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Open space suitability analysis for emergency shelter after an earthquake

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Abstract

In an emergency situation shelter space is crucial for people affected by natural hazards. Emergency planners in disaster relief and mass care can greatly benefit from a sound methodology that identifies suitable shelter areas and sites where shelter services need to be improved. A methodology to rank suitability of open spaces for contingency planning and placement of shelter in the immediate aftermath of a disaster is introduced. The Open Space Suitability Index (OSSI) uses the combination of two different measures: a qualitative evaluation criterion for the suitability and manageability of open spaces to be used as shelter sites, and a second quantitative criterion using a capacitated accessibility analysis based on network analysis. For the qualitative assessment, implementation issues, environmental considerations, and basic utility supply are the main categories to rank candidate shelter sites. Geographic Information System (GIS) is used to reveal spatial patterns of shelter demand. Advantages and limitations of this method are discussed on the basis of a case study in Kathmandu Metropolitan City (KMC). According to the results, out of 410 open spaces under investigation, 12.2 % have to be considered not suitable (Category D and E) while 10.7 % are Category A and 17.6 % are Category B. Almost two third (59.5 %) are fairly suitable (Category C).

1 Introduction

As the impacts of natural disasters continue to increase around the world, experts agree that post-event response has to become more efficient and draw on science (Balcik et al., 2010; Bharosa et al., 2010; McEntire, 2007; Rawls and Turnquist, 2010). This becomes visible for example through the formulation of the United Nations International Strategy for Disaster Reduction (UN ISDR) in 2000. Pre-disaster planning as well as risk mitigation measures have gained interest both in the scientific as well as the practitioners communities. As the primary international agreement for disaster reduction the Hyogo Framework of Action (HFA) prioritizes “strengthening preparedness for response” as one of its five priorities of action identified for 2005 to 2015 (UN ISDR and UN OCHA, 2008, p. 1).

One important concern of strategies to improve preparedness for response is the identification and provision of suitable areas for emergency shelter before disasters unfold (Chandler, 2007; Chien et al., 2002; Donohou, 2012; Perry and Green, 1982; Perry, 1979; Tai et al., 2010). Especially in urban contexts the availability of such areas is often limited and there is increasing demand for risk-sensitive land use planning which are often lacking (e.g. Global Communities, 2012).

Shelter needs can be divided according to the time elapsed from the onset of the disaster event into emergency shelter, temporary shelter, temporary housing, and permanent housing (Chou et al., 2013; Donohou, 2012; Félix et al., 2013; Johnson, 2007, 2009; Lizarralde et al., 2009; Quarantelli, 1995). The timeline for transitioning from these different phases of shelter needs – for example from emergency shelter to temporary shelter – is often variable, however, the underlying sequential process seldom becomes reality (Johnson, 2007; Ritchie and Tierney, 2011). Earthquakes confront emergency managers with special challenges due to their rapid onset and relatively short duration. Furthermore, as earthquakes are inherently unpredictable, there is usually no lead time for preemptive evacuation, which results in emergency shelter placement becoming mostly a post-event issue (e.g. Wright and Johnson, 2010). Pre-event planning and preparedness for emergency shelter placement is thus critical for ensuring a coordinated response during the complex and changing risk contexts after a large earthquake.

Planning for emergency shelter placement draws on standards, criteria and guidelines developed for emergency managers and humanitarian organizations which has been based mostly on post-disaster assessments (e.g. da Silva, 2007; SPHERE Project, 2011; UN OCHA et al., 2010; UNDRO, 1982). For example, the SPHERE Project provides minimum standards and general guidance for use in any of several response scenarios and includes provisions for strategic planning, settlement planning, covering living space, construction, environmental impact for shelter and settlements (SPHERE Project, 2011). While the minimum standards provide the basis for developing an emergency shelter placement plan, optimal siting and accessibility of shelter sites based on shelter needs from comprehensive risk assessments are also required (Indriasari et al., 2010). There is still a lack of combined approaches to investigate demand for public emergency shelter sites with their suitability and accessibility incorporating capacity constraints of (candidate) shelter sites.

In this paper we propose a methodology that examines the capacity of open spaces to be used as public emergency shelter sites, which takes into account both how well a site meets demand for public shelter as well as the level of accessibility of the site using a deterministic earthquake risk assessment. Alongside the capacity analysis, a set of suitability criteria are proposed for open spaces to be used as temporary shelter sites during an earthquake emergency. The combined Open Space Suitability Index (OSSI) will rank candidate sites according to their accessibility taking into consideration the available capacity and also their suitability for earthquake shelter purposes based on expert knowledge.

We showcase this methodology on officially identified open spaces by the National Society for Earthquake Technology, Nepal (NSET) and the International Organization for Migration (IOM) within Kathmandu Metropolitan City (KMC) using the combination of two different measures: a qualitative evaluation criterion for the suitability and manageability, and a second quantitative criterion using a capacitated accessibility analysis based on both an earthquake risk analysis and a GIS-based network analysis. We thereby assume a “worst case earthquake scenario”, in which shelter placement is exclusively based on open spaces as very few buildings, such as schools and shopping malls, can be considered stable enough to be used for shelter purposes.

The paper is structured as follows: first, the rational of a combined method to investigate capacity-based suitability of shelter sites is given. As such existing methods to calculate displaced and shelter seeking population resulting from earthquakes as the fundamental prerequisite of such a methodology are reviewed. Second, a set of categories to characterize site suitability based on qualitative indicators are proposed. Further a methodology to derive capacitated accessibility using spatial network analysis as a key measure to evaluate further shelter needs in a spatial context is introduced. Third, the combined OSSI is outlined. Fourth, the proposed methodology for open space suitability analysis for emergency shelters is applied to our case study in KMC. The final sections reflect on the results from the case study and discusses the transferability of the method.

2 Shelter suitability

2.1 Shelter need

The initial estimation of the potential number of displaced population after a disaster is a major step in emergency management and a prerequisite to calculate temporary shelter demand. While many casualty estimation methodologies exist in earthquake engineering that provide estimates of both injuries and fatalities by relating the intensity of the earthquake and/or damaged buildings to casualty potential (Coburn and Spence, 2006; FEMA, 1999, 2011; Samardjieva and Badal, 2002) , methods for estimating displaced population and population in need of shelter are far fewer. Examining data from 457 historic earthquakes from 1900–2012 in the CATDAT damaging earthquake database (Daniell et al., 2011; Khazai et al., 2014) show that while a general linear trend on logarithmic scale is observable between damaged buildings after an earthquake and the number of homeless population, for many events there are scalar differences from this trend that not only depend on external factors like building damage, loss of utilities, and weather conditions but also on internal socioeconomic and individual factors such as safety concerns or fear of aftershocks (Khazai et al., 2014).

Most Earthquake Loss Estimation (ELE) software for calculating shelter needs is based on the HAZUS methodology (ABAG, 1996; Harrald and al Hajj, 1992) and accounts for several variables on the census track level influencing the tendency to seek short-term shelter including income, ethnicity, age, and ownership (FEMA, 2011). Chou (2013) proposes to use three variables determining higher tendency to seek shelter out of all displaced people affected by an earthquake, namely low household income, rented housing tenure, and belonging to either the youngest (< 16 years) or the oldest (> 65 years) age group. Chien et al. (2002) use contextualized weights explored in a shelter survey after the Chi-Chi Earthquake in Taiwan to revise the HAZUS default values.

Shelter needs are mostly calculated directly as a function of structural damage to buildings not taking into account household decision making as well as social and demographic factors, which is considered a deficit by some authors (Khazai et al., 2011b, 2014; Tierney et al., 2001). Besides building damage, social factors have emerged as crucial in forming the decision to seek shelter or not on a household and individual level (Chang et al., 2009; Chou et al., 2013; Khazai et al., 2014). Riad et al. (1999) state that besides risk characteristics, territorial tendencies (house ownership) and personal characteristics – like social support, education, financial wellbeing – are influencing peoples' decision to seek shelter. Additionally they state, that "social influences on evacuation behavior may vary according to the resident's network size and ethnicity" (Riad et al., 1999, p. 921). Another important determinant to the number of population seeking shelter was found inter alia by Wright & Johnston (2010) and Chang & Chamberlin (2003) to be the loss of lifelines. Interactions between the physical damage state of buildings and the combined residual service level in the utility networks have been considered in a system approach to assess the habitability of buildings from which the number of displaced persons can be computed (Cavalieri et al., 2012; Khazai et al., 2013). The rationale for this is, that people are likely to seek refuge in a public shelter if they are cut off from basic necessities such as water supply or electricity, even if buildings are otherwise intact. For example during the L'Aquila earthquake of 2009, shelter seekers originated not only from non-usable (collapsed or cut off from lifelines) buildings. Up to 54 % of people living in partly damaged and non-damaged buildings were found to seek public shelter as well (Khazai et al., 2012). Furthermore risk perception and access to resources are identified as influential factors by Chang et al. (2009) and Chakraborty (2005). Upreti (2009) shows that 87 % of Kathmandu's citizens do not believe an earthquake is going to happen during their lifetime even though they are aware of the possibility. This shows that most people will be hit unprepared, should a major disaster occur in the near future.

2.2 Suitability

The SPHERE shelter and settlement standard for covered living space provides a guideline for emergency managers to evaluate or plan for immediate, short- and long-term shelter (SPHERE Project, 2011). It recommends an area in excess of 3.5 m^2 per person to meet requirements of typical household activities. The overall surface area per person including communal space for cooking, roads and footpaths, educational facilities, administration etc. within temporary communal settlements should be 45 m^2. Besides surface area, special consideration is given to water, sanitation and health (WASH), community infrastructure, security, and secondary risks. (SPHERE Project, 2011, p. 247 f.). All in all, the standards aim to use strategic settlement planning to enable "safe and secure use of accommodation and essential services by the affected population" (SPHERE Project, 2011, p. 254). Especially in densely populated urban areas, the shelter demand can exceed the supply in close vicinity of the affected population if these standards are enforced rigorously. Limited available space may urge adjustments on the applied average shelter space per person.

Suitability of open spaces for shelter purposes depends on the perspective from which it is evaluated. da Silva stresses the need to consider the "shelter occupant's perspective" (da Silva, 2007, p. 25) if shelter site quality is evaluated. Emergency planners and affected population may have a differing perception of relevant considerations in the immediate aftermath of an earthquake. For example, emergency planners evaluate shelter sites with respect to a longer time frame. Limitations for implementation, existing secondary hazards as well as future construction plans play a predominant role. A shelter-seeking person on the other hand focuses on accessibility and space

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availability when looking for an immediate emergency shelter site. Hence sheltering in the close vicinity of the own plot or house may be of greater importance than mid-term perspectives.

The indicators used for the OSSI are described in the following section and are mostly inferred from the SPHERE standards. As a matter of course other relevant indicators should be added if applicable. The selection and weighting of indicators remains the greatest difficulty and needs to incorporate expert judgment. The weighting of categories and indicators was done in a participatory way in four consecutive expert group discussions involving emergency management researchers from NSET and from the Center for Disaster Management and Risk Reduction Technology (CEDIM) in Karlsruhe, Germany. The rationale behind the choice of individual factors often lies in the stakeholders or experts experience and available data. Consequently, it is important to concisely state the scope and objectives of such an index. The methodology we propose focuses on suitability for immediate emergency shelter, with weighting of indicators and categories applicable to this context. The following three core categories have therefore been identified to explore suitability of open spaces in an urban context for immediate shelter after an earthquake: implementation issues, environmental considerations, and basic utilities supply (Table 1).

The category *implementation issues* consists of ownership, existing use and future plan. Generally, public (governmental) owned spaces should be preferred, as these can be managed easier than privately owned open spaces (cf. FEMA, 2007). Another indicator is the current type of use. A playground or a park for example is best suited for shelter, since their existing type of use does not hamper camp erection. If the space has an institutional or educational function it should not be prioritized for immediate shelter in order not to delay the resumption of daily activities and not to endanger people due to potentially unstable building conditions (c.f. SPHERE Project, 2011). A last indication regarding usage complications is given by the future planning indicator. Some sites have existing long- or even short term plans in place, are already under partial or complete construction and should thus not be preferred. During the site visits, some of the places turned out to be currently used as dumping sites and such areas were considered as the least suitable ones. The rationale behind this category indicates possible restrictions in access or continuing use.

As *environmental considerations* we comprise pollution and secondary hazard criteria. Air, water or waste pollution needs to be taken into account. Only shelter sites with clean air supply (i.e. not in areas with high air pollution discharge due to debris or road traffic) and cleared grounds (i.e. no dumping areas) should be chosen as shelter sites. Possible shelter sites should not include areas which are prone to other hazards (floods, landslides etc.). Additionally, secondary hazards like potential fire eruption from nearby hazardous materials (e.g. gas and petrol sellers) need to be taken into account and avoided by the choice for a suitable shelter area (FEMA, 2007; Tai et al., 2010).

Access to *basic utilities supply* systems and critical infrastructure such as hospitals need be considered as part of site suitability. Sufficient and continuous supply with basic utilities such as water and electricity are crucial immediately after a disastrous event (Chang et al., 2009; Chu and Su, 2011; Daley et al., 2001; FEMA, 2011). The proximity to medical services has also found wide acceptance as an important factor (FEMA, 2007; SPHERE Project, 2011). Hospitals are particularly important due to high numbers of injuries incurring during an earthquake and to prevent high numbers of post-event “fade-away” people (Coburn et al., 1992).

2.3 Accessibility

People seeking shelter rely on some sort of existing and suitable network (roads) to access available shelter areas within a certain time (Tai et al., 2010). Kongsomsaksakul et al. (2005) use a two level mathematical representation to show authorities’ selection of best-suited evacuation sites on the one hand and evacuees’ decision on the escape route to that determined site on the other hand. The number of people seeking shelter and the decision to access a particular shelter site relies on several factors, ranging from socio-cultural and economic factors, to physical constraints like road network accessibility after the event and availability of motorized or un-motorized vehicles.

Many studies focus on transportation issues in terms of time constraints to reach evacuation sites in time during preemptive evacuations (Cova and Church, 1997; Cova and Johnson, 2002; Kar and Hodgson, 2008). Others focus on different variables determining the "evacuation assistance needs" (Chakraborty et al., 2005, p. 23) based on social vulnerability and earthquake risk patterns.

Kar and Hodgson (2008) use a GIS-based suitability model to investigate the number and location of predefined shelter areas for preemptive hurricane evacuation. They identify a set of factors from official and non-official guidelines and determine the suitability of shelter sites using weighted linear combination and a pass/fail screening on raster basis. The shelter sites used in their study are mostly public multi-purpose assembly facilities like cultural or civic centers, and healthcare facilities. Factors included are proximity measures and vulnerability profiles of the population (percentage of children, elders, minorities, and low-income households). Gall (2004) highlights the importance of shelter sites for humanitarian assistance in terms of relief good distribution. The model follows some basic assumptions which are only applicable in rural areas where transportation friction can be modeled as a result of landcover and distance only.

Indriasari et al. (2010) have used a similar approach to identify the optimal siting of emergency facilities like fire brigades or hospitals. They argue that maximum coverage is more applicable for identifying suitable emergency facilities among a larger set of candidate sites than methods minimizing the distance between demand and supply. In general the main difference between the approaches is the spatial domain: Gall (2004) uses a raster based model with continuous friction data, while Indriasari et al. (2010) apply the facility location problem on a street network "taking into account the road access, barriers and road network attributes". All these methods focus on emergency facility location problems for preemptive evacuation which differ from the challenges shelter seeking population faces in the aftermath of an earthquake.

Network analysis has been proven to be a valuable tool for analyzing the strengths and weaknesses of manifold types of spatial and non-spatial networks (cf. Crucitti et al., 2006). With its theoretical foundation in graph theory, road networks are defined as elements of nodes and edges. Either using street segments as edges (primal representation) or as nodes (dual representation) (Porta et al., 2006a, b). The most important feature and analytic strength of network analysis is the inherent importance of relational topological information. Results often comprise of the summed costs (e.g. time, length) or turns of nodes between predefined sets of origins (demand) and destinations (supply). Network analysis for example allows calculating least-cost distances in terms of travel-time or distance using impedance values for different node types from/to destinations. Other measures are service areas to determine the extent of business relations or run calculations for logistic fleet management or manifold facility location problems (e.g. Toregas et al., 1971). The usability of network analysis in the emergency context has been shown on different examples, like optimal siting of emergency facilities (Indriasari et al., 2010), and emergency routing services on near-real-time basis (Neis et al., 2010; Weiser and Zipf, 2007). Differences in accessibility constraints during or after extreme events affecting road networks can be investigated using for example volunteered geographic information (VGI).

With their Urban Network Analysis toolbox (UNA), Sevtsuk and Mekonnen (2012) introduce an additional level of analysis to the traditional calculation of network centrality: the building level. Previous studies focused solely on the capabilities and centrality measures of the network itself (nodes and edges), ignoring individual elements along the edges. They promote adding buildings as supplementary nodes and establish links between single buildings and the adjacent (closest) road network.

We use the Maximize Capacitated Coverage analysis (implemented in ESRIs ArcGIS™ 10.1 Network Analyst) to determine the maximum coverage of selected sites taking into consideration network impedance, building weight and their shelter capacity. The method uses the Dijkstra's algorithm for finding the shortest paths and solves the location-allocation problem by choosing a subset of facilities (candidate shelter sites) such that the sum of the weighted distances from each demand point (with a certain weight) to the closest shelter site is minimized (ESRI, 2013). Thus it assigns each demand point (building) to the closest candidate shelter facility (supply) according to the number of people seeking shelter (weight), taking into consideration the overall capacity and the total length network distance of all buildings. Capacity of candidate shelter sites is deducted using existing standards for covered living space as described earlier. The number of people seeking shelter is used as the weighting factor for each building.

3 Open Space Suitability Index (OSSI)

The objective of this study is to model shelter site suitability considering road network accessibility, capacity and suitability of shelter. We focus on immediate shelter placement with a time frame up to several days following an earthquake. The final suitability index OSSI consists of two factors: first an expert based weighting procedure of suitability criteria and second a GIS-based accessibility and capacity measure ($\mathrm{CAM}_{\mathrm{OS}}$). Figure 1 shows the evaluation scheme applied. It is calculated using the following equations:

$$\mathrm{OSSI}_{\mathrm{os}} = \sum\nolimits_{i=1}^{n} (W_i \times I_i + W_{i+1} \times I_{i+1} + \ldots + W_n \times I_n) \times \mathrm{CAM}_{\mathrm{OS}} \quad (1)$$

$$\mathrm{CAM}_{\mathrm{OS}} = \frac{\mathrm{POPserved}_{\mathrm{OS}}}{\mathrm{POP}_{\mathrm{OS}}} \quad (2)$$

With I_i being the suitability indicator scores, and W_i the respective weight for each indicator. The Capacitated Accessibility Measure ($\mathrm{CAM}_{\mathrm{OS}}$) is calculated as the ratio between the total shelter seeking population within the one kilometer service area of each candidate shelter site ($\mathrm{POP}_{\mathrm{OS}}$) derived from an earthquake risk assessment and the people accommodated within the same spatial unit according to the Maximize Capacitated Coverage analysis result ($\mathrm{POPserved}_{\mathrm{OS}}$). The $\mathrm{CAM}_{\mathrm{OS}}$ determines the “pressure” on each candidate site to be overcrowded due to the surrounding undersupply. It shows a spatial representations of shelter demanding population that can be served with appropriate shelter space. The one kilometer cutoff value is used as a standardization factor and determined by the overall size of the used network. It helps to identify hot spots of un-served populated areas within the urban environment. Therefore the optimal facility location problem is modified to address existing suitability constraints and limited capacity of shelter areas.

4 Case study Kathmandu Metropolitan City

The territory of Nepal spans about one third of the length of the Himalayan arc leading to a long history of devastating earthquakes in Nepal. Over the last century, the Himalayan arc has experienced four earthquakes with magnitude around 8.5 in 1897, 1905, 1934 and 1950. As one of the most devastating earthquakes in the recent past, the 1934 Bihar earthquake of magnitude M_{w} 8.3 caused the collapse of 20 % of all buildings in the Kathmandu Valley; another 40 % were severely damaged (EMI, 2010; JICA and MoHA, 2002). Today, the total population in the Kathmandu Valley is eightfold what it was in 1934; its density has quadrupled. Expansion took place without political supervision, despite various efforts to enforce spatial planning (Gutschow and Kreutzmann, 2012; Thapa and Murayama, 2009; Thapa et al., 2008). As the political and cultural capital of Nepal, Kathmandu Metropolitan City (KMC) within the Kathmandu Valley is particularly at risk. With its fertile land the valley has attracted many people living off farming (Gutschow and Kreutzmann, 2012). However, with rapid growth of urban centers, much of the open land has vanished in favor of built-up living space in the recent decades (Haack and Rafter, 2006). Today with an average annual growth rate of 4.59 % between 2000 and 2005 Kathmandu is one of the fastest growing city in the world facing high earthquake risk (UN DESA, 2012). Owing to this unimpeded urban growth an earthquake of similar magnitude as the Bihar earthquake would result in significantly higher losses in form of casualties and physical destruction (Dixit et al., 2000; Guragain et al., 2008). Experts estimate that at least one million homeless people in need of immediate assistance can be expected. In addition it is highly probable that all routes into and out of the Kathmandu Valley will be blocked for weeks, if not months (NRRC, 2013). Assuming this holds true, all emergency services need to be supplied from within the valley – without external help.

The above mentioned two-fold suitability analysis of open space shelter sites is implemented in a case study for the KMC. The open spaces used (Fig. 2) in the analysis are based on 887 open spaces identified by NSET as potential sites for emergency purposes out of which 410 are located within KMC (NSET, 2010, 2012). In the assessment most publicly owned cleared areas and smaller open spaces or courtyards were included. The qualitative suitability information was obtained using structured data entry forms. Additionally, the International Organization for Migration (IOM) and the Ministry of Home Affairs (MoHA) jointly identified 83 open spaces for medium term post disaster needs including larger facilities for camp establishing (IOM and GoN, 2012). In their assessment, only publicly owned sites and areas controlled by commercial entities with which the Government could enter a formal contingency agreement were considered. The qualitative data available from both datasets were combined and converted using the weighting scheme formulated in four consecutive expert round table discussions (Table 1). They form the basis for the qualitative part of the OSSI. The available area of 2285 km^2 supplies a maximum of 253 859 persons as shelter applying a standard of 9 m^2 per person.

The Japan International Cooperation Agency (JICA) "Study on Earthquake Disaster Mitigation for Kathmandu Valley, Nepal (SEDM)" have been used do deduct building damages for a potential earthquake scenario (JICA and MoHA, 2002). Out of the different earthquake scenarios for Kathmandu Valley as well as for Kathmandu City, the worst-case scenario earthquake, has been identified as the Mid-Nepal Earthquake with M_w 8.0 (JICA and MoHA, 2002). The SEDM building damage estimates were carried out in 2000–2002 and reflected the population in 2001, and inferred the building stock from 1998. The first step in computing shelter demand for KMC was to update the 2001 population with the latest population data of 2011 census. Due to the lack of detailed recent building data including building types, the population ratio (r) serves as scaling factor to estimate building numbers for 2011 using the ward building inventory of 1998 according to Eq. (3):

$$r = \frac{\mathrm{Pop}_i^{2011}}{\mathrm{Pop}_i^{1998}} \sim \frac{\mathrm{NB}^{2001}}{\mathrm{NB}^{1991}} \qquad (3)$$

This simplification can be made since a comparison of the 1991 Housing Survey and the 2001 National Census revealed that the ratio building stock to population has not changed significantly, and population growth between 2001 and 2011 was similar to the previous decade (CBS, 1995, 2002, 2012; NSET, 2012).

The needs for public emergency shelter were computed based on a modified HAZUS methodology in a two-step approach. First the number of displaced persons in each ward from the scenario earthquake are computed by assuming all occupants of heavily damaged buildings will be displaced. Additionally, even for building damages that may be moderate, some buildings may not be habitable, as lifeline breaks (e.g. water and electricity utilities) for an extended time often leads to people seeking shelter outside of their otherwise usable homes (e.g. Khazai et al., 2013). As of today, many people especially in the core area of KMC rely on water tankers servicing the area once a week or less (UN-HABITAT, 2008). A high proportion of displaced persons can be assumed from partially damaged buildings since it is expected that secondary damages to water pipelines will affect 80 % of water users (JICA and MoHA, 2002; cf. NRRC, 2013). Finally, partially damaged buildings of low strength masonry buildings made of fired bricks in mud mortar are treated as a special category. Even where partially damaged buildings of this type could provide some shelter, past earthquake events show that aftershocks threaten to collapse these types of buildings and most survivors remain outside (Khazai and Hausler, 2005). Thus, the total number of displaced persons in 2011 (DP^{2011}) in KMC is given by the sum of displaced persons in each Ward i minus the casualties (C) in Ward i as given by Eq. (4):

$$\mathrm{DP}^{2011} = r \times \left(\sum\nolimits_i \mathrm{HD\_All}_i^{1998} + 0.9 \sum\nolimits_i \mathrm{PD\_BM}_i^{1998} + 0.8 \sum\nolimits_i \mathrm{PD\_nonBM}_i^{1998} - \sum\nolimits_i C_i^{1998} \right) \qquad (4)$$

According to Eq. (4), 100 % of people from highly damaged buildings of all types (HD_All), 90 % of people from partially damaged brick in mud mortar buildings (PD_BM) and 80 % of people from partially damaged buildings of all other types (PD_nonBM) will be displaced. While some displaced people will seek to use public shelter, experience in Nepal has shown that a fraction of the population will access other forms of shelter such as staying with friends and family or migrate to their original cities and villages. Likewise, a portion of the population will use their property or nearby areas as makeshift shelter sites (NSET, 2012). In a 2012 study on shelter response strategies by NSET it was determined that approximately 5 % of the population will take shelter with their families and friends; approximately 5 % will take shelter in damaged houses or self-managed temporary shelters nearby original houses and approximately 2 % will migrate to outside cities and villages (NSET, 2012). Two factors of residential urban fabric and migration to rural areas are thus considered here in determining a ward level distribution of populations seeking shelter in planned, public emergency shelter sites from the computed displaced population. First the shelter seeking population is obtained by reducing the total displaced population by 2 %, 10 % or 15 % depending on the corresponding levels of residential urban fabric (Table 2). The assumption is that in sparsely built urban areas where there is more outdoor space, a greater portion of the displaced population (up to 15 %) is likely to take up shelter on their own property or nearby areas rather than seeking shelter in the designated emergency shelter sites. In more dense urban areas, however, there is little or no space for self-managed shelter, thus only 2 % of the displaced population may seek temporary shelter on non-designated open spaces. Next, the displaced population seeking shelter is further reduced by the internal migration rate from each ward based on the 2001 population census (Subedi, 2010). Here the assumption used was that 5 % of the internal migrants in each ward will migrate to outside cities and villages instead of seeking public shelter.

The total displaced population within KMC is thus estimated as 406 500 while the total shelter demand sums up to 342 300 persons. Especially the core wards with their weak building structure and very high population densities are expected to have large numbers of casualties and a very high shelter demand.

The spatial representation used to calculate the $\mathrm{CAM}_{\mathrm{OS}}$ consists of building blocks and roads. A detailed road network provided by the Kathmandu Valley Development Authority (KVDA) was utilized. It consists of 1250 kilometers roads, classified into nine different types. The established topologic network has 27 724 nodes and 67 118 edges. Additionally 72 783 building footprints based on a Quickbird® satellite imagery from 2006 were included as demand points for all network-based measures. Within the core area, many buildings are not directly connected to the nearest road segment, but through a sequential arrangement of courtyards and narrow passages. In extreme cases, several high-rise dwellings share a single courtyard with only one exit point towards other courtyards before even reaching a road or trail. Mapping of such narrow trails from satellite imagery is almost impossible. In these cases, courtyards were used as building block centroids with a higher weight respectively and manually connected to the main road network. Shelter demand calculated on ward level in the first step had to be spatially disaggregated onto the building blocks. This is done neglecting day- and nighttime population and occupancy rates for different building use. Some key numbers and characteristics of the used data can be found in Table 3.

Using this spatial representation of the urban environment, each building with its assigned weight corresponding to the number of persons seeking shelter is assigned to the nearest open space, taking into consideration network impedance and the sheltering capacity of that particular space. The location problem is solved so that (a) the nearest site is selected, (b) the overall weighted distances along the network for all buildings is minimized across the study area, and (c) no site remains unselected as long as there are buildings which are not served or the capacity is not reached.

One main obstacle to most network analysis methods are spatial boundary problems. The complete network and building database was available for inside KMC only. Thus people from outside KMC seeking shelter in any open space inside the Municipal boundary, or persons inside KMC seeking shelter outside the city boundaries were not considered. In special cases along the ringroad, open spaces consist mostly of two parts on both sides of the lane. To account for intrusion of people towards KMC, we only used the ones towards KMC for the analysis. To the south, KMC borders the Bagmati river forming a physical barrier, which can only be traversed at a few bridges all considered not earthquake safe (JICA and MoHA, 2002; NSET and GeoHazards International, 1998). Hence for the chosen scenario, it can be assumed that from or to this side, no movement of population seeking shelter can be expected.

5 Results

As can be drawn from the raw numbers used for the analysis (Table 2), there is a lack of shelter space in terms of capacity. 242 300 persons were estimated seeking public shelter within KMC using 9 m^2 covered living space per person as a standard. Out of them 253 900 persons (74 %) can be accommodated using the above set restrictions in terms of distance, and capacity.

Figure 3 shows the ranking results of the qualitative suitability criteria for the upper and lower 15 ranks, only displaying the qualitative suitability indicators. The OSSI ranking results are grouped in 0.2 ranges from Category A (> 0.8 to 1.0, green) to Category E (below 0.2, red). The most suitable open spaces in Category A and B add up to a total of 116 open spaces, which accounts for almost one third of all open spaces (28.3 %). Category D and E (not suitable) account for 50 open spaces (12.2 %). The distribution of OSSI values for all 410 open spaces is shown in Fig. 4.

For Category A the average contribution from each of the qualitative indicators is 21.1 % (±0.13) for existent use, 12.0 % (±0.04) for ownership, 2.1 % (±0.04) for masterplan, 17.9 % (±0.01) for additional hazard, 14.2 % (±0.01) for pollution, 6.3 % (±0.07) for water supply, 7.2 % (±0.12) for electricity, and 19.2 % (±0.01) for nearness to critical facilities. This is similar within all categories except Category C, where existent use gains importance (28.1 %) and nearness to critical facilities drops (6.4 %). Existing masterplan forms an exception for Category A compared to the average of all

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categories (8.4 %), together with nearness to critical facilities which accounts on average for 12.8 % only. Water (5.7 %) and electricity supply (5.4 %) as well as nearness to critical facilities (12.8 %) contribute on average across all categories (A to E) less than the applied weights (11, 10, and 18 % respectively).

The map representation of OSSI reveals some hot spots of shelter needs within KMC (Fig. 5). It shows the distribution of building blocks that can be served by one of the open spaces (light blue in the background), compared to the ones that remain unserved (light orange).

Some wards are very well prepared in terms of suitable open space for shelter purposes, others have a lack in terms of either the capacity of the sites or their suitability. Especially to the west from the core wards where high rise dwellings and extremely dense areas are located shelter deficits can be observed. Clusters of well-connected and high-capacity sites e.g. around Pashupati Temple area in the East are important in reducing people's shelter vulnerability.

6 Discussion and conclusion

In this paper we analyze 410 open spaces identified as emergency shelter sites within KMC in terms of their suitability for shelter. Four aspects are evaluated: first shelter implementation issues, second environmental considerations, third availability of basic utilities, and fourth the capacity-based coverage analysis. The methodology offers a straight forward way to identify hotspots in urban settings in terms of areas underserved by open spaces that can be used for emergency immediately after an earthquake. It combines an approach to classify and rank in depth qualitative information on the suitability of open spaces for emergency shelter available through site visits and knowledge from local experts with a quantitative information on shelter capacity derived from shelter need calculations using earthquake risk analysis and site accessibility from a GIS-based network accessibility model.

On the supply side, a comprehensive database of available candidate sites is needed, spatially covering the study area. The $\mathrm{CAM}_{\mathrm{OS}}$ at the same time relies on fully functional and topological correct road network.

The selection of criteria for qualitative evaluation of open space suitability is based on thorough literature review and latest design standards (e.g. FEMA, 2007; SPHERE Project, 2011). However, the criteria, sub-criteria and indicators used can be taken as a model and customized to fit the particular needs of a different context. While the open space suitability indicators were developed to be transferable to other urban settings, they were to some extent arrived at and influenced by the Kathmandu context. We used an expert-based approach to identify the most important criteria, and evaluated the importance with the help of group discussions. Besides multifaceted objectives of different stakeholders and experts, data availability also shapes the selection of certain criteria. Additionally, Chien et al. (2002) for example found, that climate and weather conditions in different seasons influence peoples shelter-seeking behavior. This and other temporally set factors were not taken into consideration so far.

The hotspot map that were derived according to the OSSI rankings of open spaces can guide decision makers to develop strategies and earthquake contingency plans for shelter placement. The analysis specifically addresses the emergency shelter logistics and resource allocation problem: where do we expect shelter deficits, where do we need to improve site suitability or identify alternative sites.

It has been argued that optimal site selection for emergency planning needs to consider two main aspects, first a sufficient quantity of accessible shelter area, and second site quality in terms of peoples centered shelter needs. An indicator-based methodology for combining both the qualitative suitability criteria and the quantitative shelter needs and site accessibility measured has been presented through the Open Space Suitability Index (OSSI). The potential of such methods lies in its applicability to further areas, variable types of candidate sites, and/or changing timeframes of sheltering. Therefore the initial weights and scores of the suitability index need to be contextualized according to the specific purpose and possibly different hazard(s). One main recommendation is to engage local experts and decision-makers in a participatory approach in the selection and weighting process to achieve consensus around the structure and perceived importance of the different indicators.

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Table 1. Overview of suitability categories and indicator criteria for immediate shelter sites.

Category	Weight	Indicator	Score	Explanation
Implementation Issues	0.1	Ownership	1	public (governmental, community, religious, institutional, educational)
			0.7	private
	0.06	Future Plan	1	no plan OR planned park OR planned garden OR planned playground OR long term structure plan
			0.5	short term structure plan
			0	under partial or full construction
	0.2	Existing Use	1	non-used OR park OR garden OR playground
			0.7	religious
			0.5	agricultural OR institutional
			0.4	educational
			0.1	dumping site
Environmental Considerations	0.18	Secondary Hazards	1	no secondary hazard
			0.7	fire OR flood hazard
			0.5	fire AND landslide hazard
			0.4	fire AND flood hazard
			0.2	fire AND landslide AND flood hazard
	0.1	Pollution Issues	1	Category 0: no Pollution
			0.9	Category 1: noise pollution OR air pollution
			0.8	Category 2: river pollution
			0.5	Category 3: urban waste pollution
			0.4	Category 1 AND Category 3
			0.3	Category 2 AND Category 3
			0.2	Category 1 AND Category 2 AND Category 3
Basic Utilities Supply	0.1	Electricity	1	distribution line AND generator(s) OR alternative source
			0.9	generator(s) OR alternative source
			0.7	distribution line
			0.1	no electricity available
	0.11	Water Supply	1	some type of source AND tank AND piped water
			0.8	some type of source AND tank
			0.7	some type of source AND piped water
			0.6	some type of source (natural source OR ground water OR deep boring)
			0.5	tank AND piped water
			0.4	tank
			0.2	piped water
			0	no water supply available
	0.15	Nearness to Critical Facilities	0.9	hospital(s) within less than 1 km distance
			0.8	hospital(s) within more than 1 km distance, but less than 2 km
			0.6	hospital(s) within more than 2 km distance, but less than 3 km
			0.4	hospital(s) within more than 3 km distance
			0	unknown distance to next hospital

Table 2. Shelter seeking class definition.

Residential Urban fabric	Shelter Seeking Class
Sparse density residential urban Fabric	Approx. 15 % of displaced population will not seek public shelter
Medium density residential urban fabric	Approx. 10 % of displaced population will not seek public shelter
Dense to very dense residential urban fabric	Approx. 2 % of displaced population will not seek public shelter

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Table 3. Key characteristics of the used database.

Data	Value	
Number of open spaces inside KMC	410	
Available open space	2 284 731	m^2
Overall capacity	253 859	pers.
Shelter demand (ELE)	342 299	pers.
Served population (GIS)	253 806	pers.
Unserved population (GIS)	88 493	pers.
Number of buildings (GIS)	72 783	
Served buildings (GIS)	54 742	
Unserved buildings (GIS)	18 031	
Road network length (GIS)	1250	km
Road network nodes (GIS)	27 294	
Road network edges (GIS)	66 576	

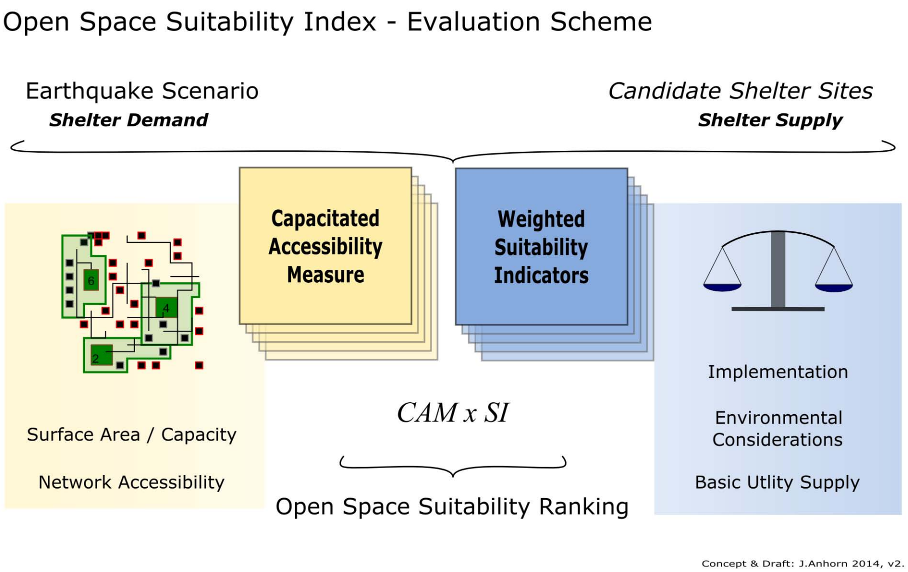

Figure 1. Open Space Suitability Index (OSSI) – evaluation scheme.

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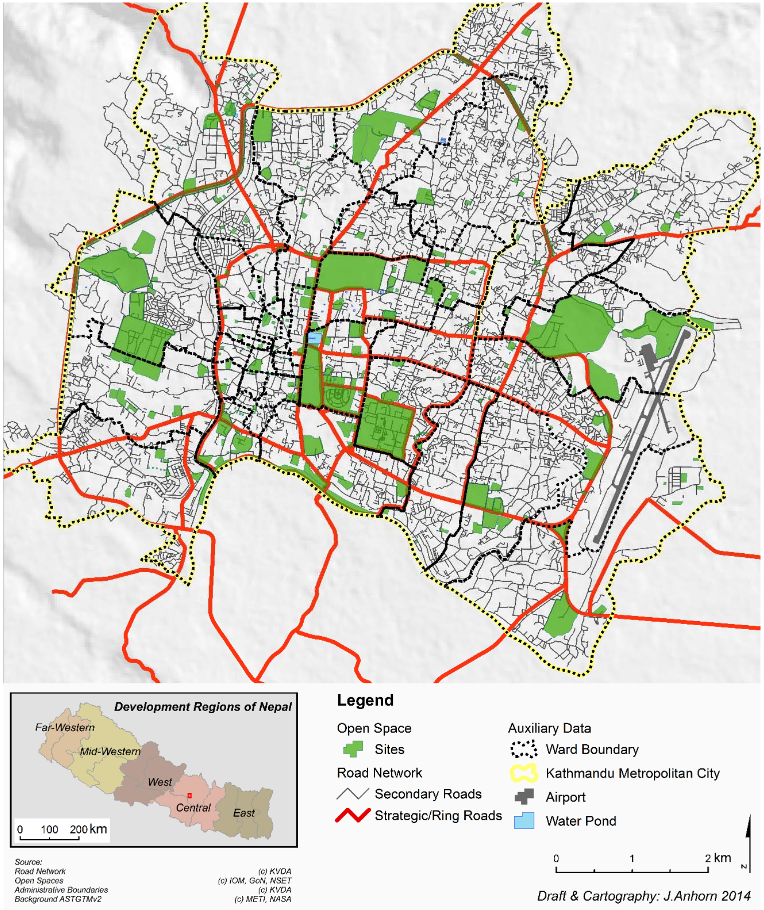

Source:
Road Network (c) KVDA
Open Spaces (c) IOM, GoN, NSET
Administrative Boundaries (c) KVDA
Background ASTGTMv2 (c) METI, NASA

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Figure 2. Distribution of open spaces in Kathmandu Metropolitan City.

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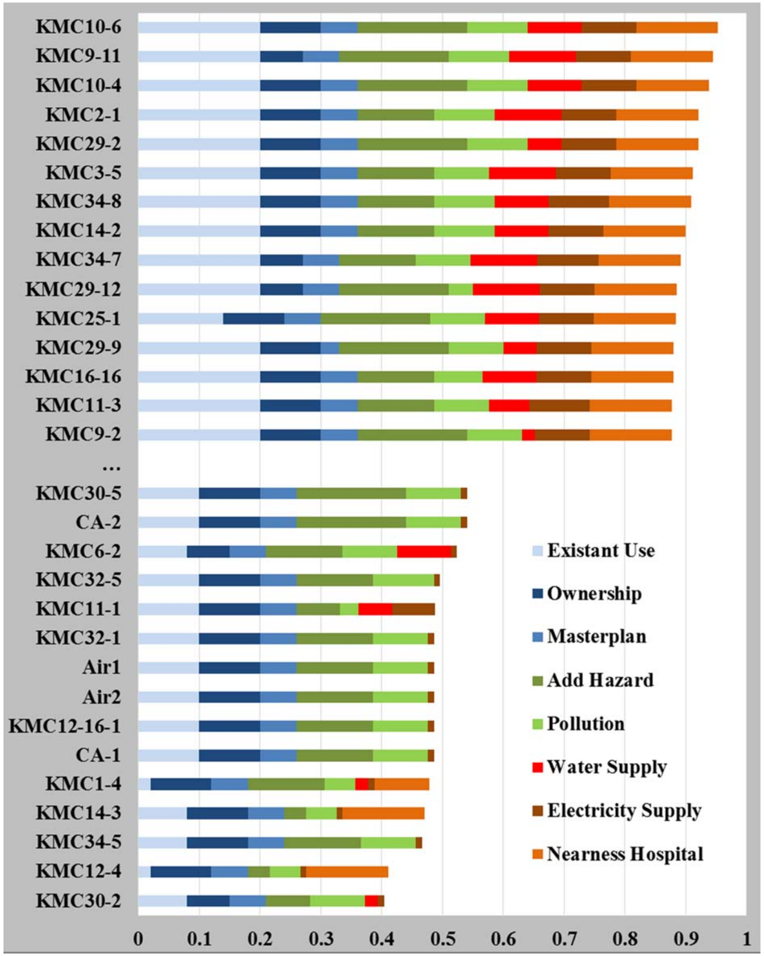


Figure 3. The first and last 15 open spaces ranked according to the suitability indicators.

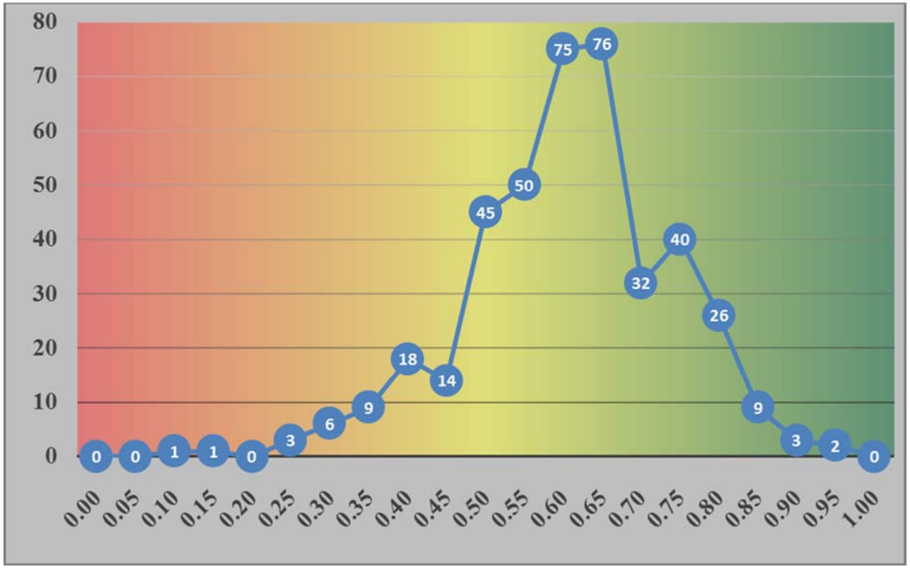
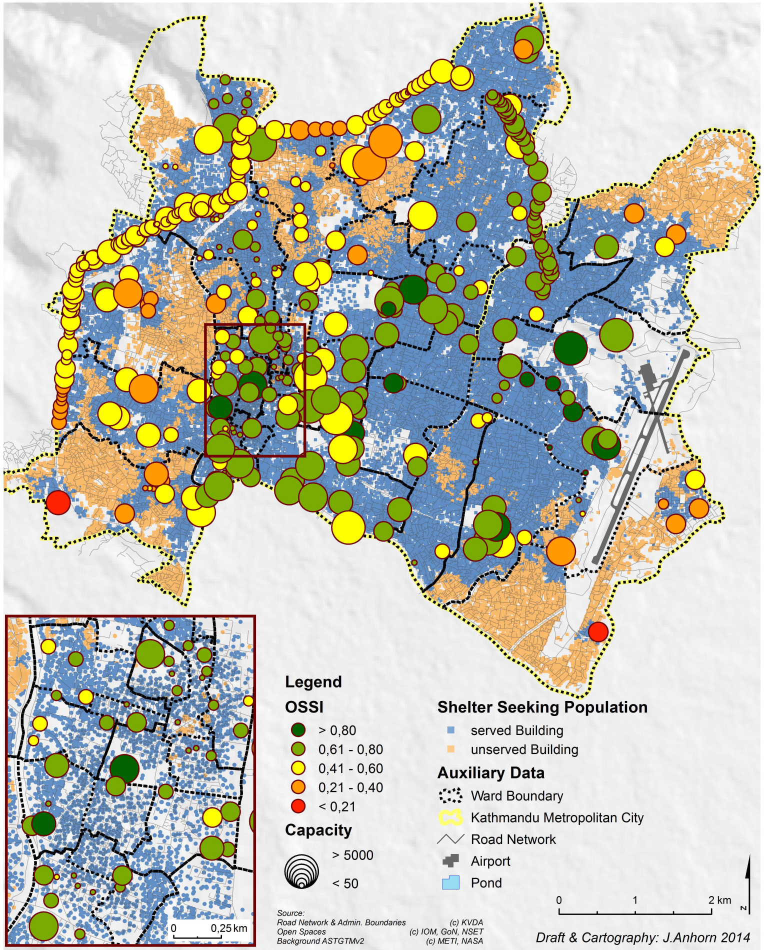


Figure 4. Distribution of OSSI values for all open spaces.



Source:
Road Network & Admin. Boundaries (c) KVDA
Open Spaces (c) IOM, GoN, NSET
Background ASTGTMv2 (c) METI, NASA

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Figure 5. Spatial representation of the Open Space Suitability Index for Kathmandu Metropolitan City.

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