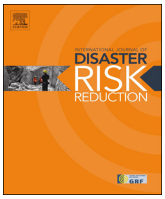
International Journal of Disaster Risk Reduction 15 (2016) 148–161

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr



Spatial assessment of social vulnerability in the context of landmines and explosive remnants of war in Battambang province, Cambodia

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ARTICLE INFO

Article history:
Received 7 September 2015
Received in revised form
14 November 2015
Accepted 15 November 2015
Available online 1 December 2015

Keywords:
Landmines
Explosive remnants of war (ERW)
Social vulnerability
Analytical Hierarchy Process (AHP)
Mine action
Cambodia

ABSTRACT

Despite recent progress in reducing the number of victims, landmines and explosive remnants of war (ERW) cause more than 3000 causalities every year, particularly affecting the most vulnerable. Current mine action programmes, however, do not consider prevailing vulnerabilities of affected communities in their priority-setting systems. We emphasise the need to consider social vulnerability in the workflow of mine action, and apply a spatially explicit approach for its assessment at a sub-national scale in Cambodia, one of the world's most heavily affected countries. Drawing on available literature and focus group discussions with domain experts, 16 socioeconomic, demographic and distance-related vulnerability indicators were identified. The Analytical Hierarchy Process was used to obtain indicator weights, revealing that *using firewood for cooking*, *distance to hospitals and health centres*, *occupation in the primary sector*, *poverty*, *conflict density*, *illiteracy* and *living in a rural area* are key factors shaping social vulnerability in the context of landmines and ERW. Results were visualised using both 2×2 km^2 grids and sub-district administrative units, a resolution often used by the Cambodian Mine Action and Victim Assistance Authority (CMAA). The results show that social vulnerability is very heterogeneous across the study area (Battambang province) with varying contributions of the underlying indicators. Significant hot spots were identified in the central, north-western, north-eastern, and southern parts of the province. The presented approach provides the means not only to assess but also monitor progress of reconstruction measures to strengthen the resilience of communities exposed to post-conflict impacts such as landmines.

1. Introduction

In late 2014, 56 countries and four other areas (Somaliland, Kosovo, Nagorno-Karabakh, and Western Sahara) were confirmed to be affected by landmines and explosive remnants of war (ERW), resulting in 3308 casualties [1]. Landmines are munitions designed to explode from the presence, proximity, or contact of a person or vehicle, while ERW are explosive munitions left behind after a conflict has ended, such as unexploded artillery shells, grenades, mortars, rockets, air-dropped bombs or cluster munitions, etc. Although a major decrease in the number of casualties compared to previous years can be observed, it is still primarily the most vulnerable, i.e. civilians, children and the poor who carry the highest burden [1–3]. Next to their impact on human health, landmines and ERW also impede sustainable development in affected areas through impacts on agricultural productivity, food security, and education as well as on the construction of new infrastructure, such as roads, etc., often affecting already marginalised areas and population groups [4–6].

Mine action aims at reducing the social, economic and environmental impact of landmines and ERW through activities belonging to five complementary components or pillars: humanitarian demining, mine risk education, victim assistance, stockpile destruction and advocacy [7]. Typically, mine action programmes in affected countries are at first implemented by the international community. Transition to national ownership is achieved notably with the establishment of a National Mine Action Authority (NMAA) charged with the responsibility for the regulation and management of mine action. Operations are planned, coordinated, overseen and sometimes implemented by a Mine Action Centre (MAC)/Mine Action Coordination Centre (MACC) on behalf of the

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http://dx.doi.org/10.1016/j.ijdrr.2015.11.003

NMAA [7]. The actual field work is generally carried out by non-governmental organisations and – to a lesser extent – commercial contractors and militaries. Since the entry into force of the Mine Ban Treaty in 1997 [8], progress in addressing the threat of mines and ERWs has resulted in significant reduction of casualties, increased national capacity, an expanded legal framework for mine action and enhanced cooperation among mine action stakeholders. However, decreases in casualties are often not only a result of progress in mine clearance. Especially since time after a conflict gets longer they are also a result of socio-economic development, enhanced coping strategies and alternative livelihood options of populations in affected areas [9,10]. Nevertheless, challenges remain as populations are still, or again, exposed to the threat of mines and ERW with the occurrence of new armed conflicts [11].

Since mine action in most countries is limited by available resources (people, funds, assets, time, etc.) mandated agencies must prioritise their activities [12]. Allocating a specific amount to a particular purpose or geographic area means that fewer resources are available for other purposes or regions. According to the Geneva International Centre for Humanitarian Demining (GICHD), achieving greater value for money is therefore of utmost importance for any mine action programme. Value in this context, however, does not strictly refer to monetary value, but rather to concepts that are of universal value (i.e., preserving human life, preventing pain/alleviating human suffering, preserving human dignity and alleviating destitution, promoting material prosperity, keeping promises/fulfilling commitments, restoring to people what they have lost through no fault of their own) [13]. Ideally, this should be achieved through the design and implementation of sound priority-setting systems [14]. To date, there exists a wide array of priority setting methods, each involving the selection of relevant criteria and the specification of a number of indicators for every criterion. The GICHD has produced a (non-exhaustive) synthetic table of possible criteria for use in mine action priority-setting, grouped according to the value to which they are related [15]. Examples include reducing risk from mines/ERW, reducing the lives and limbs lost to mines/ERW, facilitating delivery of humanitarian aid, promoting rehabilitation and reconstruction, raising economic growth and complying with treaty obligations. For each criterion a set of indicators is proposed. As an example, current indicators for reducing the risk from mines/ERW include the number of recent accidents in the area and the percentage of population that received mine risk education [13]. Whereas priority setting is not meant to provide ready-made answers, it can prove an effective decision-support tool when its concepts are clearly understood and implemented. Williams and Dunn [14] highlight that the effectiveness of prioritisation depends on two key factors: first, on the precise evaluation of priorities based on information regarding both the location of landmines and/or ERW (i.e. the hazard) and their impact on affected communities, and second, on the ability to successfully translate those priorities into action [14].

The impact of landmines and ERW is not only driven by the presence of the hazard, but also to a considerable degree by the social vulnerability of the population in affected areas [3,10]. Nonetheless current priority-setting systems do not explicitly consider prevailing vulnerabilities of the population when identifying priority areas. This gap has also been underscored by senior officials ($n=9$) of the Cambodian Mine Action and Victim Assistance Authority (CMAA) and the Cambodian Mine Action Planning Unit (MAPU) during a stakeholder workshop in Battambang, Cambodia. They argued that spatial information on the social vulnerability of the population would be of high ($n=5$) or even very high ($n=4$) relevance for improved and more efficient mine action. While vulnerability assessments nowadays are a key component of both climate change adaptation (CCA) and disaster risk reduction (DRR) efforts when it comes to assessing the impacts of given hazards and identifying possible adaptation options, vulnerability concepts are still largely ignored in existing mine action programmes and strategies. In Cambodia, for example, priority-setting currently consists of two phases. First, CMAA facilitates the selection of priority communes. This is mostly based on two indicators only, i.e., *the number of casualties over a three-year period* and *the number of contaminated areas/minefields identified by the Baseline Survey*. For about 25 per cent of communes, other elements can be taken into account such as the existence of a development project or specific donor requirements. Second, the MAPUs facilitate the selection of priority contaminated areas/minefields in the communes, typically based on needs expressed on the local level [16,17].

Against, this background, the aim of this paper is to transfer and apply the concept of social vulnerability, which is well-established in DRR and CCA, to mine action. To achieve this, we introduce a risk and vulnerability concept that has been adapted from existing frameworks (see Section 2.3) to guide social vulnerability assessments in the context of landmines (incl. both anti-person and anti-vehicle mines) and ERW. Further, we apply a methodology for the spatial assessment of social vulnerability hot spots based on the integration of a set of expert-weighted, spatially explicit socioeconomic, demographic and distance-related vulnerability indicators.

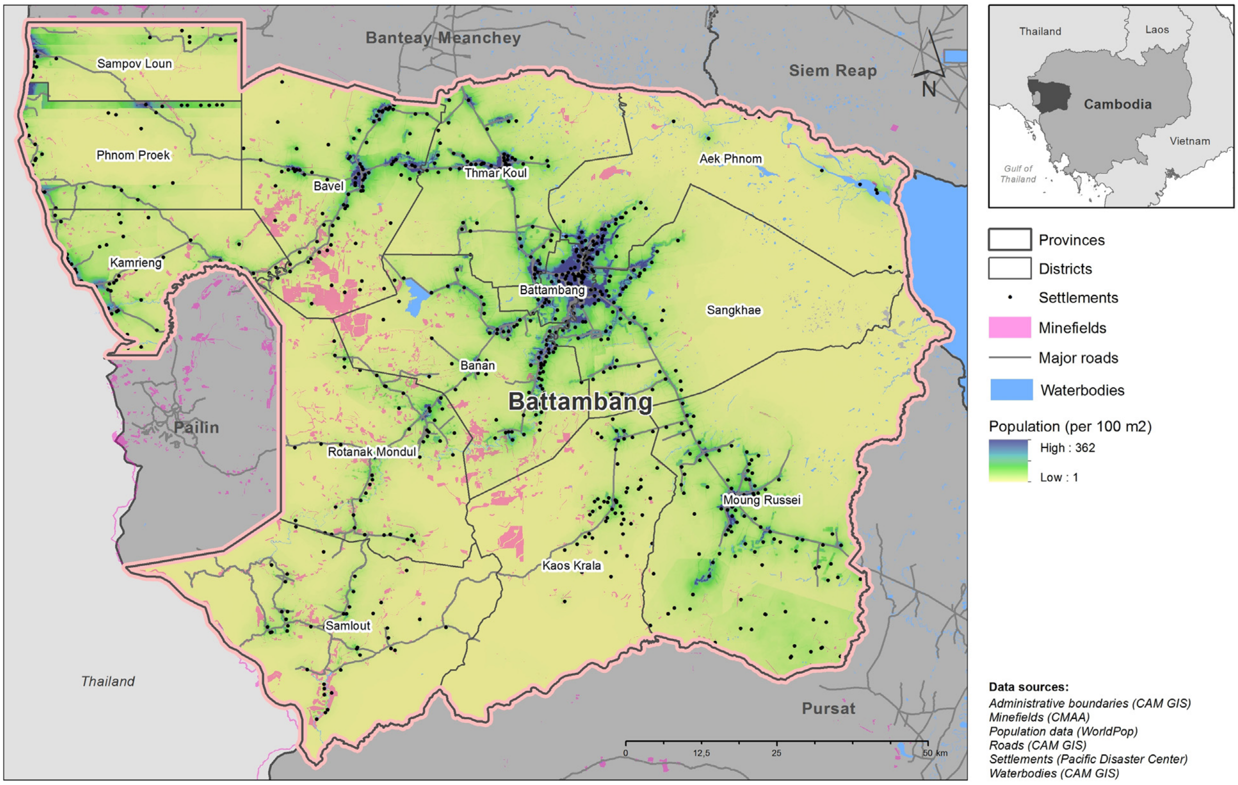
2. Methods

2.1. Ethics statement

This study presents an analysis using data derived from previously published surveys, i.e. the 2008 General Population Census of Cambodia and the Cambodia Standard 2010 Demographic and Health Survey (DHS). Both have been approved by the respective institutional review boards and national ethics committees. The 2008 Population Census was conducted adhering to the Principles and Recommendations for Population and Housing Censuses of the United Nations [18] to ensure that all the aspects of collection operations and the dissemination of results are acceptable to the public and fully comply with legal and ethical standards for protecting the confidentiality of individual responses. All DHS surveys are reviewed by an institutional review board or ethics review panel in the country to ensure the protection of human subjects [19]. Further, the following measures were taken to ensure that the data gathered from the experts during the workshops are collected and used in an ethical manner: (1) all experts were informed in advance about the scope, methods and possible uses of the research, and what their participation in the workshop involves, (2) confidentiality of information and anonymity of the experts was respected (including in this publication), and (3) participation in the weighting exercise was voluntary.

2.2. Study area

The study area is Battambang province (capital city: Battambang) in the north-western part of Cambodia (Fig.1). With its 14 districts (Khmer: *srok*), 96 sub-districts (Khmer: *khum*), 789 villages (Khmer: *phum*) and approximately 11,700 km^2 it is the fifth largest province in Cambodia. According to the latest Census more than one million people live in this province, resulting in a population density of circa 88 people per km^2 [20]. The annual population growth rate of 2.28% is higher than the population



Data sources:
Administrative boundaries (CAM GIS)
Minefields (CMAA)
Population data (WorldPop)
Roads (CAM GIS)
Settlements (Pacific Disaster Center)
Waterbodies (CAM GIS)

Fig. 1. Location of Battambang province, Cambodia. The map shows the spatial distribution of the population as well as the location of villages, major roads and minefields in the study area.

growth rate for the entire country (1.54% [9]). The provincial capital, which is the second largest city in Cambodia, is the main hub in the north-west between Phnom Penh and Thailand [21]. Due to its tropical climate, fertile soils, abundant water resources and its irrigation capacity, Battambang is the leading rice-producing province, and thus also known as the the rice bowl of Cambodia [22]. About three quarters of the workforce is employed in the primary sector, mainly in the agricultural economy. The use of aquatic resources for fishing is an important livelihood activity for families and for the landless in Battambang. It represents a major source of income, particularly when crop production fails [23].

As a result of nearly 30 years of war and violent conflict, Cambodia is among the countries most heavily affected by mines and ERW [12]. The anti-personnel mine problem is primarily concentrated in the 21 north-western districts along Cambodia's frontier with Thailand. Cluster munition-contaminated areas in contrast are mainly found in the eastern and north-eastern parts of the country close to the Lao People's Democratic Republic and Viet Nam [24]. Moreover, Cambodia faces major problems with anti-vehicle mines, which are causing even more fatalities than anti-personnel mines [24]. The Cambodia Mine/ERW Victim Information System (CMVIS) recorded a total of 64,534 mine/ERW casualties for the period from 1979 to June 2015. Of these, 79% are mine and 21% ERW casualties [25]. Within the country, Battambang is one of the most affected provinces regarding mine and ERW casualties. The reasons for this dismal record lie mostly in the conjunction of the location of Battambang province inside the dense mine belt at the Cambodian-Thai frontier, the fact that most families living in the area depend on growing crops and the extensive agricultural expansion in formerly forested areas located at the edge of the rice-growing area. Important migratory movements lead "pioneers" to push the boundary between cropland and forests ever farther [26]. Table S1 in the supplementary material lists the mine/ERW ccasualties in Battambang province by activity at the time of the accident, by age and by gender for the years 2010–2014.

2.3. *Defining risk and vulnerability in the context of landmines and ERW*

Concepts of risk and vulnerability have entered into many different application domains over the past decades, including CCA [27,28], DRR [29], and, more recently, public health [30–32]. The concept originates from social sciences/human ecology under the frame of DRR [33]. In 1983 Hewitt already demonstrated that vulnerability is a major driver of disaster risk, while the hazard itself is often merely the trigger [33]. This has led to a shift in the understanding of disaster risk from rather hazard-driven approaches in the 1970s and 1980s towards considering the conditions and processes that shape the predisposition of exposed elements (i.e., people and their assets) to be negatively affected by a particular hazard [34,35]. The latest reports of the Intergovernmental Panel on Climate Change (IPCC) [35,36] harmonised the different definitions of vulnerability within the CCA and DRR community. Vulnerability assessments identify factors that drive up disaster risk and hence influence the possible impact of given hazards or threats. The challenge with vulnerability, as with any multidimensional phenomenon, is that it cannot be measured directly, and therefore requires deductively built, heuristic frameworks, which are able to guide the selection of appropriate vulnerability indicators and their combination in a meaningful vulnerability index. Vulnerability assessments are used by scientists, decision makers and practitioners to identify intervention measures, and therefore aim to inform policy. However, despite the widespread application of vulnerability concepts, there is yet no consensus in regard to specific frameworks and whether or not

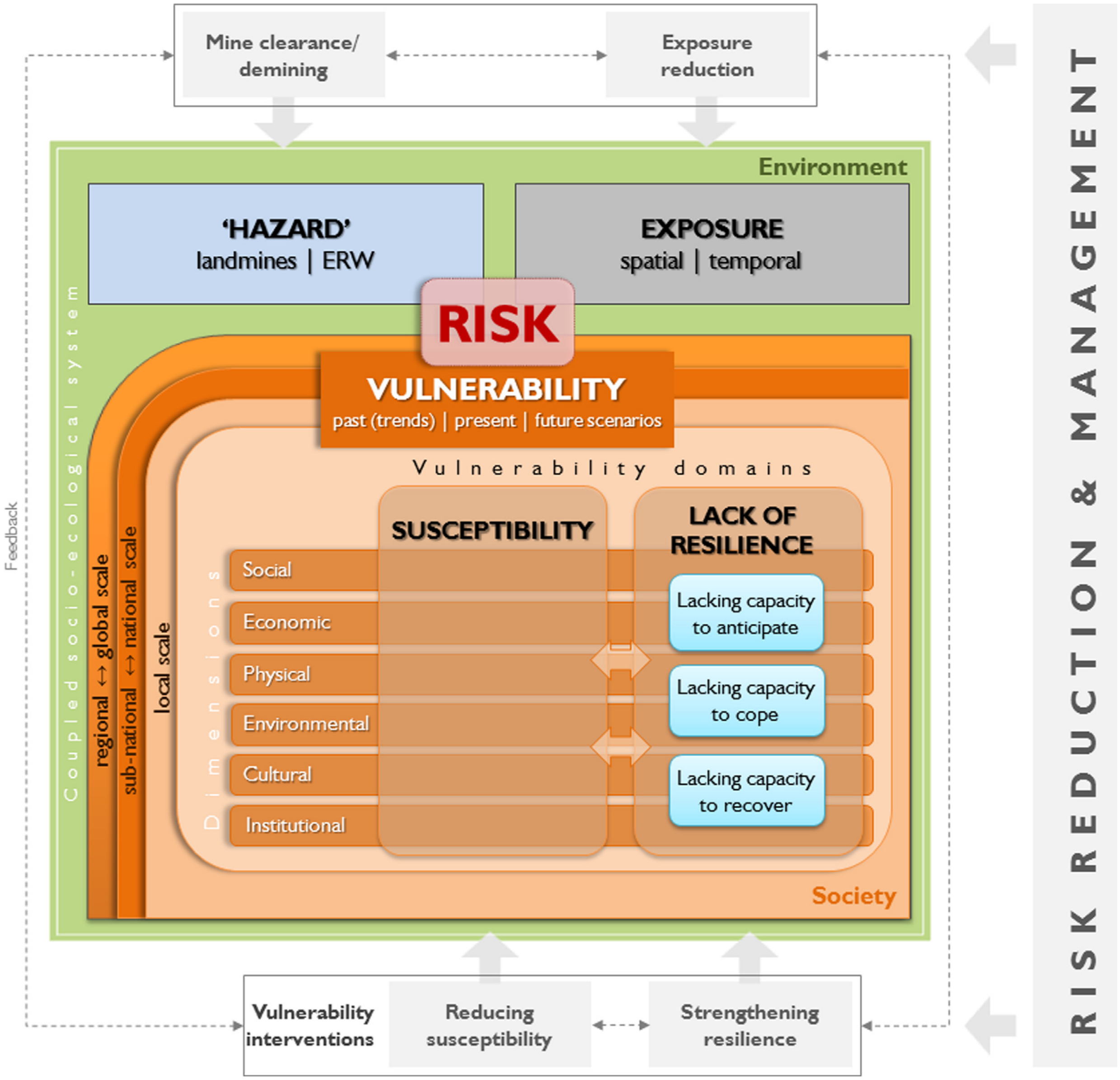


Fig. 2. Risk and vulnerability concept in the context of landmines and ERW (adapted from [29]).

indicator-based approaches are most suitable to represent the complexity of vulnerability [37].

Within this paper we present a conceptual risk and vulnerability framework (Fig. 2) which is based on the MOVE framework [29] to guide vulnerability assessments in the context of landmines and EWR. Risk is not a new term in mine action. However, risk in mine action is oftentimes perceived in terms of the visible effects of landmines as a hazard, i.e. the injuries they cause. This very narrow perception of risk results in DRR efforts that focus primarily on reducing exposure to landmines and tend to ignore the risks that are related to the social and economic vulnerability of communities [3]. In our framework, risk is thus defined as the likelihood of severe alterations in the normal functioning of a community or a society due to the presence of landmines/ERW interacting with vulnerable social conditions, leading to adverse effects, including injury, loss of life as well as loss and damage to elements (here: affected population groups). Thereby, social vulnerability is characterised through scale specific temporal and spatial processes. This is similar to a DRR approach, where high risk may lead to severe alterations and disasters, which impact the normal functioning of a system. In the context of mine action, the hazard can be understood as the (suspected) geographical presence of landmines and/or ERW [10]. As a crucial component of risk, vulnerability reflects the predisposition of the elements and processes of the social-ecological system in place (here the population) to be adversely affected by landmines/ERW. Following the herein applied definition of vulnerability of Birkmann et al. [29], vulnerability is seen as a holistic, multidimensional concept with different thematic dimensions, targeting for example social, economic, environmental, cultural, physical and institutional vulnerability. It is also widely understood in the DRR community that assessments may be best targeted when focusing on one of these dimensions; in our case social vulnerability. Vulnerability itself is characterized through the susceptibility of the population, i.e. the internal predisposition to suffer a certain degree of harm when exposed to landmines/ERW, and the lack of specific capacities, including the lacking capacity to respond to and absorb negative impacts caused by landmines/ERW. The latter, in the framework also referred to as lack of resilience, is a result of the lacking capacity of exposed population groups to anticipate, cope with, or recover from mine/ERW accidents. Within this assessment we specifically consider the social dimension of vulnerability, which is understood as the *"propensity for human well-being to be damaged by disruption to individual (mental and physical health) and collective (health, education services, etc.) social systems and their characteristics (e.g. gender, marginalisation of social groups)"* [29, pp. 8]. This understanding of risk and vulnerability is also in line with previous findings of Bottomley [3], who highlighted that depending on factors such as age, wealth, or gender, villagers tend to be more susceptible than others.

The framework provides different entry points for DRR and disaster risk management (DRM), specifically targeting the different components contributing to risk. Next to the traditional role of mine clearance as a standard hazard intervention, and the demarcation of suspected hazardous areas (SHAs) as a possible measure towards exposure reduction, the framework highlights the need to invest in vulnerability reduction measures that aim at reducing susceptibility and/or increasing resilience of exposed population groups.

2.4. Vulnerability indicators and datasets

Based on the outcomes of a non-systematic review of literature and a focus group discussion with experts ($n=14$) of the European EU-FP7 TIRAMISU project (Toolbox Implementation for Removal of Anti-Personnel Mines, Submunitions and UXO; http://www.fp7-tiramisu.eu/) during a vulnerability workshop in Salzburg, Austria, a first set of 33 vulnerability indicators was identified. Based on data availability, this list was further refined at a two-day stakeholder workshop with senior officials ($n=10$) from both the CMAA and the provincial MAPU which was held in Battambang, Cambodia, from June 16–17, 2015. Each of the participants has long-lasting experience regarding mine action in Cambodia and is highly familiar with the local idiosyncrasies (e.g. suspected hazardous areas, activities contributing to increased vulnerability, socioeconomic profiles of casualties, etc.) in Battambang province. As a result, a set of 16 socioeconomic, demographic and distance-related (e.g. distance to hospitals and health centres, etc.) vulnerability indicators was identified, including nine susceptibility (SUS) and seven lack of resilience (LoR) indicators (Table 3).

Children are particularly vulnerable to landmines [38,39]. First, they tend to play outside and pick up things out of curiosity while being unaware of the dangers associated with landmines. Second, if they are too young to understand warning signs, any visual measure taken to notify of the presence of mines is useless. Third, due to their low weight and size, they are far more likely to die from their injuries when hitting a landmine. According to data from the CMVIS[1], children account for about a half of all landmine casualties in Cambodia [25]. The CMVIS data (see Table S1 in the supplementary materials) also shows that males clearly carry a higher risk, accounting for more than 80% of the mine-related casualties since the system was established in 1979 [25]. Men and women have differing mobility and activity patterns, and thus they have different exposure and vulnerability to mines [40]. Most accidents occur during different livelihood activities. Published literature mentions several reasons why significantly more men than women are injured in Cambodia: for example, men are more negligent when dealing with landmines/ERW; women are primarily responsible for household work and thus are less likely to become mine victims compared to men, who show greater mobility due to their role in agriculture (e.g. land preparation) and foraging (cutting wood, hunting, gathering food); social attitudes relating to men and women's behaviour, i.e. many village deminers are males who do not allow females and children to get close to mine clearance areas, since in their attitude high risk work belongs to men [3,41]. Similar findings have also been reported by Surrency et al. [42] who identified risk factors associated with landmines in Afghanistan. Consequently, data on the number of children under the age of 15 and the percentage of the male population was acquired from the 2008 village census. Specific activities, such as collecting wood/timber and water for fuel and cooking or as construction material, farming or tending animals also increase susceptibility [14,43]. This is also supported by the casualty statistics provided by CMVIS [25]. Therefore, geo-coded data on households which have to collect water from wells, springs, rivers, dams, lakes, ponds or irrigation channels and households which have to collect firewood (incl. wood, straw, crops and animal dung) for cooking was acquired from the 2010 Demographic and Health Survey (DHS) [44]. Data on the percentage of the population being employed in the primary sector was obtained from the 2008 village census. Since violent conflict hampers economic growth and development, has an impact on healthy systems and governance, but also results in migration of the population, data on violent conflict from 1997 to 2010 was downloaded from the Armed Conflict and Event Database (ACLED; http://www.acleddata.com) to calculate a density layer of violent political conflict. Since most accidents occur in remote, rural areas, data on both rural extent and the travel time to the closest urban centre was acquired from the CAM GIS and the JRC/World Bank [45]. During the workshop it was highlighted by the experts that due to the steadily increasing population in the country (growth rate of 1.8% in 2015), population pressure is leading to increased susceptibility of the population, forcing people to settle in SHAs and pushing people towards the periphery in search for farmland [46]. CMVIS reports that the handling with mines/ERW caused 29% of the accidents from mid-2014 to mid-2015 [25]. This is most likely also related to a lack of education. Many young Cambodians are competing for jobs at the low end of the labour market, since major parts of the labour force barely completing lower secondary education [47]. Since illiteracy, or low levels of education, not only impact people's ability to read warning signs, but also might lead to risky behaviour, data on education levels (here: no/low education) as provided by the 2008 village census as well as the distance to schools was included in the analysis. Access to media can be crucial to receive news regarding the location and presence of SHAs. Hence, a binary variable indicating whether or not a household has access to radio or television was acquired from the 2010 DHS. In the case of a mine accident, access to health services is of utmost importance to ensure the proper treatment and survival of the casualty. Hence, the location of both hospitals and health centres was used to calculate a distance layer, which served as a proxy for access to health services. During the stakeholder workshop CMAA officials highlighted the higher relevance of hospitals over health centres for the successful treatment of mine victims. Thus, distance to hospitals was assigned a weight of 57% and distance to health centres a weight of 43% when calculating the combined distance layer. Since having access to a vehicle decreases the time needed to travel to the closest health facility during an emergency, data on the prevalence of households without a car or truck was obtained from the 2010 DHS. Ultimately, it is well documented in literature that poverty has an impact on vulnerability to various threats and hazards [48,49], including landmines. Due to a lack of reliable data on income and expenditures, we used the 2010 DHS Wealth Index, focusing on the poor and poorest households, as a proxy for poverty, an indicator several studies have associated with chronic poverty [50–53]. The DHS Wealth Index is calculated using data on a

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[1] Data provided by Mr. Tan Sara, Database Unit Manager of the CMAA.

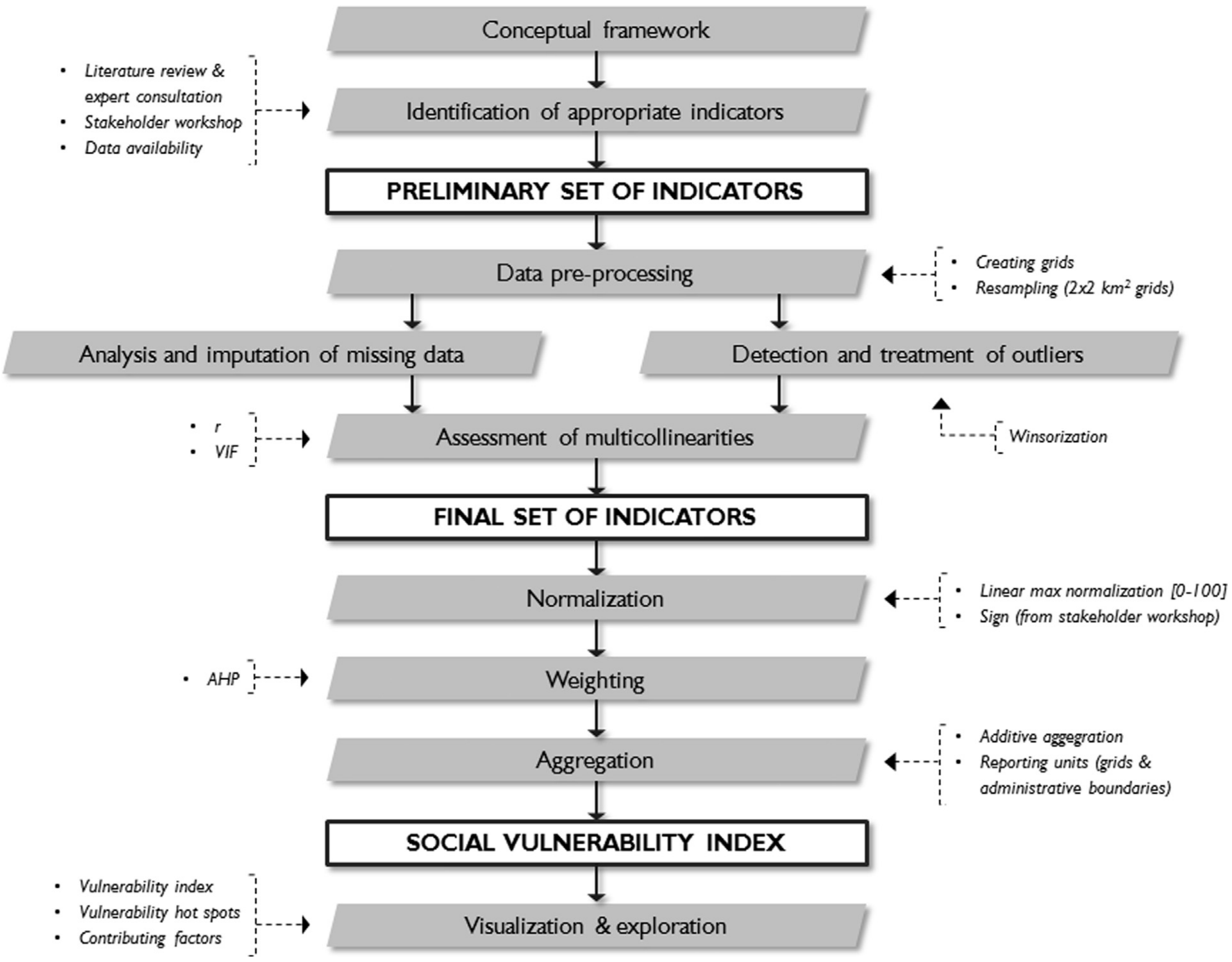

Fig. 3. Workflow for the spatial assessment of social vulnerability (based on [32,61]. Grey boxes represent modelling stages; white boxes represent outputs.

household's ownership of selected assets, such as electronic devises, materials used for housing construction, and types of water access and sanitation facilities. Each household asset is assigned a factor score generated through principal components analysis. The resulting asset scores are standardized using z-scores, which then form the basis for the creation of break points that define wealth quintiles [54].

2.5. Spatial modelling of social vulnerability

Most spatial vulnerability assessments follow a similar, largely sequential workflow to construct a vulnerability index. Independent of the hazard that is addressed, common modelling phases include (1) the definition of the conceptual framework and identification of appropriate vulnerability indicators, (2) data acquisition and pre-processing, (3) normalisation, (4) weighting, (5) aggregation, (6) sensitivity analysis and (7) visualisation [32,49,55–60]. Fig. 3 shows the workflow for modelling social vulnerability as applied in this paper.

2.5.1. Data pre-processing

After data acquisition, the spatial datasets were pre-processed in a Geographic Information System (GIS) and using statistical software. This included (1) creating gridded surfaces, (2) resampling of the data to 2×2 km^2 grids, (3) cropping the data to the boundaries of the study area, (4) analysing and, where necessary, treating missing data and multicollinearities in the data, as well as (5) rendering the datasets comparable by means of normalisation.

As a first step gridded surfaces were created for all point data, including the village census (*number of children under age 15*, *sex ratio*, *occupation in the primary sector*, *illiteracy* and *dependency ratio*), DHS data (*household has no access to safe water*, *household uses firewood for cooking*, *household has no radio/TV*, *household has no health insurance*, *household has no car/truck* and the *wealth index*), the ACLED data on *violent conflict*, as well as for *distance to hospitals*, *health centres* and *schools*. For the village census and conflict data a kernel density surface was created in ArcGIS (ESRI, Redlands, USA), while prevalence surfaces for the DHS data were generated based on a kernel density estimator approach using the prevR package [62] in R statistical software [63]. The two layers *distance to hospitals/health centres* and *schools* were created using the path distance tool in ArcGIS, which calculates the least accumulative cost distance from each cell to the nearest source, while accounting for surface distance and horizontal (here: roads and land use/land cover) and vertical (here: elevation) cost factors based on an inverse linear function. Information on land use/land cover (LULC) was obtained from the GlobCover 2009 dataset, while the elevation information was obtained from the Shuttle Radar Topography Mission (SRTMv4) mission. The rationale behind including LULC information into the calculation of the least accumulative cost distance was that it is for example more difficult to travel through an area covered by dense forest, than through an area covered by grass or meadow land. To account for the fact that for some remote regions of Battambang province it might be faster/closer to access a hospital, health centre or school in a neighbouring district, a modelling extent which also covers parts of the surrounding provinces was created using a 20 km buffer, and was used for generating the raster surfaces.

Table 1
Multicollinearity statistics.

Indicator name	VIF (before)	VIF (after)
SUS_01: Number of children (age < 15 years)	4.7	4.7
SUS_02: Sex ratio (male population)	1.8	1.8
SUS_03: Household has no access to safe water (%)	1.4	1.4
SUS_04: Household uses firewood for cooking (%)	1.4	1.4
SUS_05: Occupation in primary sector (%)	3.3	3.3
SUS_06: Conflict density (km^2)	1.9	1.9
SUS_07: Travel time to the closest urban centre (mins)	1.2	1.2
SUS_08: Population numbers (people per grid square)	2.2	2.2
SUS_09: Rural extent/areas (yes/no)	1.2	1.2
C2A_01: Illiteracy: no/low education (%)	13.5	1.2
C2A_02: Distance to schools (cost path)	3.3	3.2
C2A_03: Household has no radio/TV (%)	2.5	2.5
C2C_01: Distance to hospitals/health centres (cost path)	3.4	3.4
C2C_02: Household has no car/truck (%)	1.9	1.8
C2R_01: Wealth index: poorest, poor (%)	2.3	2.3
C2R_02: Dependency ratio	13.6	Indicator removed

Table 2
AHP scores.

AHP scale of importance for comparison pair	AHP scores
Extremely more (less) important than	9 (1/9)
Very strongly more (less) important than	7 (1/7)
Strongly more (less) important than	5 (1/5)
Moderately more (less) important than	3 (1/3)
Equally important	1

Since the datasets were available in different spatial resolutions (Table 3), all datasets were resampled to 2×2 km^2 grids and projected to a common geographic reference system using the Universal Transversal Mercator (UTM 48 N) projection before cropping them to the boundaries of Battambang province. Multicollinearities in the data were assessed using both the Pearson correlation coefficient r (with $r > 0.9$), and considering the variance inflation factor ($VIF > 5$) following guidelines described by the Organisation for Economic Co-operation and Development [61]. Using this approach two lack of resilience indicators were identified as highly collinear: *illiteracy* and *dependency ratio.* After removing *dependency ratio,* which was assigned a very low weight by the experts, no further issue of multicollinearity was observed (Table 1).

In a subsequent step all indicators that did not fall in the zero to 100 interval (i.e., those indicators not representing percentages) were normalised using linear max normalisation based on the following equation:

$$v_i' = \frac{v_i}{v_{max}} * 100 \tag{1}$$

Where v_i refers to the actual indicator value, and v_{max} to the max value of the respective indicator. This results in normalised values v_i' in a range between zero and 100.

2.5.2. *Analytical Hierarchy Process to define indicator weights*

The choice of an appropriate method to assign indicator weights – reflecting the relevance of single vulnerability indicators – has been subject to much debate. To date, three main approaches for assigning indicator weights are widely applied in spatial vulnerability or risk assessments. These range from approaches based on equal weights (e.g. [48,49], over statistical procedures such as factor and principal component analysis [58,64] or regression analysis [32], to participatory approaches, where expert opinion is used to evaluate the influence of the single indicators on overall vulnerability (e.g. [59,60]. The benefits and challenges of available methods have been discussed by Jones and Andrey [65], by the Organisation for Economic Co-operation and Development (OECD) in their Handbook on Composite Indicator Construction [61] and more recently by Fritsche et al. [57]. Since equal weights most likely do not capture the given, often highly context-specific contribution of single indicators to social vulnerability, this paper makes use of a participatory approach to evaluating indicator weights. Two prominent participatory methods for identifying indicator weights include budget allocation, where experts have to assign a budget (e.g. 100 points) to the single indicators (e.g. [57,66] and the Analytical Hierarchy Process (AHP) method which is used here.

AHP is a participatory approach to multi-criteria decision making developed by Saaty [67] in which the relative contribution of indicators is derived from pairwise comparisons. Based on the set of indicators listed in Table 3, a pairwise comparison matrix was created which was used to calculate the weights. In the matrix, an importance score from 1 (=equally important) through 9 (=extremely more important than) was used to record the relative level of importance for the pairwise combinations of the indicators. Table 2 shows the importance scores used in this study, as well as their reciprocals in brackets.

To obtain indicator weights the AHP method was applied during a two-day stakeholder workshop which was held in Battambang in June 2015. As indicated earlier, the consulted experts ($n=9$) included high-level officials from the CMAA and the MAPU. One of the advantages of the AHP method over other participatory approaches is that it enables an evaluation of the consistency of the experts' judgements. This is achieved by calculating a consistency ratio (CR) that indicates for each expert the likelihood whether or not his/her judgements in the pairwise comparison matrix were generated randomly [68]. The CR is obtained from:

$$CR = \frac{CI}{RI} \tag{2}$$

where CI is the consistency index and RI is the random index. While the RI is a direct function of the number of indicators used in the assessment and can be obtained from literature (here: $RI = 1.59$), the CI is calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{3}$$

where n represents the number of criteria. According to Saaty [67], a $CR < 0.1$ indicates a consistent judgement by the experts involved in the exercise, which however represents a subjectively defined threshold. Five experts revealed a $CR < 0.2$, which was considered an appropriate threshold for this study. Consequently, the final weights were obtained by taking the average of the judgements of those experts with a $CR < 0.2$. To evaluate the degree of consensus among experts, the standard deviation was calculated for all indicator weights (see Table 3).

2.5.3. *Social vulnerability index*

A social vulnerability index (SVI) was constructed in a GIS by integrating the normalised indicator values v_i' using weighted additive aggregation according to the following equation:

Table 3
Final set of social vulnerability indicators.

Indicator name[a]	Resolution[b]	Sign[c,d]	AHP weights[d]	Std (weights)	Data source (year)
SUS_01: Number of children (age < 15 years)	Point layer	+	0.04	0.01	Census (2008)
SUS_02: Sex ratio (male population)	Point layer	+	0.02	0.03	Census (2008)
SUS_03: Household has no access to safe water (%)	Point layer	+	0.04	0.03	DHS (2010)
SUS_04: Household uses firewood for cooking (%)	Point layer	+	0.13	0.04	DHS (2010)
SUS_05: Occupation in primary sector (%)	Point layer	+	0.10	0.01	Census (2008)
SUS_06: Conflict density (km^2)	Point layer	+	0.10	0.08	ACLED (1997-2010)
SUS_07: Travel time to the closest urban center (mins)	30 arc-seconds	+	0.03	0.07	JRC/WorldBank (2000)
SUS_08: Population numbers (people per grid square)	100 m	+	0.03	0.04	WorldPop (2010)
SUS_09: Rural extent/areas (yes/no)	Polygon layer	+	0.08	0.04	CAM GIS (2008)
C2A_01: Illiteracy: no/low education (%)	Point layer	+	0.09	0.03	Census (2008)
C2A_02: Distance to schools (cost path)	Point layer	+	0.05	0.03	Pacific Disaster Center (2009)
C2A_03: Household has no radio/TV (%)	Point layer	+	0.04	0.04	DHS (2010)
C2C_01: Distance to hospitals/health centres (cost path)	Point layer	+	0.11	0.02	Pacific Disaster Center (2011)
C2C_04: Household has no car/truck (%)	Point layer	+	0.04	0.02	DHS (2010)
C2R_01: Wealth Index: poorest, poor (%)	Point layer	+	0.10	0.07	DHS (2010)

[a] SUS = susceptibility, C2A = Lack of capacity to anticipate, C2C = Lack of capacity to cope, C2R = Lack of capacity to recover; C2A, C2C and C2R are sub-domains of lack of resilience (LoR).

[b] Spatial resolution before the data was resampled to 2 × 2 km^2 grids.

[c] Sign indicates if high indicator values increase (+) or decrease (−) vulnerability.

[d] Weights and signs were obtained based on expert knowledge ($n = 5$ experts).

$$SVI = \sum_{i=1}^{n} (w_i * v_i') \tag{4}$$

where w_i refers to the AHP weight. Thereby, two different units of analysis were used, i.e. 2 × 2 km^2 grids and sub-national administrative boundaries. Continuous grids were used to reveal the highest possible degree of spatial variability of social vulnerability in the study area (Fig. 4). Since grids are of little use for policy makers, and the CMAA targets its interventions at both sub-district and village level, the results were aggregated for the 96 sub-districts of Battambang province (Fig. 5) by taking the mean of the SVI scores. As the aggregation process removes the variability within each sub-district, variability of social vulnerability was mapped for each commune using the standard deviation of the SVI and its domains (Fig. 6).

2.6. Mapping hot spots of social vulnerability

The Getis-Ord GI statistic [69,70] was used to identify both cold and hot spots of social vulnerability in Battambang province. Using the sub-district level SVI scores as an input, the method highlights statistically significant spatial clusters of high (i.e., hot spots) and low vulnerability index scores (i.e., cold spots) for the 90% (p-value < 0.1), 95% (p-value < 0.05) and 99% (p-value < 0.01) confidence level. The method was applied since high index scores

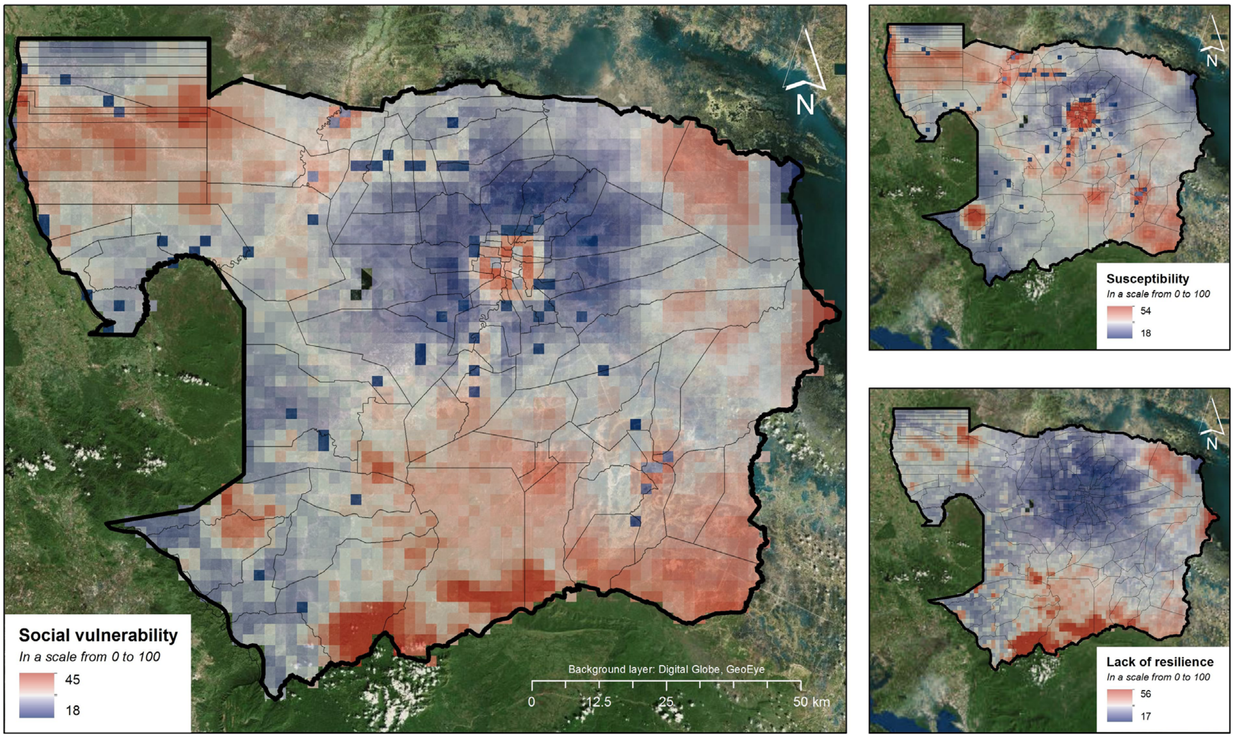

Fig. 4. Social vulnerability (left) and its two domains (right) in the context of landmines and ERW using 2 × 2 km^2 grids as the reporting unit.

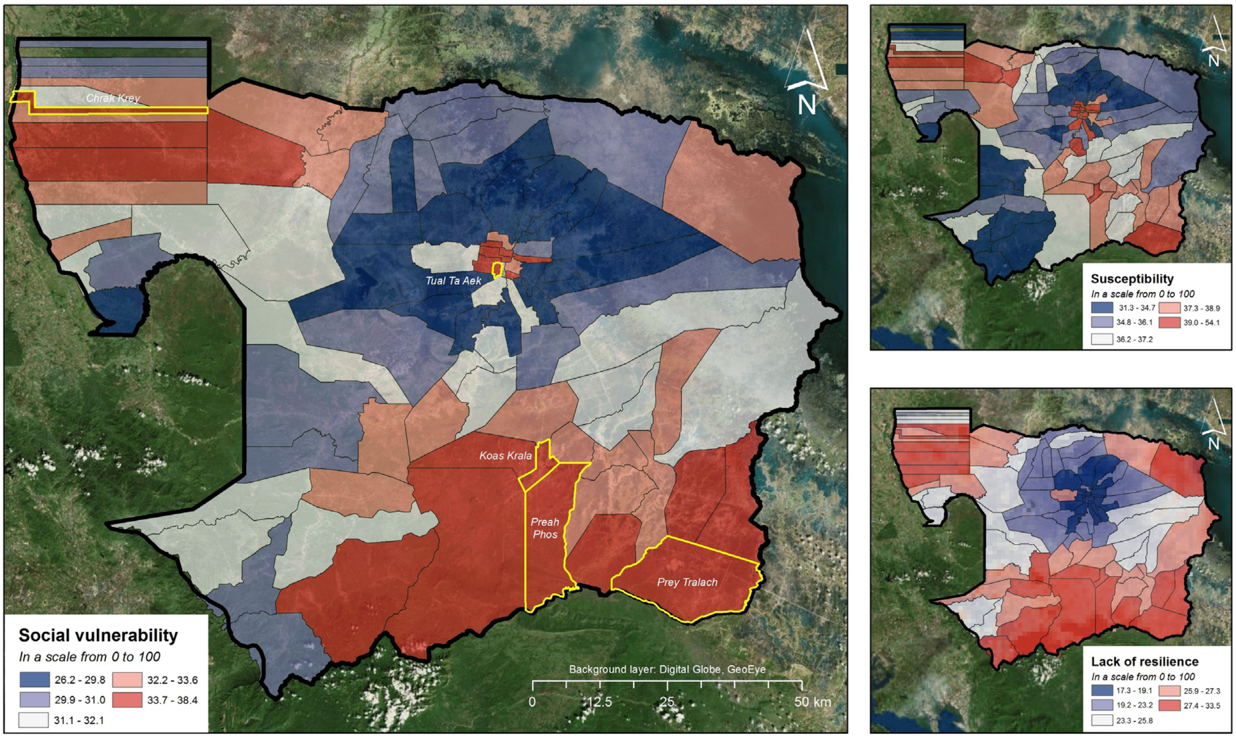

Fig. 5. Social vulnerability (left) and its two domains (right) in the context of landmines and ERW using communes as the reporting unit (classification using quantiles).

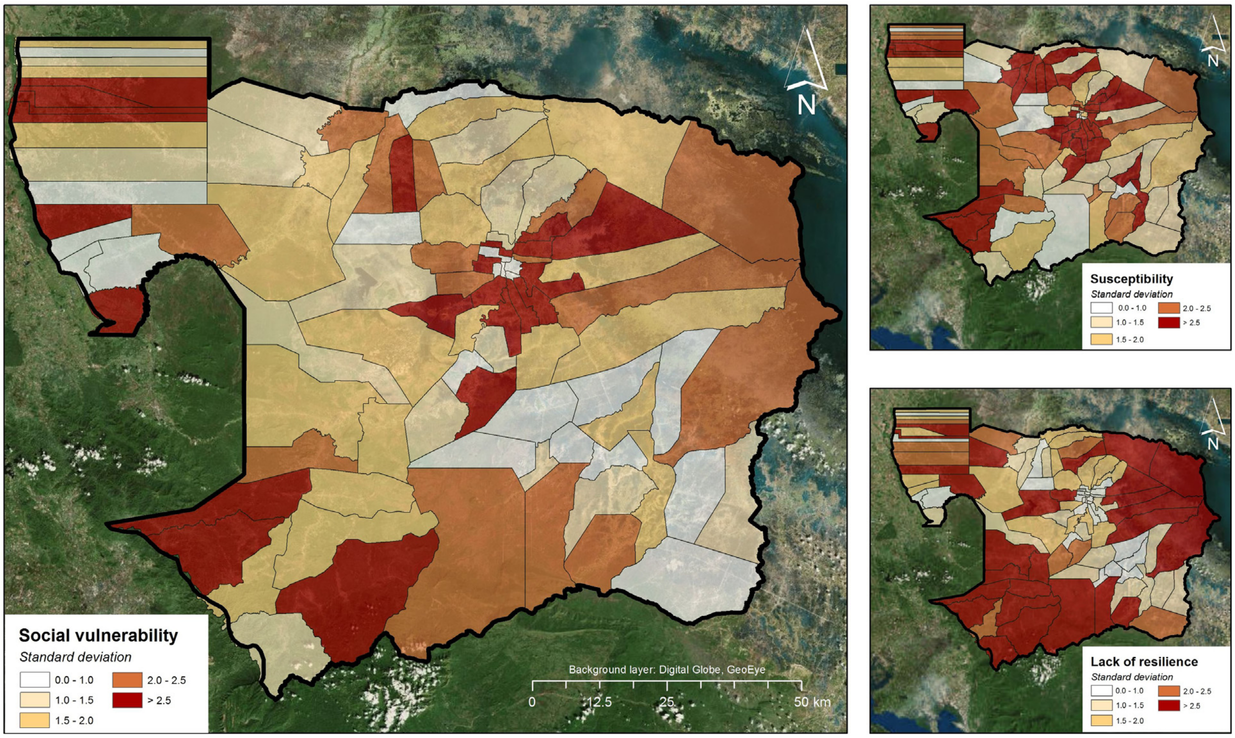

Fig. 6. Variability of social vulnerability (left) and its two domains (right) within the communes as measured by the standard deviation. High standard deviation reflects high internal variability within the respective commune.

might be interesting, but do not necessarily represent a statistically significant hot spot. Most spatial vulnerability assessments so far, however, simply use a specific threshold (e.g. $VI > 0.75$, in a scale from 0 to 1) or the “red areas in a map” to determine vulnerability hot spots [66,71], which might result in misleading policy messages. The resulting hot/cold spot map (Fig. 7) shows hot and cold spots based on the 90% confidence level.

3. Results

3.1. Vulnerability indicators and weights

Table 3 presents the final set of social vulnerability indicators, their spatial resolution (before data was resampled to $2 \times 2\ \text{km}^2$ grids), their respective signs, data sources and weights. The table

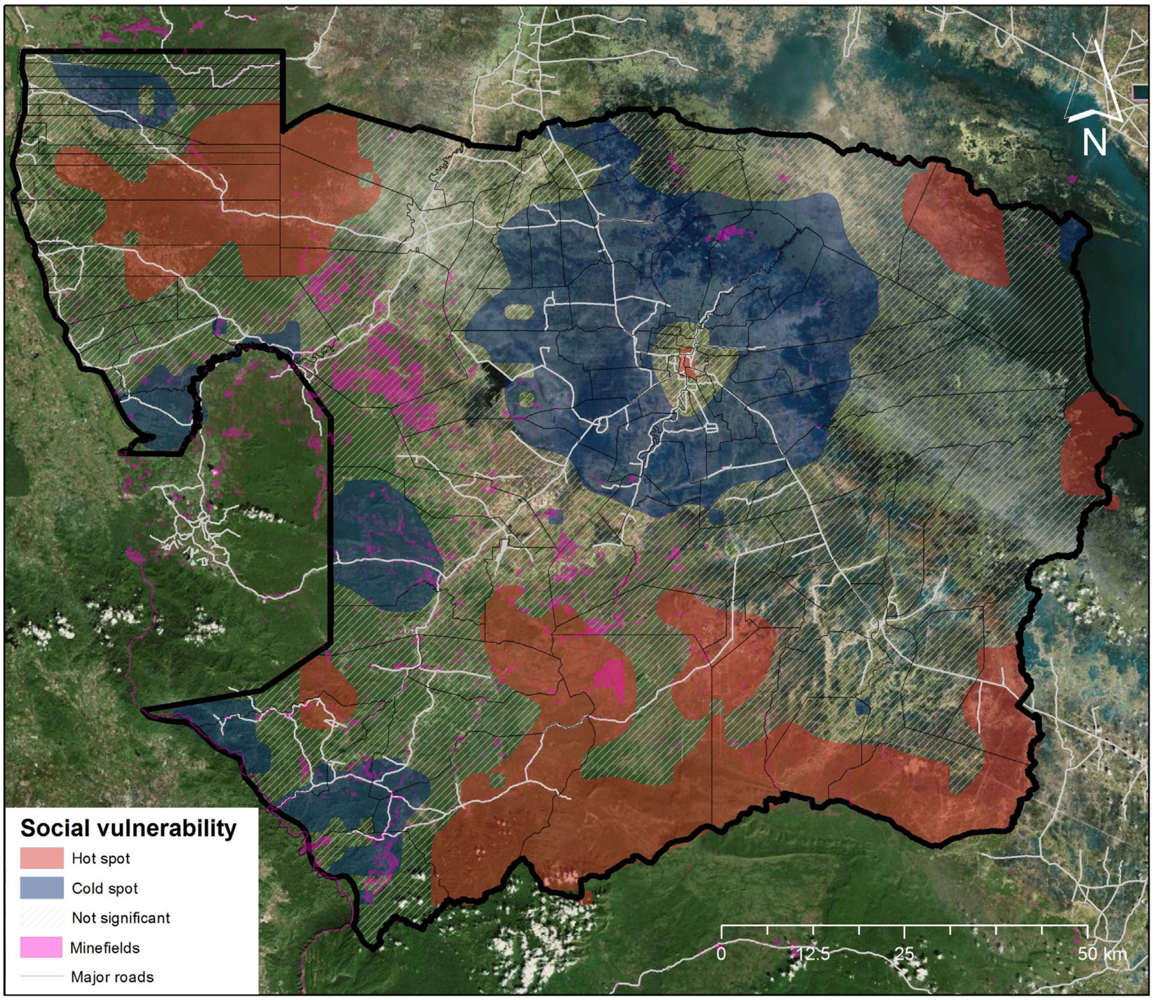

Fig. 7. Hot spots of social vulnerability in Battambang province.

clearly shows that not all indicators were considered to be of equal importance for social vulnerability in the context of landmines and ERW. Five indicators were identified to be particularly important by the experts: (1) *household uses firewood for cooking (%)*, (2) *distance to hospitals and health centres*, (3) *occupation in the primary sector (%)*, (4) *poverty*, as measured by the Wealth Index, and (5) *conflict density (km^2)*. Further, *illiteracy (%)* and *living in a rural area* were also considered to be highly relevant to social vulnerability. Next to the actual weight, the standard deviation (std) of the weights is also presented for each indicator, indicating the degree of consent/dissent among the stakeholders who participated in the workshop. Overall, a high degree of consensus regarding indicator weights was observed, however, there was slight disagreement regarding the relevance of *conflict density* (km^2), *travel time to the closest urban center (mins)*, and the *Wealth Index (%)* for social vulnerability in the study area.

3.2. Social vulnerability to landmines and ERW

Fig. 4 shows the SVI, as well as its two domains (susceptibility, lack of resilience), calculated for Battambang province based on 2×2 km^2 grids as the unit of analysis (administrative boundaries representing communes are shown for reference). Grid cells of high levels of social vulnerability are visualised in shades of red, while low levels of social vulnerability are displayed in shades of blue. Relatively high levels of social vulnerability are found in the central, north-western, north-eastern and southern part of the province. Also it becomes obvious that the entire study area reveals at minimum low levels of social vulnerability, with lowest vulnerability scores of 18 (in a scale from zero to 100). The three maps clearly show that high social vulnerability does not necessarily imply that both vulnerability domains are high. For example, despite its low lack of resilience (LoR), social vulnerability in the central part of the study area is quite high, due to high levels of susceptibility (SUS).

Since the CMAA and the Cambodian Mine Action Centre (CMAC) spatially target their interventions either at the village or commune level, the gridded maps were also aggregated at the commune level (Fig. 5). The five communes with the highest vulnerability score are Tuol Ta Aek (score of 38) in Battambang district, which presents a high susceptibility (54) and a medium lack of resilience (17), followed by Prey Talach (VU: 36; SUS: 40; LoR: 31) in Moung Russei district, Koas Krala (VU: 36; SUS: 41; LoR: 28) and Phrea Phos (VU: 35; SUS: 37; LoR: 32) in Koas Kala district, and Chak Krey (VU: 35; SUS: 40; LoR: 29) in Sampov Loun district (highlighted in yellow in the map).

Due to the generalisation process which removes the variability within the communes, the maps in Fig. 5 depict a smoothed scenario. However, the spatial patterns shown in Fig. 4 are still discernible. For the planning of targeted interventions aiming at reducing susceptibility and strengthening resilience it is, however, important to provide decision makers with information on the variability of vulnerability within a commune. Fig. 6 shows the variability in social vulnerability within the communes as

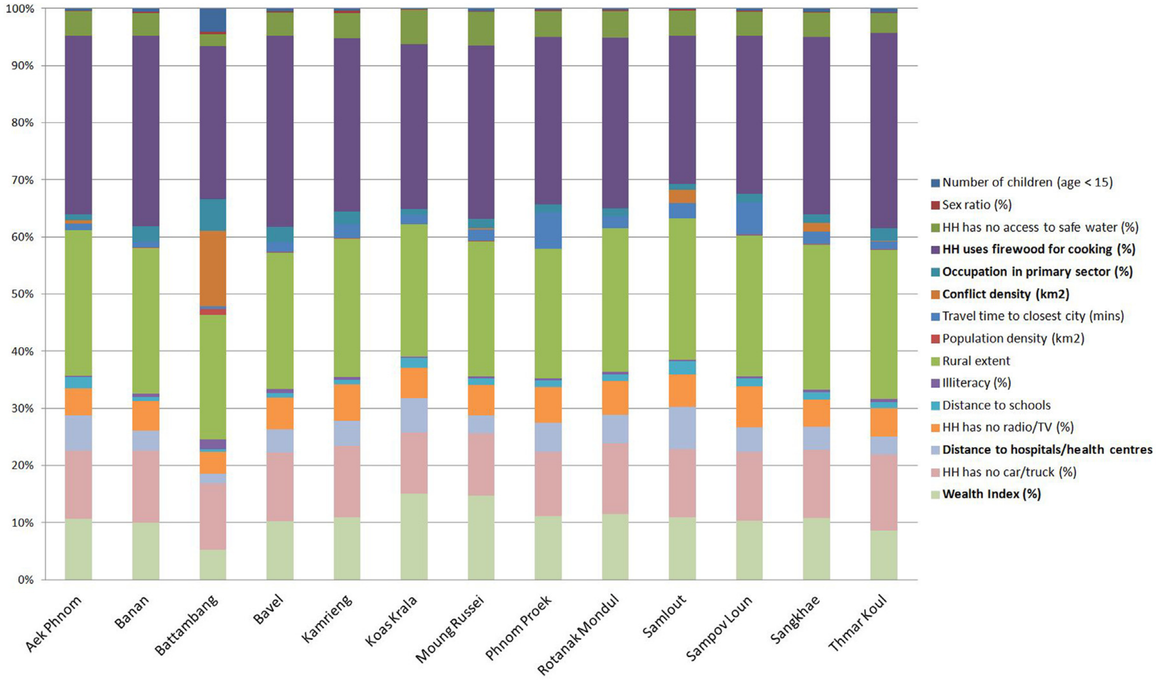

Fig. 8. Contribution of the single indicators to the SVI for the different districts of Battambang province. Indicators highlighted in bold were identified as key indicators by the experts.

measured by the standard deviation. Thereby, high standard deviation reflects high variability within the commune, and thus areas where interventions have to be spatially targeted within the commune addressing local idiosyncrasies observed in vulnerability and its underlying factors.

As indicated earlier, areas of high vulnerability do not necessarily represent statistically significant hot spots. Therefore, Fig. 7 shows the outcome of the vulnerability hot spot mapping that was carried out using the $2 \times 2\ \text{km}^2$ grids as an input. The overall spatial pattern remains the same, with significant hot spots observed in the central, north-western, north-eastern, and southern part of the study areas, indicating areas where interventions are most urgently needed to reduce prevailing vulnerabilities of the population.

3.3. Contributions of underlying factors to social vulnerability in the districts

To provide decision makers and practitioners with a better idea of the underlying factors contributing to social vulnerability in Battambang province, the contribution of each (weighted) indicator to the SVI was evaluated for each district (Fig. 8) following Hagenlocher and Castro [32]. The graph clearly shows that four indicators contribute most to prevailing levels of vulnerability across all districts: (1) *household uses firewood for cooking*, (2) *rural extent*, (3) *household has no car/truck*, and (4) *poverty*. For Battambang district, *conflict density* is another crucial factor contributing to high levels of social vulnerability, which is less relevant for the remaining districts. This pattern is a result of the fact that, according to the initial data source (i.e. the Armed Conflict & Location Event Data Project – ACLED; http://www.acleddata.com), eight out of 17 armed conflicts (i.e. almost 50%) which were reported for Battambang province occurred in Battambang district. This has crucial policy implications, since these factors need to be addressed foremost to effectively reduce social vulnerability to landmines in the different districts.

4. Discussion

The use of spatial approaches in humanitarian crises or disaster risk reduction is not new. The capabilities of Geographic Information Systems (GIS) in the context of humanitarian action have recently been highlighted by Kaiser et al. [72], and several studies have utilised GIS in the context of mine action. For example, Andersson and Mitchell [73] used GIS to produce population-weighted maps to support the evaluation of mine risk education (MRE) in Afghanistan. Benini et al. [74] discuss the benefits of GIS for the integration of multiple datasets to support decision making processes in mine action. With the aim to support decision-making in the context of mine action and ERW, Riese et al. [75] present a GIS-based approach to forecast the presents of ERW. Lacroix et al. [76] explored the utility of different cartographic representations in a GIS for the visualisation of ERW to support mine action decision making in Afghanistan, and more recently a first attempt to map vulnerable areas in the context of landmines has been made by Alegria et al. [77]). They used a GIS to assess the spatial distribution of landmines (i.e. the hazard), and linked it with population data and transportation infrastructure to identify vulnerable areas. However, they also highlighted the limitations of their approach and that further research considering the role of social and economic factors is needed. Our study complements these efforts by transferring the concept of vulnerability, which is considered a key concept in both DRR and CCA, to mine action and proposing a spatial explicit approach for mapping it using GIS.

Based on existing theories and concepts, a risk and vulnerability framework has been proposed to guide the assessment of social vulnerability as well as the identification of targeted, comprehensive DRR measures in the context of landmines and ERW. Guided by the framework, we used a quantitative, spatial-explicit approach to assess social vulnerability in one of the most heavily mine-affected provinces in Cambodia. As for every vulnerability assessment, a crucial step was the selection of appropriate indicators. Here, we followed a multi-stage approach, which included a review of available literature, a focus group discussion with experts of the TIRAMISU project during a dedicated vulnerability workshop, and the consultation of Cambodian mine action experts during a two-day stakeholder workshop in Battambang, Cambodia. Following this approach, and after accounting for multicollinearities in the data, we were able to identify a set of 16 socioeconomic, demographic and distance-related indicators that best represent social vulnerability to landmines/ERW in the study area. Indicator weights, reflecting both the validity and relevance of single indicators for overall social vulnerability in the study area, were obtained from a participatory approach using the AHP method during the stakeholder workshop in Cambodia. Although more complex, the method overcomes the limitations of other participatory weighting methods by providing information on the consistency of the experts' judgements. It turned out that enough time needs to be scheduled for performing such a weighting exercise with local experts, and that a common understanding of all indicators is a prerequisite to obtain reliable indicator weights.

This study naturally has some limitations. Data availability, for example, is a general limitation for most, if not all, spatial vulnerability assessments. Although the indicators and datasets used in this study are considered as the most relevant ones by the CMAA experts, several possibly relevant indicators were excluded from the assessment due to a lack of geospatial datasets. This includes spatial data on *scrap metal collection, migration* and/or *mobility, corruption, available budget and support of authorities for local communities regarding mine action, level of mine risk education,* or *availability of mine victim assistance programmes*. Another limiting factor is that the datasets used in this study stem from different sources and years, and that they are available at different and rather coarse spatial resolutions, which is why 2×2 km^2 grids and sub-district administrative boundaries were chosen as the unit of analysis. Such a resolution, although being fine enough to capture the spatial variability of social vulnerability in the study area, does not enable any inferences on finer scales (e.g. village level), which might be preferred by sub-national stakeholders, such as the MAPUs. Although the reliability of the data and their sources was carefully checked, a degree of uncertainty regarding the quality of the data (e.g. completeness, correctness) cannot be fully avoided. Another issue is that each dataset, and thus ultimately the vulnerability assessment, represents only a snapshot in time, which does not account for the dynamic nature of vulnerability. Frequent updates and a systematic monitoring of changing socioeconomic and demographic conditions are hence required for the assessment of possible changes in social vulnerability in the study area. Finally, using a participatory approach to indicator selection and weighting, by design the resulting SVI scores are partly driven by expert choice. Although expert-based approaches are quite common in vulnerability assessments, another limitation could be that only nine experts participated in the AHP-based weighting exercise. Involving more experts and representatives from affected communities could lend more weight to the outcomes of such an exercise. Given the existing divide between the perception of risk by professional mine action organisations, affected communities and village deminers, the involvement of representatives from affected communities seems crucial [3]. However, given the seniority, professional background and experience of the participants regarding mine action in Cambodia in general and the idiosyncrasies in Battambang province in particular, this issue is seen as less critical here. Nonetheless, more efforts should be devoted to including the views and perceptions of affected communities directly into such quantitative assessments and mine action decision making processes in general.

Since the presented method relies on a set of indicators that were confirmed to be valid by local domain experts and that were analysed in an integrated manner, the mentioned limitations could be mostly overcome. The proposed concept and method show a high degree of transferability, both to other regions and different spatial scales. The success of any transfer, however, again largely depends on data availability. Since this study is based solely on publically available data obtained from global and/or national data repositories, this might also be less of a limitation. Spatially explicit information on prevailing levels of social vulnerability of people living in mine affected regions was considered of high or even very high relevance for improved mine action by the CMAA experts, who also expressed their high interest in the future integration of the results in their mine action activities. Such information cannot only contribute to the prioritisation of demining efforts, but also help decision makers identify priority areas for mine risk education and the implementation of development activities and projects. Thus, the integration of social vulnerability in both mine action and broader development agendas seems to be highly relevant to reduce the risk of landmines and ERW in post-conflict settings. Further research is also needed regarding the integration of the physical hazard of landmines/ERW with the outcomes of such vulnerability analyses into spatially explicit risk assessments, and how such analysis can support the evaluation of adaptation options in addition to identifying priority-areas for demining.

5. Conclusions

What does it mean to people to be 'secure' after a conflict ended? They naturally want a future that is prosperous, free from fear and hunger, and opportunity-rich. To provide the conditions for stable livelihoods after shocks and disruptions is an essential pre-requisite for sustainable development to (re-)start – in terms of e.g. social security, economic activities, healthcare, and education. However, migration, displacement and the existence of landmines and ERW are long-term impacts of armed conflicts which are interlinked and cannot be removed through short-term measures. Current security strategies do not consider adequately the interdependence between conflict legacy, social vulnerability and development options. Hence, a paradigm shift towards understanding and considering the underlying vulnerabilities of people living in mine/ERW affected areas is needed. Only recently the notion of 'resilience' starts to occupy a more central role in the preparation of a new European Security Strategy ESS [78]. The authors note that resilient societies that have been built in ways and means to absorb, recover and learn from shocks will manage their responses far more effectively than ill prepared and more fragile communities. Post-conflict reconstruction cannot only mean the re-establishment of infrastructure, but needs to concern local livelihoods including the protection from harm. The presented methodology – with future evolution – provides the means not only to assess but also monitor progress (or limitations) of measures to strengthen the resilience of communities exposed to post-conflict impacts such as landmines, while highlighting – once again – the benefits of integrated spatial analysis for disaster risk reduction.

Acknowledgements

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007–2013) under Grant no. 284747 TIRAMISU (http://www.fp7-tiramisu.eu/) when the lead author was still with the University of Salzburg's Department of Geoinformatics (Z_GIS). The authors would like to thank Pablo Cabrera-Barona (Z_GIS) and Raphael Spiekermann (Z_GIS) for their valuable comments and feedback regarding the AHP method, and Barbara Friedl (Z_GIS) for her support in the early stage of this research. Further, we would like to thank the two anonymous reviewers for their valuable feedback on a previous version of the manuscript.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ijdrr.2015.11.003.

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