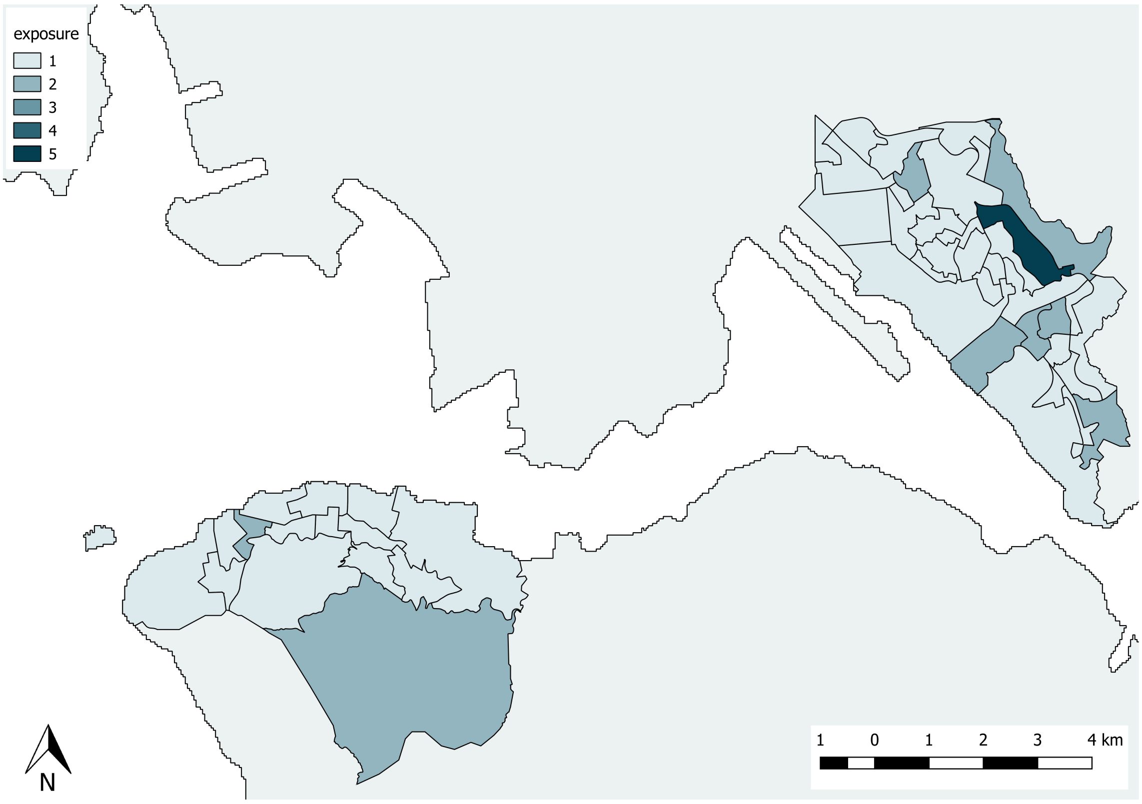

Figure 8:
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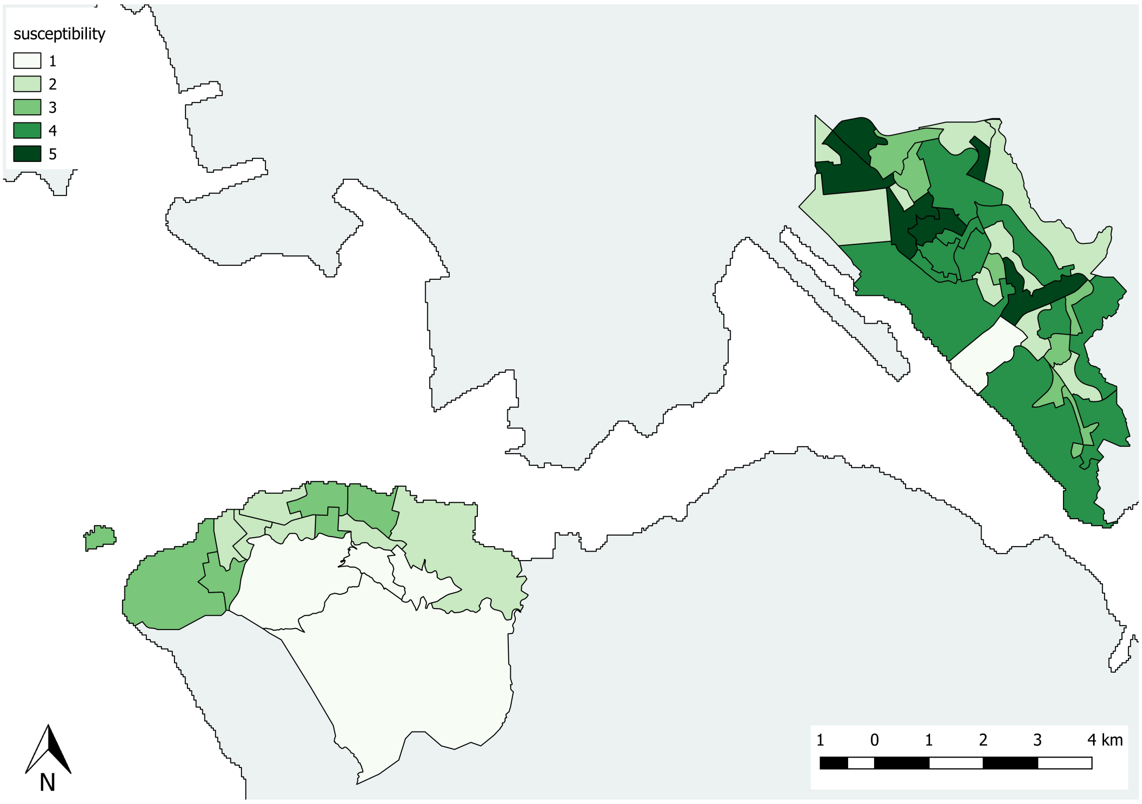

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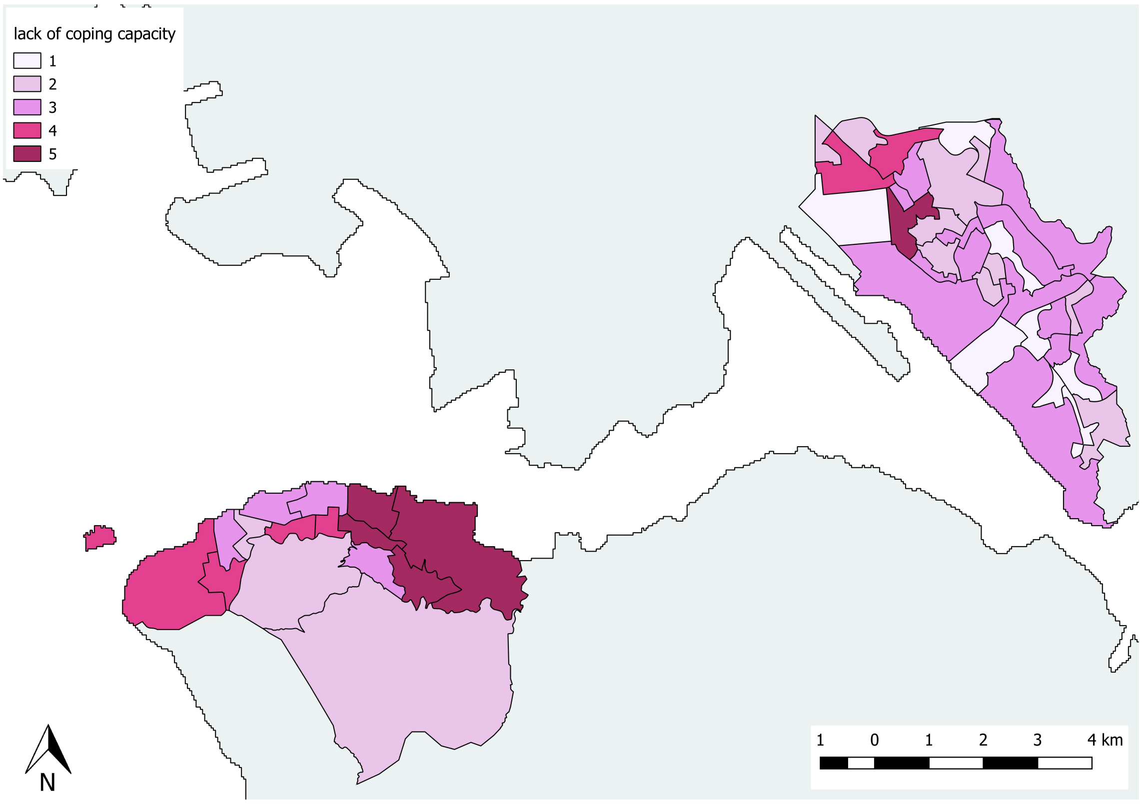

Figure 10:
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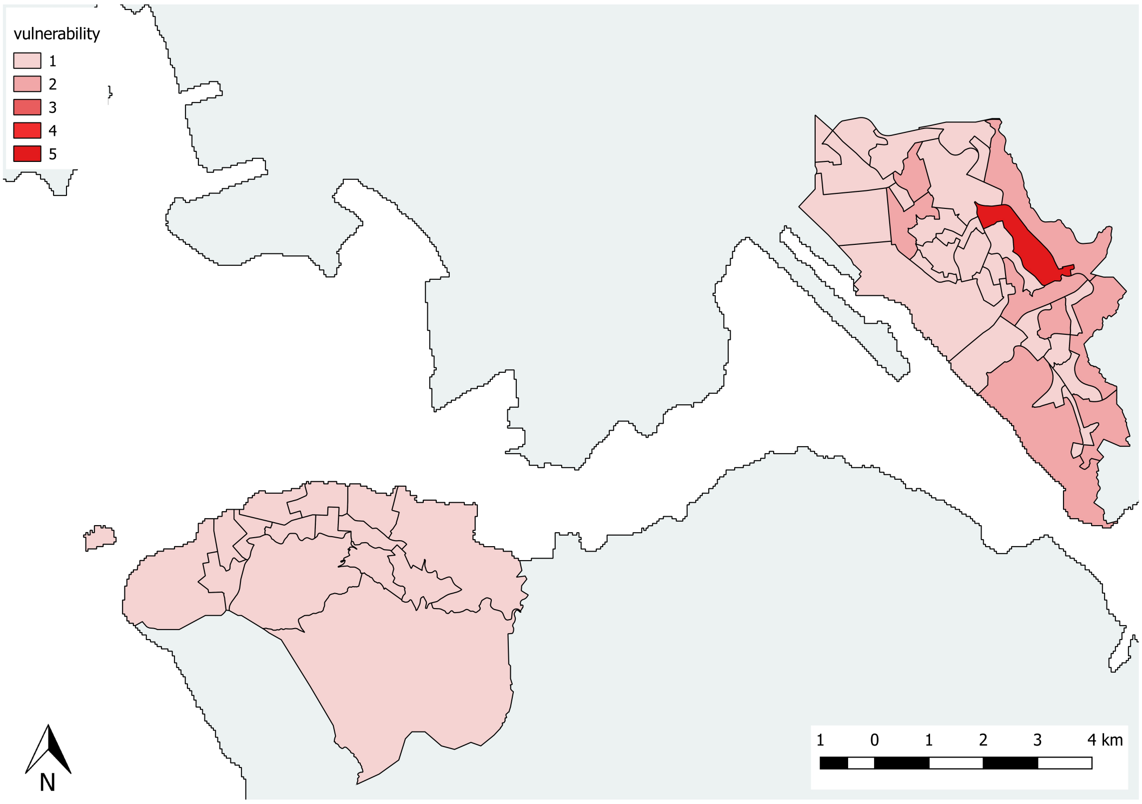

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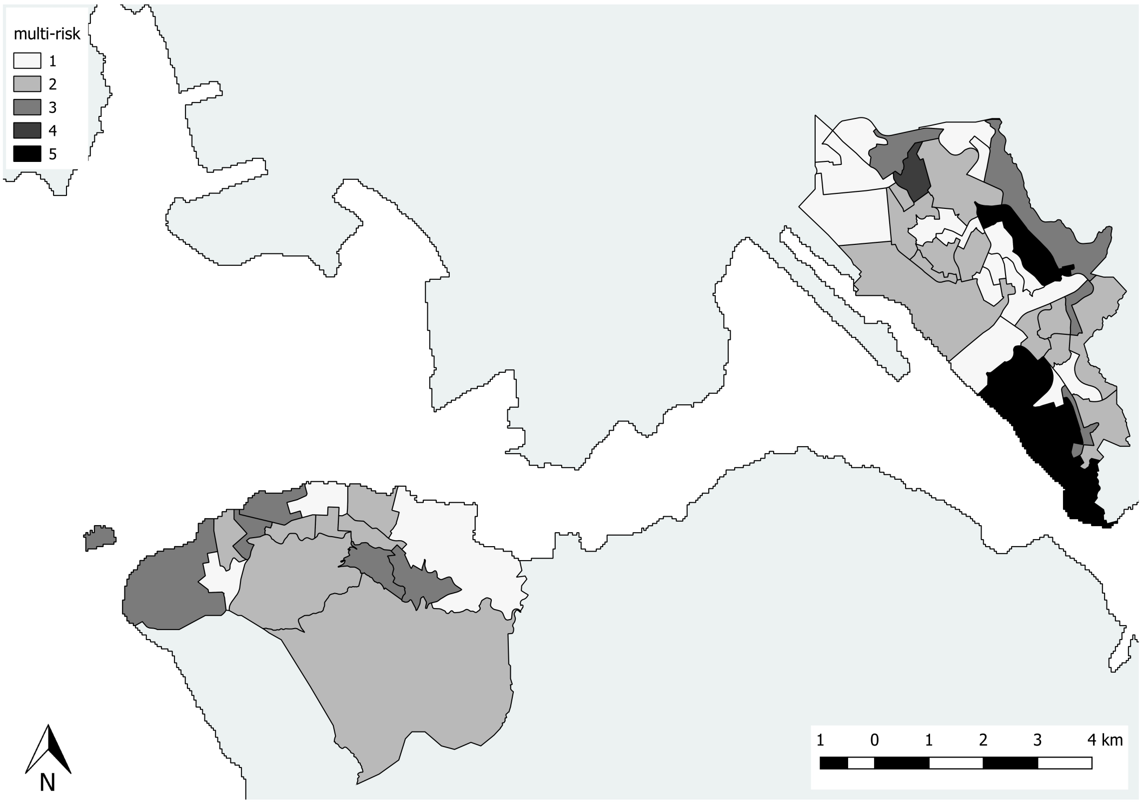

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