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A framework for pluvial flood risk assessment in Alexandria considering the coping capacity

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Abstract

Urbanization and climate change are likely to aggravate the flood risk especially in the developing regions where these are also lack of resources. Risk assessment at the local scale can be seen as an important tool to assist the decision makers to identify and prioritize development, preparedness, and emergency. This paper introduces an integrated framework to assess urban pluvial flood risk, taking into consideration the available coping capacity arrangements as the coping capacity is considered to be the main factor to control the risk impact. The presented framework incorporates the pluvial flood inundation model; the building and social vulnerabilities indices; and coping capacity indicators to identify the risk level in the urban areas and to test the different scenarios for the disaster risk reduction measures. The proposed risk assessment framework has been applied to the city of Alexandria, located in northern Egypt, as there is an increase in pluvial floods in the city causing economic and human losses. A risk map for Almontaza district has been prepared to reveal the risk level for each block, this map can be used for the planning purposes. The introduced framework can increase the efficiency of the preparedness and emergency plans; it can also help the planners to direct the available development resources to the priority areas.

Keywords Urban flood · Risk assessment · Extreme events · Risk modeling · Coping capacity

1 Introduction

Throughout the last decades, disaster risks have increased in several countries, while the climate change leads to increase the frequency and intensity of natural hazards (Ahmed 2013). Heavy rainfalls, heat waves, and intense storms surges became more frequent and are likely to increase in the future (Revi et al. 2014). Also, rapid urbanization pushes us out of our comfort zone, which, in turn, means that the exposure to different hazards and human vulnerabilities to natural hazards witness a remarkable growth (UNESCO 2010). Therefore, disaster risk studies, particularly in the area of disaster risk assessment, came to the forefront. Such studies present an understanding of the risk in terms of aggravation factors, and the expected consequences to support the disaster risk management activities (GFDRR 2016). Also, risk analysis based on probabilistic quantitative methods has been widely used and has been useful for dealing with predictable disaster situations (Linkov et al. 2014).

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In this regard, various methods have been used for disaster risk assessment. Risk indicators are widely used as a way to overcome the intangible nature of risk and turn it into tangible values (Hauger et al. 2006). For example Müller et al. (2011), Jordan and Javernick-Wil (2012), Sungay et al. (2012), Birkmann et al. (2013), Chen et al. (2013) Huang et al. (2015), Hung et al. (2016), Ostadtaghizadeh et al. (2016), and Romero-Lankao et al. (2016) proposed lists of indicators to assess the vulnerability and resilience. The vulnerability refers to the fragility of communities and susceptibility to natural hazards (Tedim et al. 2014), and the resilience refers the capacity of the system to continue performing critical functions through disruptive events (Fox-Lent et al. 2015). Furthermore, a number of researchers applied modeling approaches to investigate the disaster risk management (DRM) including preparedness, emergency, response, and recovery activities and their influence on risk levels. For instance, Hirokawa and Osaragi (2016) and Barahona et al. (2013) developed a model to simulate the response and emergency activities for expected disasters. Also, Ramezankhani and Najafiyazdi (2008) and Hwang et al. (2015) developed system dynamics models to investigate and evaluate recovery efforts in disaster situations.

There is a complex nexus between cities and disasters, with some forms of a bidirectional liaison, constantly shaped by other processes such as climate change and population increase (Wamsler and Brink 2014). A systematic view of risk is recommended in order to address the complexity, dynamic character, and inter-disciplinary needs of management options (Simonovic 2012). Wherefore, Fox-Lent et al. (2015) posit that the decision makers should incorporate four stages of disaster management (plan/prepare, absorb/withstand, recover, adapt) with four management domains (physical, information, cognitive, social) in order to ensure an effective disaster risk management and increase the community resilience. A number of researchers introduced integrated approaches by incorporating risk assessment methods and modeling to introduce a holistic view of the risk in the urban system. For example, Simonovic and Peck (2013) presented a quantitative resilience framework to be implemented through the system dynamics model in an integrated computational environment. Their framework combines economic, social, organizational, and physical impacts of natural disasters on coastal megacities to estimate their resilience in temporal pattern considering arrangements for prevention, mitigation, preparedness, recovery, as well as response. Irwin et al. (2016) introduced a system dynamic model to estimate the resilience of an urban system to flooding events. In addition, the geospatial techniques are used to illustrate spatial distribution introducing an interactive tool to estimate the resilience of some cities (http://resilsim-uwo.ca/).

This paper demonstrates an integrated framework to estimate the pluvial flood risk at the local scale including flood hazard modeling, vulnerability assessment for physical and social dimensions, and institutional capacity assessment. While floods are the most significant natural hazards in the world in terms of damage and number of events (UNU-EHS 2016), they have often been associated with indirect or cascading impacts such as infrastructural failures (Pescaroli and Alexander 2015). In developed countries, flood hazard events are not expected to generate high risk concerning their magnitude because of low vulnerability and some of them have also high resilience; meanwhile, in less developed countries even smaller magnitude floods can generate a large disaster (Alcántara-Ayala et al. 2015). Risk knowledge is expected to boost the efficiency of crisis management and significantly reduces the devastating social and economic impacts caused by such hazards (Dilley et al. 2005). In this regard, the proposed method is expected to be useful particularly for developing countries. The method overcomes the lack of data in these regions, while it tries to deal with the available data to introduce an approximate risk assessment in local scale.

2 Research methodology

The research methodology is based on an integrated approach which includes pluvial flood hazard modeling, vulnerability assessment indices, and institutional capacity measures. The methodology aims to assess the urban pluvial flood risk at the local scale and to test the effects of institutional arrangements on the risk level in urban areas. The first step is to define the model boundary and to identify its main variables affecting the risk level, which was performed through the review of previous flood risk assessment researches and global risk indices. It also took into consideration the experiences of experts and involved persons in DRM. In this context, the conceptual system model presented in Fig. 1 illustrates the main variables and their interrelations. The figure shows that the development and planning element has a significant impact on several factors, which consequently reduce vulnerability. Moreover, the preparedness activities could increase the coping capacity, which could also decrease the risk level. On the other hand, the hazard magnitude and extension increase exposure, which can be reduced via effective DRM as shown in the figure.

Risk assessment and management should consider efforts to prevent or mitigate disasters risk impact by focusing on the system ability to withstand and respond to threats (Linkov et al. 2018). Therefore, in order to analyze risk management, it is divided into three stages through their temporal relationship to disaster. The first stage is the development and planning which represents the long-term arrangements which have a significant impact on several factors as shown

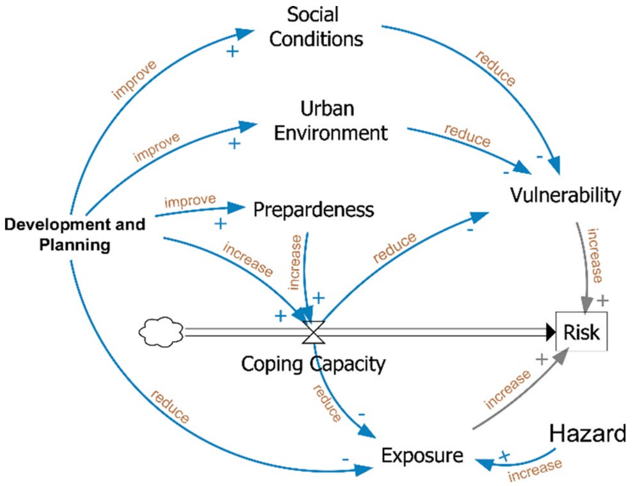

Fig. 1 System diagram illustrates the conceptual model boundary and interrelations

in Fig. 1. The second stage is the preparedness, which represents the short-term period before an expected disaster, and it could increase the coping capacity factor. The third stage is the response and emergency, which represents the activities during disaster time to confront and reduce its impact. Every stage builds upon various factors as presented in Fig. 2. This paper will focus on the preparedness, response, and emergency stages.

The detailed framework was established through dismantling each variable to basic influencing factors, and the relations between these factors were identified through a proper mathematical model that reflects the risk level. The influencing factors are categorized as follows: the hazard factors, the urban environment factors, and the institutional measures factors as shown in Fig. 3 which illustrate the proposed model while identifying the controllable institutional factors to improve the coping capacity and to reduce the risk level. The framework mainly consists of three stages. The first is the pluvial flood hazard modeling stage to determine the flood level and the flood duration for each city block. Secondly, the vulnerability assessment stage assesses the buildings and social vulnerabilities. In the third stage, the response capacity is estimated based on the capacity of the emergency services and their responsiveness. These steps will be explained in details in the next section.

In order to estimate the expected risk level for each block and to illustrate its spatial distribution in the urban area, the geographic information system (GIS) software was used. Figure 4 shows the stages and GIS data examples from Alexandria based on data from a 2010 official survey to illustrate the hazard, vulnerability, and risk. The GIS software used in this study is ArcMap.

2.1 Modeling of the pluvial flood hazard

Hazard analysis is the initial step in risk analysis (Hauger et al. 2006), denoting that the pluvial flood hazard modeling is the first step in the proposed framework. It introduces flood exposure maps identifying the hazard level for each block per hour during the disaster event. In order to carry out this step, a previous hydrodynamic inundation model

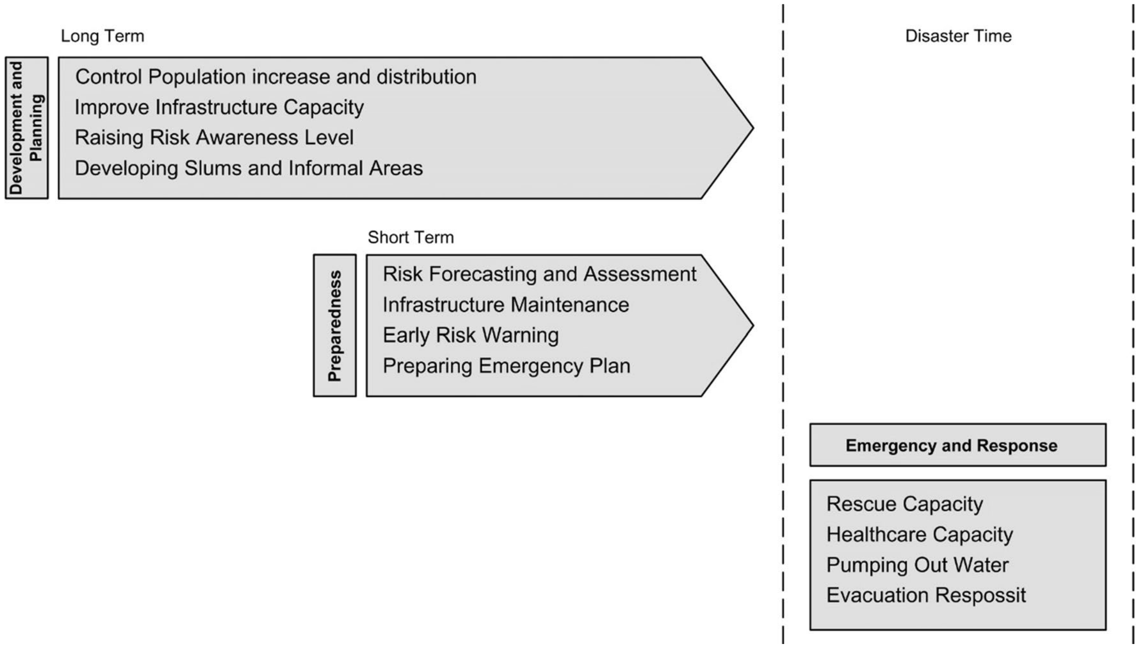

Fig. 2 Disaster risk management stages and related factors

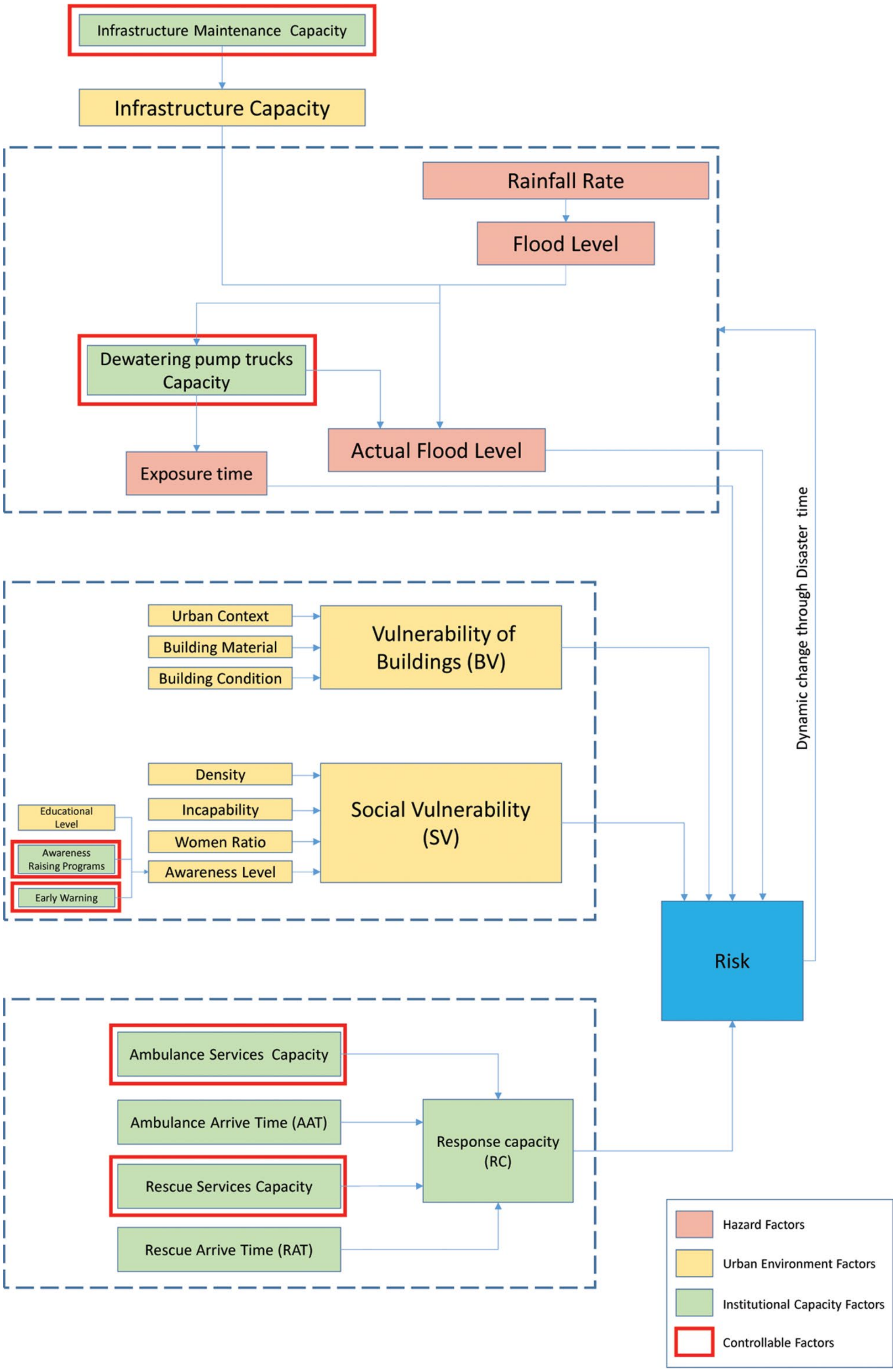

Fig. 3 The proposed framework to estimate urban pluvial flood risk

called the Wetland DEM Ponding Model (WDPM), which was developed by the Centre for Hydrology at the University of Saskatchewan (http://www.usask.ca/hydrology/WDPM.php), was used. It introduces the spatial distribution of water over digital elevation model (DEM) by using two modules: Add and Subtract. The Add module adds a specified depth of water simulating the forecasted rainfall rate in every one hour, and it also provides a map that shows the submerged areas and the water level in each cell. The Subtract module subtracts a specified depth of water from the inundation map produced by the Add module thus representing the water drainage and pumping out. Finally, the exposure areas and

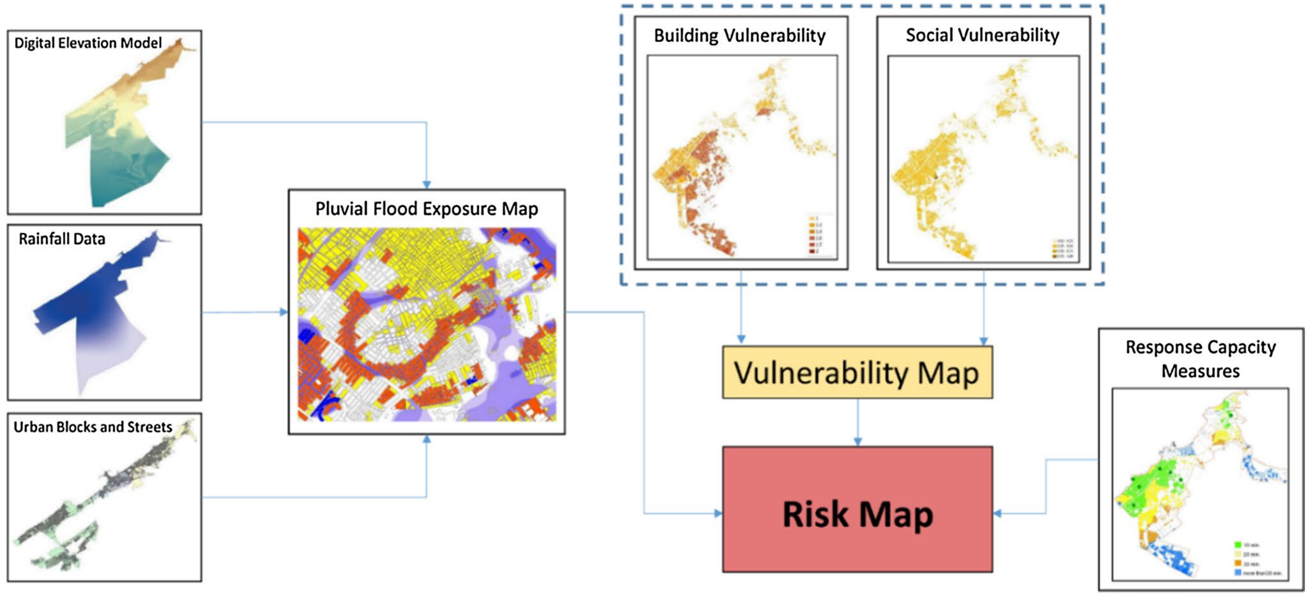

Fig. 4 Risk map modeling steps using GIS software

the water level are defined for each DEM cell producing the hazard map. Alexander et al. (2011) have divided the flood into various levels of severity based on the water height and velocity. In the case of pluvial floods in urban areas, these levels can be used by neglecting the water velocity where there are no strong slopes or large open areas which means it is equal to zero, the flood hazard is divided into four levels as illustrated in Table 1.

2.1.1 Vulnerability assessment

The vulnerability is defined as the susceptibility and fragility to an expected hazard resulting from physical features or operational attributes (DHS 2010). A key risk assessment element is to identify critical components of a system that are vulnerable to failure and subsequences (Bostick et al. 2018); therefore, various methods are developed to assess vulnerability to floods. Huang et al. (2012) grouped the primary methods into three categories; the vulnerability index, the vulnerability curve, and the method based on disaster loss data. In this research, and due to the limitation of data and related researches in the case study, the simple index is adopted to estimate the building and social vulnerabilities. Since the vulnerability index is composed of multiple weighted indicators, the choice of these indicators needs proper deliberations with involved persons in the DRM (Keisler and Linkov 2014). Therefore, several interviews were carried out with local decision makers in Alexandria Governorate, and the Disaster and Crisis Management administration in Alexandria allowed a broader estimation of information and deeper insight into the local, site-specific conditions.

2.1.2 Vulnerability of buildings

The vulnerability of buildings refers to the degree of likely damage following a disaster event depending on the characteristics of its elements at risk (Papathoma-Köhle 2016). Literature review for the vulnerability of buildings to floods reveals a number of influencing factors such as the buildings' conditions, the construction materials, the time of construction, and the number of floors (Dall'Osso et al. 2009). Also, the urban context is considered as an indicator of the building's vulnerability. The informal areas are suffering from lack of formal engineering criteria in construction together with their generally poor construction quality (De Risi et al. 2013). Depending on the discussion with experts considering the pluvial flood situation and the available data in this research, the chosen factors for vulnerability of building index are as follows:

Table 1 Levels of pluvial flood (Alexander et al. 2011)

Hazard level	0	1	2	3
Water level (m)	Less than 0.3	From 0.3 to 0.6	From 0.6 to 1.5	More than 1.5
Danger level	No danger	Danger for some	Danger for most	Danger for all

1. The urban context which indicates whether the urban area is an informal and slum area or a formal area.
2. The building's material.
3. The building's condition which, in turn, refers to the status of the building through the efficiency of construction and general appearance.

Using these factors, the vulnerability of buildings (BV) index was adopted following the proposed index by (Dall'Osso et al. 2009) as shown in (Eq. 1).

$$BV_i = w_u \cdot U/2 + w_m \cdot M/3 + w_c \cdot C/3, \tag{1}$$

where w is the weighting coefficient of each attribute, U is the urban context, M is the building material, and C is the building condition. The attributes have been weighted using expert judgment as demonstrated in Sect. 2.2.3. Every indicator is divided into various levels and a value assumed for each, as shown in Table 2.

2.1.3 Social vulnerability

Social vulnerability is primarily confined to the susceptibility of the human communities to hazard; it contains various dimensions such as economic, psychological, and physical dimensions (Houston et al. 2011). In this regard, the social vulnerability index captures characteristics of certain social groups that render them exposed, susceptible, or adaptive to disaster risk (Fekete 2009). The social vulnerability indicators are varying depending on the scale of analysis, the specificities of the hazard and the particular conception of vulnerability adopted by the study (Felsenstein and Lichter 2014). At the global scale, specific indicators such as relative mortality rate and relative GDP losses have been used (Birkmann 2007). At the regional scale, the indicators related to exposure, socioeconomic status and resilience have been used (Balica 2009), (Liu and Li 2016). At the local scale, various methodologies have been suggested which differed based on the context of the analysis and availability of the data. In the context of flood hazard, Felsenstein and Lichter (2014) have constructed a vulnerability index contains a number of indicators such as disability and age. In this context, this research focuses on factors that reflect the human susceptibility to flood hazard and indicate the ability to avoid danger and evacuate during a disaster. Accordingly, four variables were defined through literature review and discussion with experts as follows: (1) population density, (2) incapability which reflects the percentage of children, disabled and elderly people, (3) women's ratio which refers to the proportion of women in households. Taking into consideration the fact that previous researches indicate higher mortality of women than men to natural disasters (Barsley et al. 2013), and (4) risk awareness level which indicates the public knowledge to deal with disasters. According to the proposed framework, the risk awareness level is expected to be influenced by educational level, early warning system efficiency and risk awareness programs coverage. Because of the lack of data, the educational level is used as the indicator for the risk awareness level. Then, the social vulnerability index was driven following Felsenstein and Lichter (2014) as shown in Eq. 2.

$$SV_i = w_d.D + w_i.I + w_w.W - w_a.A, \tag{2}$$

where w is the weighting coefficient of each attribute, D is the population density, I is the incapability ratio including the disabled, children and the elderly, W is the women's ratio, and A is the risk awareness level. The attributes were weighted using expert judgment as demonstrated in Sect. 2.2.3.

2.1.4 Attribute weights

Determination of attribute weights is one of the biggest challenges. The most common method is to assign the same attribute weight to each factor and sum them. However, this method argues for the equivalence between the indicators and does not give each one its relevant status, whereas experts' judgment could indicate the weights based on their influences (Zhang 2013). Such questionnaires have been sent out to experts working in the urban development and planning profession asking them to rate the vulnerability factors according to their relevance in the study area and experience. The questionnaire included several values in order to evaluate the importance of each factor, while, 0% means not important and 100% very important (See "Appendix"). The average ranking results for ten questionnaires completed by experts were then calculated. After that, the attributes' weights are calculated by estimate the equivalent percentage for each factor that makes the summation of the attributes' weights for each index equal 100%. Table 3 shows the average rating estimated from the collected questionnaires, and

Table 2 Vulnerability of building factors and their categories

Indicator	Categories					
	Value	Description	Value	Description	Value	Description
Urban context	1	Formal area	2	Informal area and slum		
Building material	1	Reinforced concrete	2	Masonry	3	Others
Building condition	1	Good	2	Moderate	3	Bad

Table 3 The estimated weights for vulnerability factors

Vulnerability factors	Questioners' average rating (%)	Related attribute	Attribute weight
Vulnerability of building factors			
Urban context "U"	75	w_u	0.39
Building material "M"	56.25	w_m	0.29
Building condition "C"	31.15	w_c	0.31
Social vulnerability factors			
Population density "D"	28	w_d	0.28
Incapability ratio "I"	25.33	w_i	0.26
Women ratio "W"	16	w_w	0.16
Public risk awareness level "A"	30	w_a	0.30

the final weight was calculated by giving an equivalent percentage to each average rating.

2.2 Response capacity (RC)

In order to reduce the vulnerability and the losses during the disaster time, the coping capacity is essential and could influence the risk level (Carreño et al. 2007b). Coping capacity is defined as using available resources and abilities by people or institutions to face the adverse conditions, emergencies, or disasters, which involve various actions and arrangements (UNISDR 2009). Developing a better road infrastructure, training emergency crews and prepare adequate emergency equipment could improve the overall resilience of communities facing floods that affect transportation and public services (Linkov et al. 2014). In the pluvial flood case, the most available and effective actions to improve the drainage network capacity by maintenance and pumping out water from submerged streets, these included in the hazard modeling step, and the emergency actions which represent the relief and rescue processes. For the purpose of this research, the term "the response capacity" will be used. The evaluation of response capacity depends on the expected arriving time of the ambulance and the rescue vehicles, and the services ratio which refers to the available number of vehicles. It was assumed that there is an inverse relationship between the services ratio and the response capacity affecting the expected arriving time. Equation 3 represents the response capacity.

$$RC_i = \frac{ASR}{AAT} + \frac{RSR}{RAT}, \tag{3}$$

where AAT is the ambulance arriving time, RAT is the rescue arriving time, ASR is the ambulance services ratio, and RSR is the rescue service ratio. The estimation of arriving time depends on measuring the network distance between every block and the nearest ambulance and rescue point using the network analysis in GIS depending on the roads network. The arriving time is divided into four categories to present the arriving time zones. The first category is up to 10 min, the second category 20 min, the third category 30 min, and fourth category more than 30 min.

2.3 The risk index

The risk is defined as the combination of the probability of an event and its negative consequences (UNISDR 2009). Also, it is supposed to be directly proportional to the hazard and vulnerability, while the coping capacity can reduce its severity (Morales ALM 2002). Regarding the INFORM index, the risk can be calculated by the following equation (IASC 2016):

$$\text{Risk} = \text{Hazard} * \text{Vulnerability} * \text{Lack of coping capacity}$$

Also, Carreño et al. posited that the socioeconomic fragility and the lack of resilience likely to be aggravated by the physical risk (Carreño et al. 2007a). Consequently, the risk index is formulated in Eq. 4 using the flood level (FL) to represent the hazard and the building vulnerability has been multiplied by the social vulnerability, while building vulnerability is expected to aggravate the social vulnerability at the disaster time. Also, the division on the response capacity is used to represent the lack of coping capacity. The index is used to estimate the hourly risk level for each city block, starting from the rainfall start time till the hazard finish time in order to investigate the changing risk level. After that, for each block, the total risk is estimated by summation of the hourly risk records using Eq. 5. Then, the results are used to produce pluvial flood risk map.

$$R_{it} = \frac{FL_{it}.BV_i.SV_i}{RC_i}, \tag{4}$$

where R = risk level, i is the block number, t is the number of hours from rainfall start, FL is the flood level, BV is the building vulnerability, PV is the People vulnerability, and RC is the response capacity.

$$R_i = \sum_{t=0}^{t=t_{\text{end}}} R_{it}, \tag{5}$$

where R = risk, i is the block number, t is the number of hours from rainfall start, t_{end} = the number of hours until the hazard is ended in the urban area. After that, the result of the risk index is rescaled to a percentage ratio by dividing the result by the maximum record and multiplying by 100.

Also, the summation of the hourly risk for all blocks estimated at each hour as shown in Eq. 6. These records represent the hourly risk level for the urban area during the disaster time which can be used to estimate the risk probabilities for different scenarios and compare them to test the scenarios effectiveness and efficiency. The risk probability is calculated by dividing the hourly risk level by the maximum-recorded risk in the most aggressive scenario.

$$R_t = \sum_{i=1}^{i=N} R_{it}, \tag{6}$$

where R_t = risk level for the urban area in a specific time during the disaster, i is the building block number, N = the total number of building blocks in the urban area, and R_{it} is the risk for block i at time t during the disaster.

3 Case study, Alexandria, Egypt

Alexandria is the second largest city and contains Egypt's major port. Also, it is an important tourist area. It is a metropolitan city with an area up to 2210 km^2, and a population approaching 4.8 million (Pagnoni et al. 2015). Egypt as a developing country has a critical economic and social situation where the economic growth is insufficient compared to the rapid growth of population causing lack of resources in various fields, such as the urban development and disaster risk management (World Bank 2015). Since Alexandria is prone to various climate-associated hazards, disaster management has become a pressing issue in the city. The literature reveals that a large number of researches discussed the sea level rise hazard in Alexandria (Eckert et al. 2012; Kaloop et al. 2016; Kloos and Baumert 2015). Also, Eckert et al. (2012) and Pagnoni et al. (2015) have tackled the city's vulnerability to a tsunami. Despite the repeated pluvial floods and the highly related lives and economic losses, there seems to be a rarity in the number of researches that have discussed this problem. Zevenbergen et al. (2017) pinpointed the role of rainfall forecasting to mitigate the storm hazard in addition to present a number of recommendation measures. Obviously, the high variability and uncertainty of rainfall in Alexandria call for a robust and flexible strategy which considers a portfolio of measures able to absorb the negative consequences of extreme events (Zevenbergen et al. 2017). Hence, this paper introduces the first contribution to evaluate the pluvial flood risk in Alexandria and presents a helping method to improve the DRM in the city.

3.1 Pluvial flood hazard in Alexandria

World Bank (2011) investigated the daily rainfall in Alexandria from the year 1940 to the year 2000 and conducted a statistical analysis that introduces the expected rainfall for the different return periods as shown in Table 4. This reveals that the maximum record was 125 mm for 100 years return period (World Bank 2011). However, Alexandria is highly vulnerable to pluvial floods due to frequent storms and around 410 mm of annual rainfall from October to March (Ali 2015). Furthermore, climate change is supposed to result in more extreme rainfall events in Alexandria and increase pluvial flood risks (Zevenbergen et al. 2016).

However, on November 4, 2015, Alexandria and some other neighboring coastal cities experienced an unexpected severe rainfall event up to 227 mm felt in 12 h, which is more aggressive than the 100-year return period record, which caused severe flooding (see Fig. 5). The event has been described as the worst flooding in the city over the past few decades regarding the number of affected population and the economic losses (Zevenbergen et al. 2016). Furthermore, Table 5 illustrates the historical record of storm events in Alexandria and their effects.

3.2 Alexandria vulnerability to pluvial floods

Alexandria is suffering from various urban problems, which increase the vulnerability to the expected hazards. The drainage systems deterioration and its low capacity are the main problems (African Development Bank 2015). The capacity of the city drainage system is about 1.6 million m^3/day (Zevenbergen et al. 2017) which is sufficient to drain a rainfall rate of 26 mm/day (World Bank 2011). Furthermore, the lack of proper maintenance to clean the accumulated solid waste causes a partial loss of the network capacity (Ali 2015). Accordingly, in the greater event, the network would be insufficient to drain the water, which leads to overflows and flooding in the streets (World Bank 2011). Other factors also amplify flood severity in Alexandria such as its high population density (1600/km^2), expansion of urban areas, and lack of vegetation areas which increase water accumulation (Ali 2015) and the inequity of services distribution. Furthermore,

Table 4 Expected rainfall rate regarding the different return periods in Alexandria (World Bank 2011)

Return period	2 years	5 years	10 years	20 years	50 years	100 years
Daily rainfall(mm)	24	41	58	76	102	125


(a) (b) (c)

Fig. 5 Alexandria pluvial floods in 2015. **a** Source: http://gate.ahram.org.eg. **b** Source: https://egyptianstreets.com. **c** Source: https://egyptianstreets.com

Table 5 Previous extreme rainfall events in Alexandria

Date	Rainfall height	Rainfall duration	Economic loss	Human loss	Ref.
Dec 31, 1991	74 mm	N/A	N/A	80 died	Reliefweb (1996)
January 26, 2004	N/A	N/A	N/A	N/A	CRED (2009)
November 30, 2010	180 mm	12 h	N/A	2500 family affected	World Bank (2011)
December 12, 2010	15 mm	9 h	28 building collapse	18 died 11 injured	World Bank (2011), CRED (2009), The Weather Company (2017), Crisis and disasters management in Alexandria
November 14, 2011	12 mm	9 h	N/A	N/A	The Weather Company (2017)
September 29, 2015	5 mm	2 h	N/A	N/A	Williams and Ismail (2015)
October 25, 2015	53 mm	18 h	9.7 million dollars	13 died 16 injured	CRED (2009), Zevenbergen et al. (2016), Xinhua (2015), Flood List (2015)
November 4, 2015	227 mm	12 h	N/A	N/A	Zevenbergen et al. (2016)

the expansion of informal areas reached 50 areas different in size with massive population density (Soliman 2007). The buildings in these areas generally suffer from poor structure, without taking safety factors into account, and the materials used for construction are particularly vulnerable to water infiltration and seepage during extreme rainfall and flooding (De Risi et al. 2013). Figure 6 shows the location of informal areas in the city. In this research, Almontaza district was selected as a study area, it is located in the northeast part of the city (See Fig. 6). Although Almontaza district area represents around 15% of the city area and it contains approximately 25% of its population, it is considered to be the most vulnerable district in the city. It contains nine informal areas, which represent 35% of the total informal areas of the city, with population up to 700000 persons (MHUUC 2015).

In order to estimate the vulnerability of buildings, surveyed data carried out by the General Organization for Physical Planning (GOPP) in 2010 were used. These data provide the buildings condition map classified into three categories; a good condition, which refers to the good structure and mostly new buildings, a medium condition, which refers to buildings that have minor cracks, needs painting and balcony maintenance, and bad condition, which refers to dangerous status with major cracks and very old buildings. Also, building material divided it into three categories; reinforced concrete which refers to the building consists of a concrete structural system and brick walls, masonry which refers to the bearing walls buildings, and others which refer to the fragile building material such as wood(World Bank 2011). Similarly, in order to estimate the social vulnerability, the data used were collected from the Central Agency for Public Mobilization and Statistics (CAMPUS). Then, according to the proposed building vulnerability and social vulnerability indices, the building and social vulnerabilities maps for Almontaza district were produced as shown in Figs. 7 and 8.

3.3 The response capacity in Alexandria

As mentioned earlier, the most significant institutional actions in the pluvial flood situation are the pumping out of the water and the readiness of the emergency teams including ambulance and rescue. Accordingly, in the November 2015 event, about 84 dewatering pump trucks were provided by the municipalities of Alexandria, Cairo, and Giza, as well as the army, while Alexandria municipality reported that the floods required more than 200 dewatering pump trucks

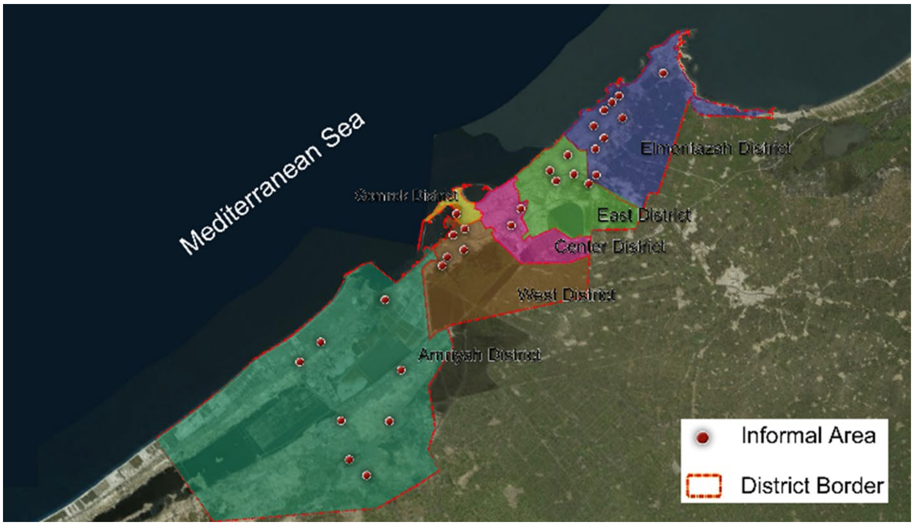

Fig. 6 Informal areas in Alexandria (World Bank 2011)

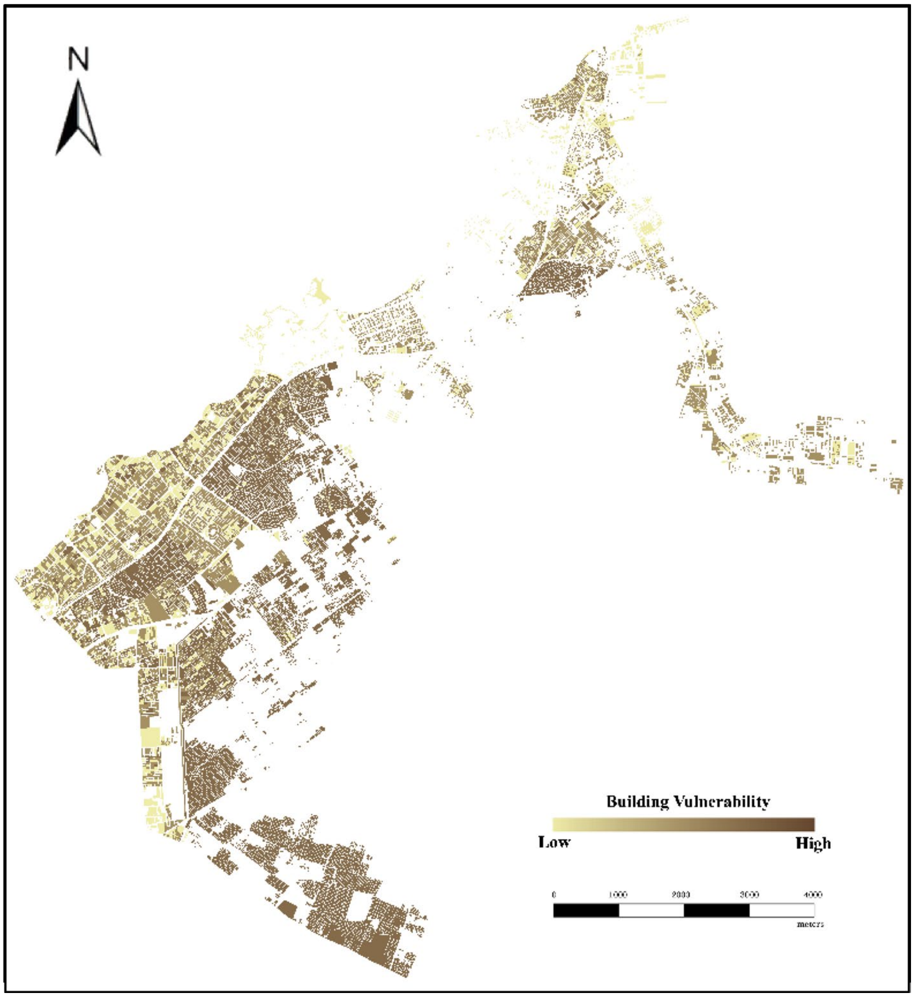

Fig. 7 The building vulnerability map, Almontaza district

(African Development Bank 2015). Also, the investigation and field survey revealed that there are 45 ambulance stations and 35 firefighting and rescue stations in the city. The field interviews with the inhabitants revealed a shortage of the emergency services. The vehicles arriving time mostly delayed by more than 30 min, while these should arrive in

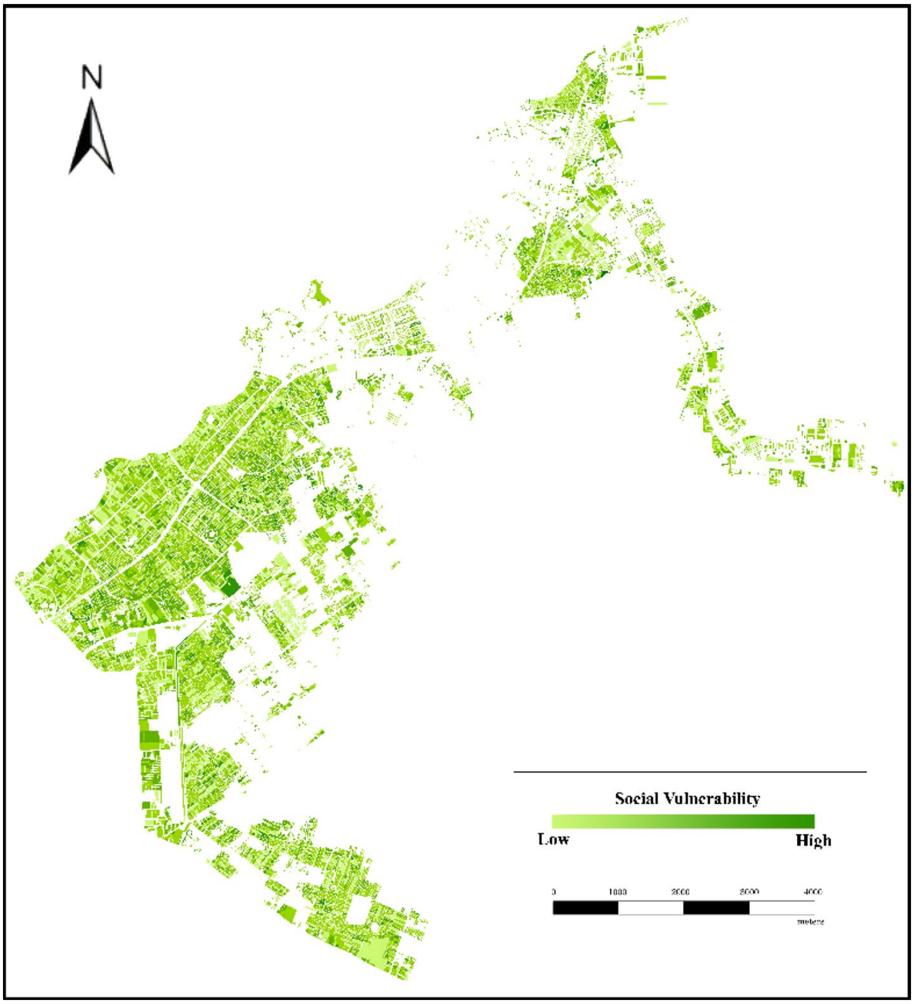

Fig. 8 The social vulnerability map, Almontaza district

10 min as announced by the Ministry of Health. Figures 9 and 10 illustrate the distribution of the ambulance and rescue points in Almontaza district and the excepted arriving time zones. The arriving time zones were generated using GIS network analysis based on the road network data derived from GOPP.

4 Scenarios to test the efficiency of adaptation measures

Three scenarios were adopted in order to investigate and test the efficiency of institutional adaptation measures. These scenarios based on changing three controllable factors in the proposed framework which were selected through semi-structured interviews with experts from Alexandria governorate, the crises and disaster management administration, and a number of householders, furthermore, giving priority to cheap measures in compliance with limited financial resources. Accordingly, the changing factors in this research are (1) improve the drainage network capacity through proper maintenance (by removing the debris) and activating efficient solid waste collecting programs, (2) increase the capacity of pumping out the flood water (by increasing the number of dewatering pump trucks and the early starting time for pumping out the water from the streets), and (3) the capacity of ambulance and rescue teams with proper ratio (by increasing the number of vehicles) and reasonable expected arriving time.

As seen in Table 6, the first scenario tries to simulate the pluvial flood situation in November 2015 with a rainfall rate approximately 200 mm in 12 h, and the drainage network is assumed to work with half its capacity. Also, the pumping out equipment is estimated to be around 20 dewatering pump trucks, and the water suction from the streets starts one day after the rainfall event. Regarding the response capacity, the total announced number of ambulance cars in the city is 80 vehicles. Assuming they were equally distributed, in light of the lack of information, each point contained two cars. Also, the rescue vehicles were assumed to be two vehicles per point. In the second scenario, the changed factors from the first scenario were the drainage network capacity by assuming that it will work with its full capacity and the water pumping out was increased by doubling the number

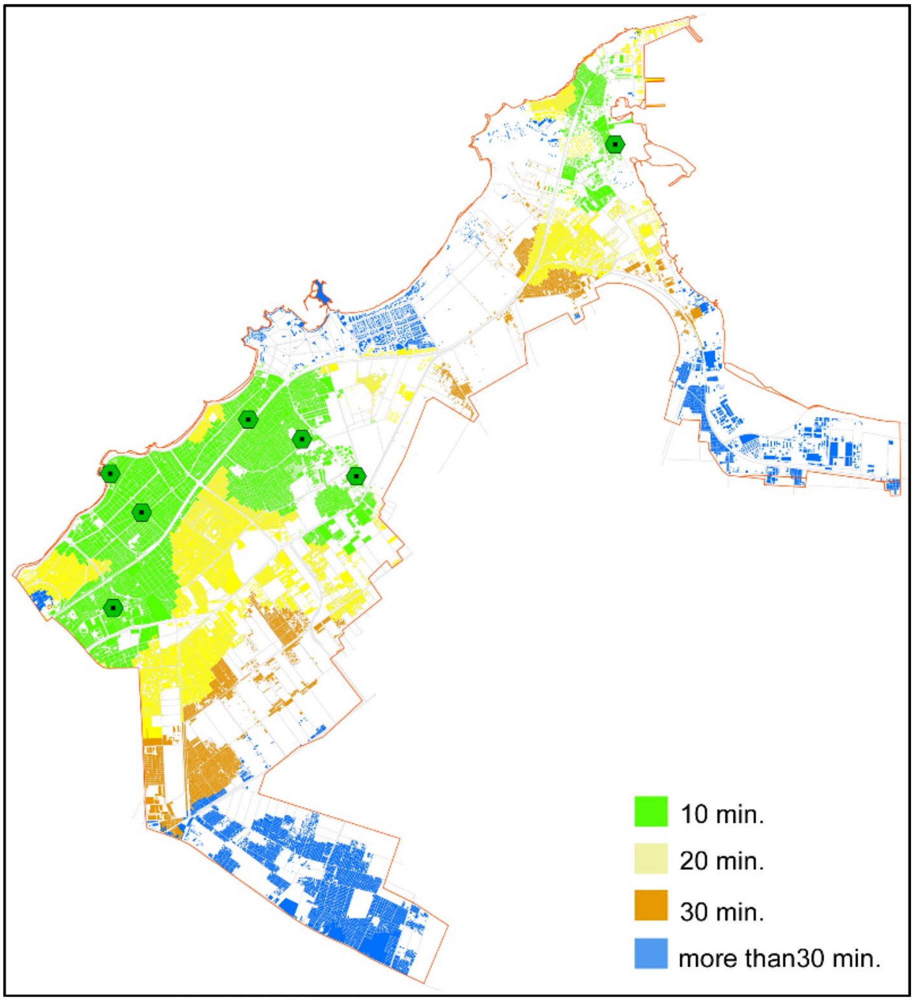

Fig. 9 Ambulance arriving time zones map, Almontaza district

of pumping trucks. Also, the water suction was assumed to start immediately after the rainfall has stopped. For the third scenario, all factors are the same as the second scenario, but the changed factors were the number of ambulances and rescue vehicles, which are assumed to double.

The present scenarios aim to simulate three different levels of coping capacity in the disaster situation. The first scenario tried to simulate the actual situation in November 2015 with the low water drainage capacity and delay response for the water suction equipment. The second one tested the impact of increasing the network drainage capacity by performing the proper maintenance and the immediate response of the water suction equipment. The third one tested the impact of increasing the emergency capacity by increasing the number of its vehicles.

As a first step of the proposed framework, hourly pluvial flood hazard maps were drawn from rainfall start until its end for each scenario depending on the assumed rainfall, water drainage, and pumping out rates. The data used in the DEM were produced through contour map obtained from the General Organization for Physical Planning (GOPP) in Egypt.

5 Results and discussion

Figure 11 gives examples of the pluvial flood exposure map for the first scenario after 12, 80, and 140 h. The presented maps illustrate the water height and identify the hazard level for each building block. After that, the vulnerabilities maps and response capacity measures were combined with the hazard maps to produce the risk map as shown in Fig. 12, which illustrates the total risk in the first scenario for every block (R_i) according to Eq. 5 and divided the risk to five levels as shown in Table 7.

The introduced risk map in Fig. 12 can improve the efficiency of the disaster risk reduction activities through including it in the different disaster risk management phases. For an instant, in the planning and development phase, the risk map reveals that the high-risk areas are concentrated in the informal and slums areas of the district, and that confirms the need to prioritize the development of these areas. In addition, the unequal distribution of ambulance and rescue services affects the risk level in the urban areas. Therefore, the redistribution and the creation of new services

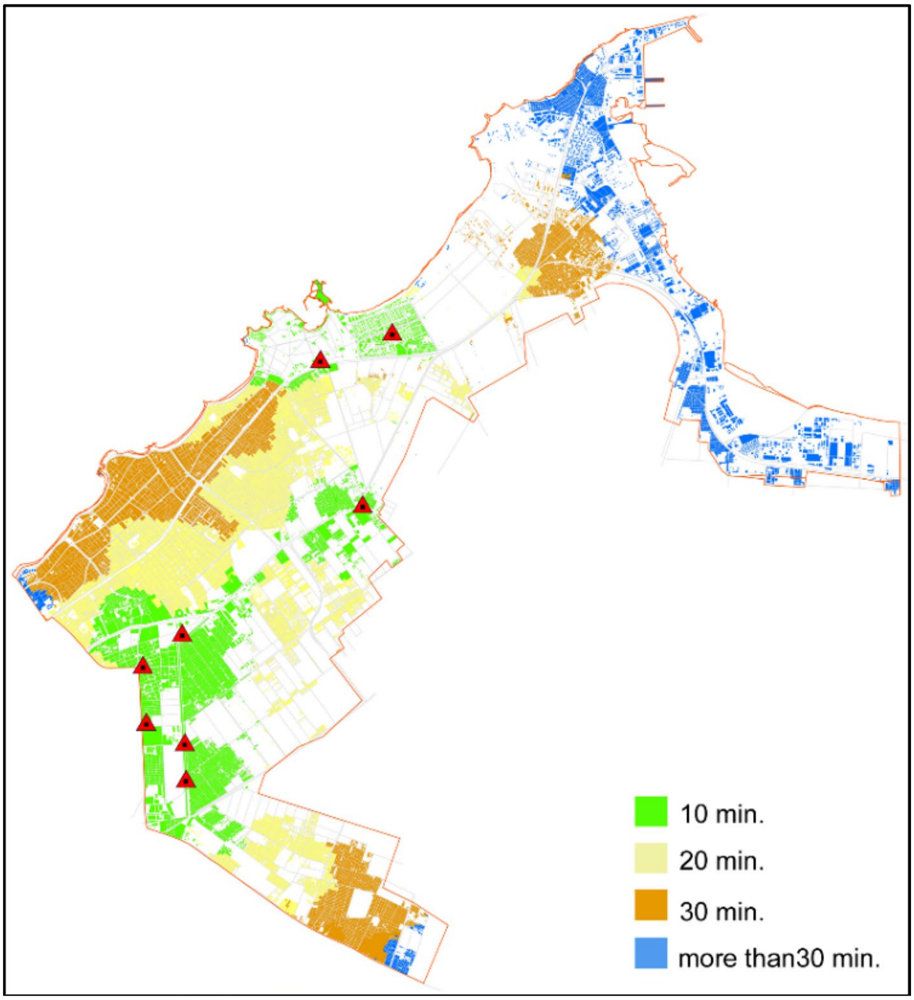

Fig. 10 Rescue arriving time zones map, Almontaza district

Table 6 Different scenarios measures

	First scenario	Second scenario	Third scenario
Rainfall rate and duration	200 mm/12 h		
Drainage network capacity (%)	50%	100%	100%
Pumping out equipment (no. of dewatering pump trucks)	20 dewatering pump trucks	40 dewatering pump trucks	40 dewatering pump trucks
Water suction start time	One day after rainfall stopped	After the rainfall has stopped immediately	After the rainfall has stopped immediately
Number of ambulance cars for each point	Two vehicles	Two vehicles	Four vehicles
Number of the rescue vehicles for each point	Two vehicles	Two vehicles	Four vehicles

points are essential to mitigate the risk levels which can be conducted with the assist of the risk map. Also, in the response and emergency phase, the risk map can help to elaborate the emergency plan by allocating the temporary rescue points and select the priorities of the areas to pump out water while the lack of proper and sufficient dewatering pump trucks.

Furthermore, during the decision-making process, it will be useful to test the efficiency of the different alternative of disaster risk management measures and procedures. For this purpose, the risk probability curve is proposed to compare the change in the expected risk level for different scenarios. The risk probability is calculated by dividing the hourly total risk level for the urban area by the maximum expected level in the most aggressive scenario for each hour during the

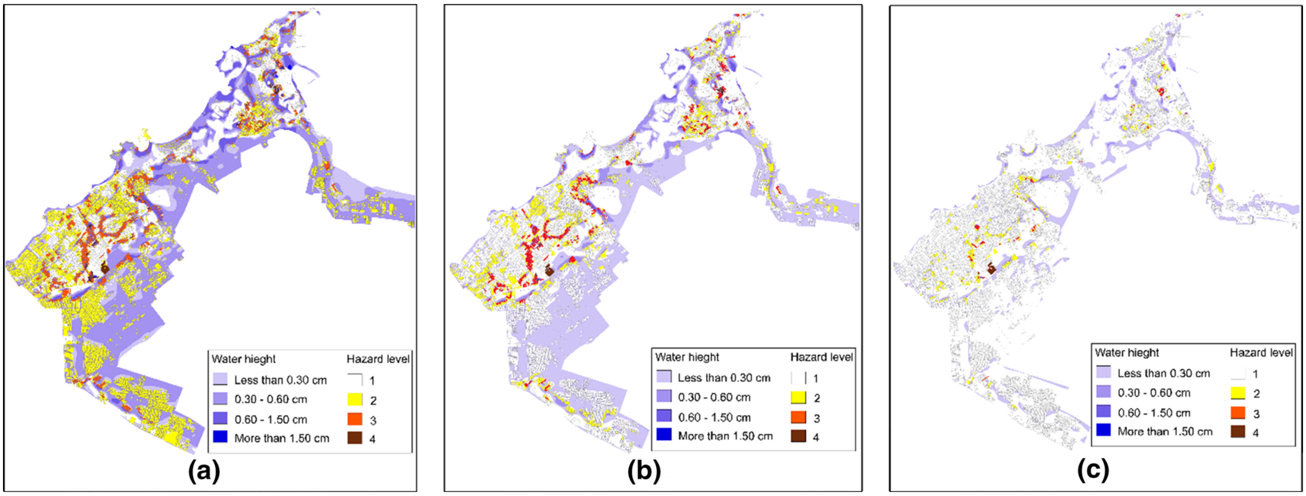

Fig. 11 Examples of pluvial flood exposure maps for Almontaza district. **a** After 12 h from the hazard beginning. **b** After 80 h from the hazard beginning. **c**. After 140 h from the hazard beginning

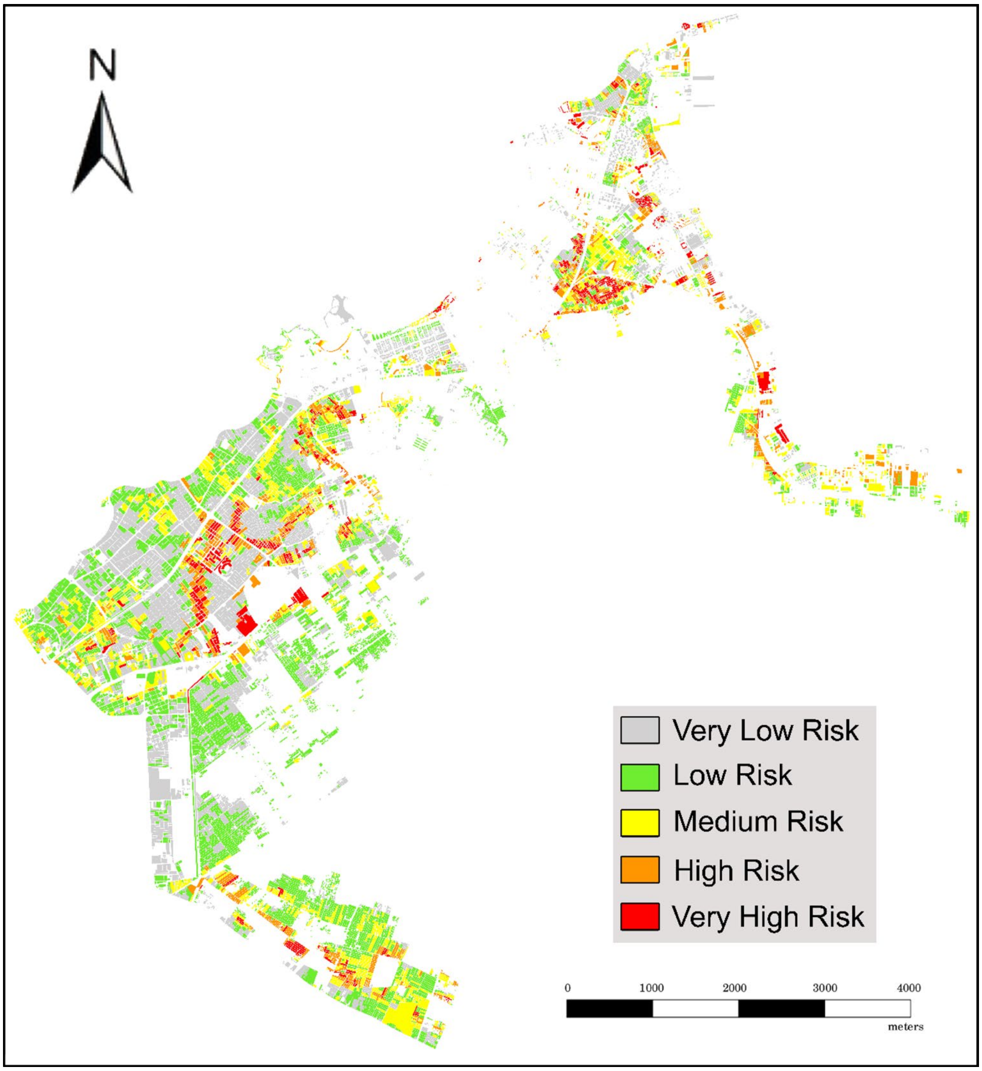

Fig. 12 Pluvial flood risk map, Almontaza district

Table 7 Risk levels' ranges

Risk level	Very low risk	Low risk	Medium risk	High risk	Very high risk
Risk index (%)	0–20	20–40	40–60	60–80	80–100

disaster time. Figure 13 contains the risk probability curves for the three proposed scenarios in this research. The first scenario presents the most aggressive one, and its curve is considered the reference to estimate the risk probability for others scenarios. For the second scenario curve, it reflects the effect of the maintenance of the drainage network and the increase in the water pumping out capacity in reducing risk level. For the third scenario curve, it also reflects the effect of upgrading the response capacity in the risk level by increasing the number of ambulance and rescue vehicles.

However, this study presents a first attempt to assess the pluvial flood vulnerability and risk in Alexandria, where the sea level rise and tsunami risks are investigated in previous researches. This study presents a preliminary framework to assist decision makers in identifying the urban risk levels and determining the most effective measures to reduce the disaster risk impact. In a sense, the introduced framework could help in establishing a proper emergency plan including the allocating of temporary relief and rescue services, planning for the pumping out water process, organizing of evacuation issuing. Also, it could help in establishing the risk awareness programs to decrease the social vulnerability. In addition, it could guide the land use planning and allocate of ambulance and rescue services. This can help to overcome the vulnerability of the urban area within limited resources and available time.

Regarding the research limitation, although a number of data are difficult to obtain, the research attempts to investigate the risk situation through the limited available data to pave the way to such studies in the city, which became urgent in the last period. For example, the inundation maps were conducted based on the average drainage rate, while the detailed data about the sewage network are not available. Also, the used DEM was driven from a counter map, while there is no available high-resolution DEM. In addition to that, there are no data about public risk awareness, which reflects the absence of such programs, therefore the educational level used as an indicator to present the public awareness level. Furthermore, there is a lack of data about the day population density; therefore, the used population density represents the number of households in the residential building. However, the produced risk and vulnerability analysis can be a powerful tool for the decision makers to prepare the emergency plans and the future land use planning to reduce the expected risk from pluvial floods.

6 Conclusion

This research presents an integrated framework to assess the urban pluvial flood risk in a temporal and spatial distribution at the local scale. The proposed risk assessment framework includes pluvial flood hazard modeling, vulnerability assessment indices, and response capacity measures. For the flood modeling, a previous inundation model called (WDPM) was used to generate the exposure maps in the time series of the disaster time depending on the rainfall rate and the water drainage capacity. Also, building and social vulnerabilities maps are introduced based on vulnerabilities indices. The indices factors are weighed with the participation of experts and specialists.

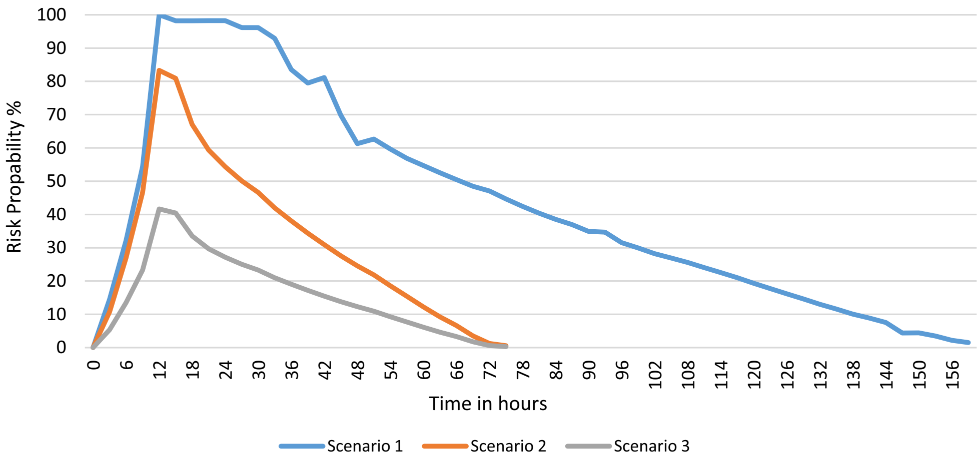

Fig. 13 Risk probability for different scenarios

Furthermore, the response capacity is measured using the field survey data for the ambulance and firefighting locations, and their arriving time zones are generated by GIS software depending on the streets network. The above factors have been compiled to produce the risk assessment in the urban context. The presented risk map can help the decision makers to orientate the development plans for the most vulnerable areas. In addition, it can help to elaborate the risk emergency and preparedness plans. For example, it can help in allocating the emergency services and manage the evacuation process properly and effectively. In order to achieve the desired objectives, the presented framework implies the possibility to compare different coping capacity scenarios in order to improve the efficiency of the DRM.

Application in Alexandria reveals that the high-risk levels are mostly associated with high flood level, long exposure time, lack of enough emergency services, and the existence within the slums or informal areas. The presented risk assessment can improve the DRM in the study area through choosing the proper arrangements in the long and short term. In order to improve the utility of research this research, it is recommended to apply the proposed framework to the rest of the city and use the results to elaborate and implement a comprehensive disaster risk reduction plan to avoid the significant loss in the expected such hazards in the future. Furthermore, the other factors such as public awareness programs and early warning system are recommended to be included in the risk assessment and to be activated in the future plans, while they can reduce the expected risk and improve the DRM. In addition, the vulnerability of the emergency services points and the effect of that on the risk. Another addition, the development and preparedness scenarios can be compared economically to reach the optimum scenario according to limited economic resources. This research provides a significant practical value as it enhances risk knowledge and it can improve the disaster risk management in the developing countries, which are suffering from the lack of proper resources and needed data. The introduced framework can increase the efficiency of the preparedness and emergency plans; it can also help the planners to direct the available development resources to the priority areas.

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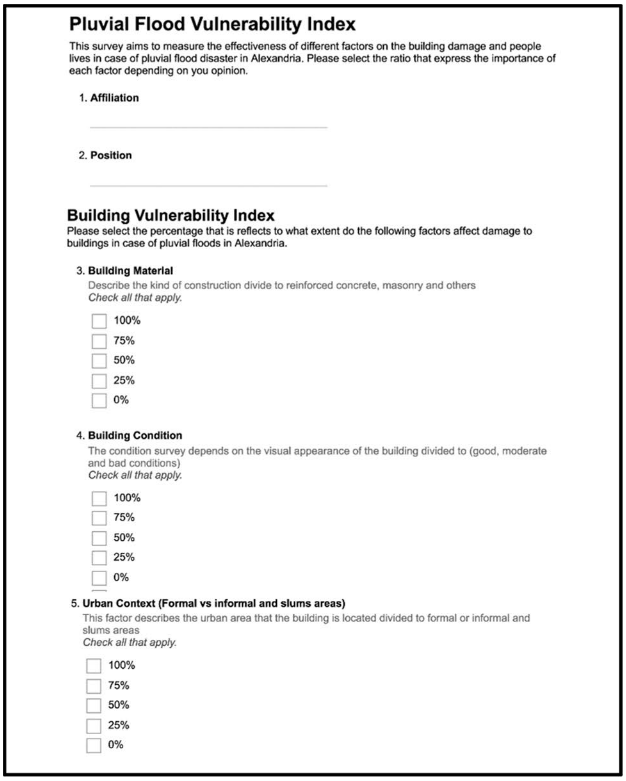
Appendix



Pluvial Flood Vulnerability Index

This survey aims to measure the effectiveness of different factors on the building damage and people lives in case of pluvial flood disaster in Alexandria. Please select the ratio that express the importance of each factor depending on you opinion.

1. **Affiliation**

2. **Position**

Building Vulnerability Index

Please select the percentage that is reflects to what extent do the following factors affect damage to buildings in case of pluvial floods in Alexandria.

3. **Building Material**

Describe the kind of construction divide to reinforced concrete, masonry and others
Check all that apply.

☐ 100%
☐ 75%
☐ 50%
☐ 25%
☐ 0%

4. **Building Condition**

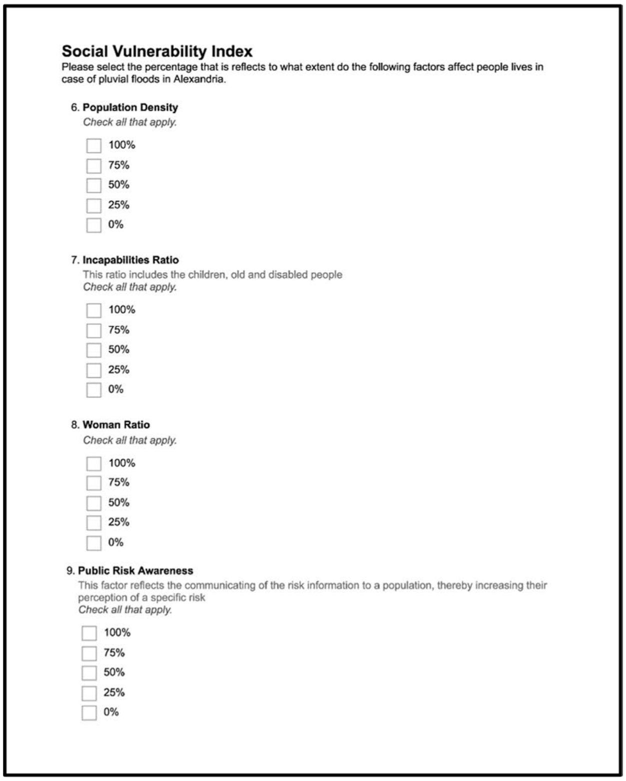
The condition survey depends on the visual appearance of the building divided to (good, moderate and bad conditions)
Check all that apply.

☐ 100%
☐ 75%
☐ 50%
☐ 25%
☐ 0%

5. **Urban Context (Formal vs informal and slums areas)**

This factor describes the urban area that the building is located divided to formal or informal and slums areas
Check all that apply.

☐ 100%
☐ 75%
☐ 50%
☐ 25%
☐ 0%



Social Vulnerability Index

Please select the percentage that is reflects to what extent do the following factors affect people lives in case of pluvial floods in Alexandria.

6. **Population Density**

Check all that apply.

☐ 100%
☐ 75%
☐ 50%
☐ 25%
☐ 0%

7. **Incapabilities Ratio**

This ratio includes the children, old and disabled people
Check all that apply.

☐ 100%
☐ 75%
☐ 50%
☐ 25%
☐ 0%

8. **Woman Ratio**

Check all that apply.

☐ 100%
☐ 75%
☐ 50%
☐ 25%
☐ 0%

9. **Public Risk Awareness**

This factor reflects the communicating of the risk information to a population, thereby increasing their perception of a specific risk
Check all that apply.

☐ 100%
☐ 75%
☐ 50%
☐ 25%
☐ 0%

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