Measuring Community Vulnerability to Environmental Hazards: A Method for Combining Quantitative and Qualitative Data

Bayes Ahmed [1], Ilan Kelman [2,*]

Abstract: This article has developed and implemented a method for incorporating and combining quantitative and qualitative data in measuring community vulnerability to environmental hazards. To illustrate the method in practice, a case study of landslides in Chittagong City Corporation (CCC), Bangladesh is used. Quantitative information from household-level questionnaires is combined with qualitative maps and diagrams from participatory rural appraisal (PRA) surveying. Seven different PRA tools were implemented: social and resource mapping, transect mapping, vulnerability and dream mapping, mobility mapping, Venn diagrams, pair-wise ranking, and strengths, weaknesses, opportunities, and threats (SWOT) analysis. A convergent parallel design and weighted average decision support method is applied, covering community vulnerability indicators for physical, social, economic, ecological, institutional, and cultural aspects. The overall vulnerability on a scale of 0-1 of Motijharna, Batali Hill, and Golpahar communities in CCC is calculated respectively as 0.75, 0.68, and 0.56.

[1] UCL Institute for Risk and Disaster Reduction and UCL Humanitarian Institute, University College London (UCL), Gower Street, London WC1E 6BT, UK; bayesahmed@gmail.com and bayes.ahmed@ucl.ac.uk

[2] * Corresponding author, UCL Institute for Risk and Disaster Reduction (IRDR) and UCL Institute for Global Health (IGH), University College London (UCL), London WC1E 6BT, UK and University of Agder, Kristiansand, Norway; ilan_kelman@hotmail.com

Keywords: Bangladesh, disaster risk reduction, landslides, participatory rural appraisal, vulnerability

Introduction

Around 1,388 disasters involving environmental hazards were reported worldwide from 2013-2016 and around 45% of all those disasters occurred in Asia (CRED 2017). Landslides occur frequently in South Asia due to rainfall (Glade et al. 2005). From 2004-2010, a total of 2,620 non-seismic and fatal landslides were recorded worldwide causing at least 32,322 deaths, with the majority of human losses occurring in Asia, especially along the Himalayan Arc (Petley 2012).

In Bangladesh, at least 22,500 people were reported as being killed and 130 million people were reported as being affected by disasters from 1995-2014 (CRED 2017). At present, Bangladesh is ranked as the world's fifth most disaster-prone country (World Risk Report 2016; CRED 2017). Historically, flooding, tropical cyclones, storm surges, and drought were the most common hazard recorded in Bangladesh. The recent trend of unplanned urbanization in the hills (covering approximately 10% of Bangladesh's total land area) and the adverse impacts of landslides on hilly communities may indicate an escalation of landslide difficulties in Bangladesh, as shown by Ahmed and Dewan (2017).

For example, a landslide on 30 May 1990 killed 11 people in the Chittagong Hill Districts (CHD), followed by 17 fatalities on 13 August 1999, 31 fatalities on 5 May 2003, 128 fatalities on 11 June 2007, and 47 fatalities on 15 June 2010. More recently, on 13 June 2017, about 162 people died and hundreds were injured in different hills of CHD because of rainfall-triggered landslides while a similar scenario emerged on 26 June 2012 when 90 people died and 150 were injured in Chittagong City Corporation (CCC) in Bangladesh (Ahmed 2017). Rapid urbanization, extreme population pressure, improper land use planning, illegal hill cutting for settlements, and indiscriminate deforestation are aggravating landslides in CCC (Ahmed 2015; Ahmed and Dewan 2017).

This article aims to measure community vulnerability to environmental hazards by developing and applying a novel method which considers all the various dimensions of vulnerability, especially through combining quantitative and qualitative approaches. The originality and major contribution of this article lies in developing, applying, and critiquing this innovative method for incorporating and combining quantitative and qualitative data. The proposed method reflects an approach in assessing community vulnerability that overcomes limitations in previous literature. To apply, validate, and critique the proposed method, landslides are taken as the environmental hazard to be investigated and CCC in Bangladesh is selected as the case study area.

Theoretical background

In this article, “landslide” refers to a mass movement of soil (earth) down a slope. Although landslides are hazards trigged by a variety of environmental phenomena including rainfall and earthquakes, human activity increases the probability of landslide occurrence and can trigger landslides irrespective of other environmental phenomena. Vulnerability is “The characteristics and circumstances of a community that make it susceptible to the damaging effects of a hazard” (UNISDR 2017, online) as well as the social and political processes permitting such a situation to be created and perpetuated (Hewitt 1983; Lewis 1999; Wisner et al. 2004).

Disaster risk is a combination of hazard and vulnerability, so the disaster arises from not just the landslide hazard but also from the vulnerability to the hazard (O’Keefe et al. 1976; Hewitt 1983; Lewis 1999; Wisner et al. 2004). To reduce landslide disaster risk, a complete understanding is required of the various components of vulnerability, defining the primary motivation for this research. The physical, social, economic, cultural, environmental, and institutional dimensions of vulnerability to landslides must be considered in assessing it (Alexander 2004; Glade 2003; Glade et al. 2005).

Traditionally, research relating to disasters involving environmental hazards has focused on physical aspects. Since at least the 1940s, it has been recognized that concentrating on only physical components of risks and associated mitigation strategies is insufficient to reduce disaster impacts (White 1942). To understand the components of a disaster, it is important to study both hazards and vulnerability along with their interactions (Quarantelli 1998; Alexander 2000; Lewis 1999; Wisner et al. 2004). Various perspectives on vulnerability exist, such as some social scientists preferring to avoid the terms “natural disaster”, “natural risk”, and even “natural hazard” while some engineering and natural science perspectives relate vulnerability to the susceptibility of elements at risk focusing on built structures. The latter approaches sometimes emphasize technological perspectives while the former require a significant social component (e.g., cultural make-up of a society and risk perception) (Alexander 2000).

Based on social aspects of vulnerability, the pressure and release (PAR) model was proposed, starting in the 1980s. The basis for the PAR model is that a disaster occurs because of two elements: the progression of vulnerability and the occurrence of a hazard (Wisner et al. 2004). The PAR model argues that disasters are not natural, but are rather the product of social and political forces, including economics. In PAR, explicit attention is given to root causes, drawing on the standard baseline that risk is the intersection of hazard and vulnerability. These concepts led to quantification and indices such as the Social Vulnerability Index (SoVI) from, for example, Cutter et al. (2003) while being cognizant of the critiques and improvements (e.g. Beccari 2016; Holand and Lujala 2013). This article is based on these fundamental concepts of vulnerability and scales for it.

Vulnerability scales operate at international, regional, national, local, community, and individual levels. However, measuring vulnerability at a community scale is challenging considering the dynamics and differences within local populations, difficulties in index construction, sensitivity of quantitative features, and constraints in data collection alongside datasets with varying units and types (Chakraborty et al. 2005; Tate 2012). Multi-scalar, multi-dataset, and multi-method approaches are rarely enacted despite the need for them in order to develop broad and deep vulnerability assessments. In the absence of a universal approach for measuring or assessing community vulnerability, some researchers have applied quantitative methods while others have used qualitative methods (e.g. Bankoff et al. 2004; Naudé et al. 2012).

For example, at global, national, and sub-national scales, index approaches for measuring vulnerability are primarily dominated by analyzing quantitative datasets (Krishnamurthy et al. 2014; Gerlitz et al. 2017). Conversely, for local scale vulnerability assessment, a tendency is seen to develop a community-based vulnerability index by applying a scaling and weighting method, and bottom-up approaches, along with questionnaires and surveys (Cutter et al. 2003; Pandey and Jha 2012; Yadav and Barve 2017). Eidsvig *et al.* (2014) presented a model using an indicator-based approach to assess the relative socio-economic vulnerability to landslides in Europe, ranging from local to regional scales. Yoon (2012) developed an indicator aggregation method for assessing social vulnerability to natural hazards considering both inductive and deductive approaches. Other quantitative methods for assessing vulnerability use geographic information systems (GIS) and remote sensing (RS) techniques (Ebert et al. 2009) or multi-criteria analysis (Martins et al. 2012; Walker et al. 2014). For qualitative data extraction, community-based participatory rural appraisal (PRA) tools (Chambers 1994) are increasingly applied. Antwi et al. (2015) applied community asset mapping, focus group discussions and transect walks at the community scale to assess vulnerability to flooding.

Thus, by analyzing a wide range of literature on vulnerability assessment, the following limitations are identified:

- Numerous disaster risk reduction (DRR) frameworks, methods, and theories are available for assessing vulnerability. In many cases, proper guidelines to apply those methods in solving real-world problems for directly reducing disaster risk are missing.
- Most research is based on secondary data following the inductive approach and tends to be most applicable for national scale. Since it requires primary data collection through field surveying and is time consuming and costly, research on community vulnerability is not always completed. Data constraints at the community scale are a major challenge for any context.
- Most research is based on quantitative datasets collected from various organizations. Consequently it does not necessarily represent the complete scenario or community views while not fully capturing all the dimensions of vulnerability at the community scale, especially when relying on only GIS, RS, and modelling techniques.
- Vulnerability assessment methods can lack sufficient data leading to the selection of inappropriate indicators, whereas fieldwork and surveying activities are more reliable for primary data collection and context validation.

Consequently, vulnerability assessment research has become enormously challenging, considering the multifaceted dimensions of vulnerability, spatial strata, temporal dynamics, absence of a universal definition and assessment methodology, challenges in indicator selection, weighting and aggregation, constraints in incorporating local contexts and cultures, and applying theory in practice.

Overall, neither quantitative data only nor qualitative data only could capture all the dimensions of community vulnerability to environmental hazards. To overcome such challenges, a method for combining quantitative and qualitative datasets is proposed in this study. The empirical example of CCC, Bangladesh is used to test and justify this method's applicability. The proposed method here is original and innovative; can generate accurate, in-depth, and comparable results; covers all vulnerability dimensions; is based on primary data collected from fieldwork; is valid in real-world DRR; and is replicable for different local contexts. Consequently, it contributes to overcoming the challenges of assessing vulnerability to environmental hazards which are mentioned above. The proposed method has undertaken a standard index based method, yet the integration of qualitative data is unique as it has never been attempted before in landslide vulnerability assessment at a community scale.

Methodology

Case study

Chittagong City Corporation (CCC), part of the southeastern Chittagong hill districts (Fig. 1a), is located in Chittagong district, Bangladesh (Fig. 1b). The Bay of Bengal is located to the west and the Karnafuli River is located to the east of CCC (Fig. 1b). The average annual rainfall of Chittagong is approximately 2917 mm. On average each year, it rains ≥ 50 mm for 18 days and ≥ 20 mm for 41 days; and the city expects about 15 days of consecutive rainfall during a monsoon (Ahmed and Dewan 2017). The population of CCC increased by 152% over the past three decades (1.02 million to 2.58 million from 1981 to 2011) in an area of 155 km^2 (BBS 2014). This population increase creates immense pressure on the city's urban morphology. In recent years, people have started to cut into the hills to meet the growing housing demand. As a result, the urban built-up area of CCC has increased four-fold over the past 25 years (1990-2015) and hill forest is disappearing (Ahmed and Dewan 2017).

To begin with, the past records of landslides were analyzed in order to select the case study areas or communities within CCC. After consultation with local landslide experts in public organizations, academics, and professionals, the study areas were finalized. Three highly landslide-affected communities locally known as Motijharna, Batali Hill, and Golpahar were selected for the community vulnerability assessment carried out here. These communities are relabeled as CCC_1, CCC_2, and CCC_3 respectively.

After selecting the communities, household-level questionnaires and community-based PRA surveying were conducted. The research ethics committee of the authors' principal institution formally reviewed and approved the surveying method and research work plan (Ethics project ID number: 5373/001). In Bangladesh, necessary household-level datasets are not available, so the questionnaire and PRA surveying collected household and community information needed for the vulnerability assessment. A total of 248, 142, and

114 households in the three respective communities (CCC_1, CCC_2, and CCC_3) were surveyed using a stratified random sampling method. The sampling method ensured the principles of reliability, validity, and standardization (Bryman 2016).

There is no specific rule or pattern for selecting population and sample size for conducting social research, either quantitative or qualitative. Sampling primarily depends on the research aim, achieving theoretical saturation, available time, and surveying cost (Bryman 2016). In this study, around 20-40% of households within each community were covered by the questionnaires. Houses located near steeper slopes or in areas otherwise vulnerable to landslides were selected based on field observations. A structured questionnaire was developed, piloted, and then used for collecting household information on community vulnerability to landslides covering physical, socio-economic, experiential, and DRR aspects.

Questionnaire indicator selection

Parameters representing community vulnerability were considered for household questionnaires and PRA surveying. The selection of indicators was based on achieving the research aim and analyzing the past literature as cited above, followed by an iterative process during the fieldwork and expert opinion surveying, using local knowledge to emphasize the most important indicators. A complete justification for selecting the 28 indicators from the questionnaires is described in Table 1.

As one example, the average monthly income of the surveyed households was classified into five groups: <5000, 5000–10000, 10001–15000, 15001–25000, and >25000 BDT (BDT is the Bangladeshi Taka, with the exchange rate being approximately 78.45 BDT = 1 USD, i.e. American dollar, on 12 July 2016). The general assumption from the literature, as cited above and according to local views, is that a household with less monthly income is economically more vulnerable to landslides. As well, marginalized people around CCC are often forced to live in hazard-prone locations, such as on slopes, where accommodation is cheaper (BUET-JIDPUS 2015). It means a household earning 5,000 BDT is more vulnerable to landslides than a household earning 20,000 BDT. As a result, the indicator ‘Monthly income < 10,000 BDT’ is selected. A higher vulnerability score is assigned for a household earning 5,000 BDT and a lower score is assigned for a household earning 10,000 BDT. The scores were later scaled to 0–1 to avoid negative values. In this way, the indicators that solely contribute to increasing landslide vulnerability (positive aspects) at a community scale were chosen for this research, thereby helping to minimize the uncertainties associated with index-based vulnerability assessment approaches.

PRA methods and indicators

Seven different PRA tools were implemented to cover a wide range of data sources while minimizing overlap: social and resource mapping, transect mapping, vulnerability and dream mapping, mobility mapping, Venn diagram, pair-wise ranking, and strengths, weaknesses, opportunities, and threats (SWOT) analysis. These PRA tools collect specific and qualitative information that a quantitative questionnaire could not collect. The PRA surveying was conducted after questionnaires and people interested in further discussions about landslides were invited to focus groups. The participants were local adults (men and women) and the discussions took place in a suitable place in each community, such as near a market place or in open public space, from July–September 2014.

These PRA techniques are important for collecting qualitative data for assessing community vulnerability (Chambers 1994; Kumar 2002; Antwi et al. 2015). Social and resource maps are used to depict the nature of housing, social infrastructure, and natural resources. Vulnerability maps depict the location of landslide vulnerable areas. Dream maps are about the future, depicting people's aspirations for landslide DRR. Transect mapping provides a cross-sectional representation of resources (Kumar 2002). Venn diagrams analyze the various institutions and individuals, and their influence and interaction on the local people. Mobility maps are used to understand the movement patterns of local people (i.e. frequency of visits, distances, modes of transport, preferences, and accessibility). Pair-wise ranking identifies the problems within each community relative to each other (Kumar 2002). SWOT analyses help in understanding the various components of hazards, vulnerabilities, and DRR that can impact a community. The justification for selecting the seven PRA tools is further described in Table 2, from which additionally, 19 indicators were generated (Table S1).

Indicators related to physical components of vulnerability such as density of houses, number of community services, existing road networks, and level of various activities within the community have been measured from the social and resource maps. For instance, Motijharna (Fig. S1a) has more road networks, community facilities, and households on or near dangerous slopes than Golpahar (Fig. S1b). Moreover, areas vulnerable to landslides, risk perception, and landslide disaster preparedness within communities are evaluated using the vulnerability and dream maps (Fig. S2 and Fig. S3). Findings suggest that Motijharna community (Fig. S2a) is physically more vulnerable than Golpahar (Fig. S2b), because a higher score occurs for Motijharna community for the indicator 'areas vulnerable to landslide hazards'. In Motijharna, for dream mapping, people suggested installing more water points, building a retention wall by the side of the hills, constructing the houses in an orderly manner, and restricting the development of houses on the slopes and down the hills (Fig. S3a). Considering the soil quality and geomorphological aspects, it might be difficult to construct a retaining wall in Motijharna (BUET-JIDPUS 2015). It can even trigger landslides during the monsoon by causing structural failure. In contrast, in Golpahar, the people are simply focusing on planned households in safer locations (Fig. S3b). Consequently, Golpahar's risk perception is higher and they receive lower score values (a lower indicator score value means that vulnerability is lower) for this indicator extracted from dream maps. The justification for selecting and scoring other PRA indicators are described in the Supplemental Material.

Vulnerability index calculation

A convergent parallel design was chosen to address the shortcomings in existing literature, as discussed above. This particular design simultaneously collects the quantitative and qualitative data and gives equal priority and weighting to the datasets while capitalizing on the strengths of each, so that the resulting analysis is compared or merged to form an integrated whole (Bryman 2016). This study combines the qualitative data from the PRA survey and the quantitative data from the household questionnaires—and hence is mixed methods research for measuring vulnerability at community scale.

A weight-based method ranks the relative vulnerability of each indicator using a scale to permit comparison. Here, the scale is chosen as 0–1, where 0 corresponds to the lowest vulnerability and 1 to the highest vulnerability. Three methods are typically used to assign weights to indicators: (1) equal weight, (2) expert opinion, and (3) statistical approaches such as principal component analysis or analytic hierarchy process (Tate 2012). Applying equal weighting is entirely arbitrary, with little justification or understanding of the relationship between indicators and the local context. It is also inaccurate because indicators do not equally affect vulnerability. Statistical approaches are mostly suitable for inductive research. As this research is based on primary data collection through fieldwork, expert judgment is used with the help of community people through focus group discussions to assign a weight (1–3) for each indicator.

For quantifying each indicator score for the household-level questionnaire, the relevant categorical variables/indicator values were displayed as percentages of average. As the units of the indicators are different, those values were normalized using the scale 0–1. As an example, the average monthly house rent paid by each household (categorized into four groups) in the respective communities is shown in Table 3. The percentage values were converted to scale values. Based on the community feedback and field experiences, households paying monthly rent of more than BDT 2000 are taken to be (economically) vulnerable to landslides. After combining the two categories of 2001-3000 and 3001 - <10000 BDT per month, this particular indicator (monthly house rent > 2000 BDT) score is calculated to be 0.7, 0.3, and 0.1 for CCC_1, CCC_2, and CCC_3 respectively (Table 3). Each indicator was weighted (from 1–3) by the community people which was obtained through focus group discussions (Table 4).

The PRA tables, maps, and diagrams were analyzed for identifying the most suitable qualitative indicators. The method for merging the quantitative and qualitative datasets, and calculating the overall vulnerability index, is as follows:

(a) For the household-level questionnaires, the indicator score is calculated straight from the SPSS database with the indicators (i.e. the average percentage value). The percentage value is scaled to 0–1 (where 0 corresponds to the lowest vulnerability and 1 to the highest vulnerability).

(b) For community-based PRA surveying, the indicators are scored by the researchers from 0–1 based on comparing the PRA maps and diagrams produced with the help of community people during focus group discussions.

(c) As the degree of influence of the selected indicators is not equal, each indicator is individually weighted from 1 (less important) to 3 (more important) by the researchers with the help of community people during focus group discussions.

(d) The score of each indicator is then multiplied by its corresponding weight and is summed up (i.e. additive aggregation) to develop a composite vulnerability index using Equation 1.

(e) The final vulnerability index is calculated by dividing the composite vulnerability index by total indicator weights (i.e. arithmetic mean).

(f) The vulnerability index is separately calculated for the questionnaires, the PRA survey, and for a combination of both by weighting each equally.

(g) The overall vulnerability index is classified into three groups using an equal interval scale: 0–0.33 = low vulnerability; 0.34–0.66 = medium vulnerability; and 0.67–1.0 = high vulnerability. This kind of measurement scale helps to interpret the results (Vincent 2007; Tate 2012; Eidsvig et al. 2014) and compare the state of community vulnerability to environmental hazards.

$$VI = \frac{(W_1 \times S_1) + (W_2 \times S_2) + (W_3 \times S_3) + \cdots \ldots \ldots \ldots + (W_n \times S_n)}{W_1 + W_2 + W_3 + \cdots \ldots \ldots \ldots + W_n} \ldots \ldots \ldots \text{(Equation 1)}$$

Where, VI = respective vulnerability index, W = indicator weight, S = indicator score, and n = total number of indicators.

Results and discussion

Vulnerability assessment from the household questionnaires

The indicator descriptions, indicator scores, and indicator weights from the questionnaires are shown in Table 4. The indicator scores (quantitative data) represent the percentage of households that are vulnerable in each community. For example, households with less literate people and unemployed members are more vulnerable to landslides, because mostly they stay at home and are less aware of landslide risks and DRR (Krüger et al. 2015). Table 4 displays a total of 28 indicators, a few of which are explained here to illustrate. For instance, the indicator score for 'household not owned by the respondent' was calculated as 0.7, 0.8, and 0.6 for CCC_1, CCC_2, and CCC_3 respectively (Table 4). Consequently, in CCC_2, most respondents (about 80%) rent a house, contributing to their vulnerability to landslides. As another example, the indicator score for 'non-accessibility to micro-credit' was found to be 0.7, 0.9, and 0.6, respectively for CCC_1, CCC_2, and CCC_3 (Table 4). Accessibility to micro-credit is a sign of economic wellbeing in CCC. It can be stated that CCC_3 (Golpahar) has the highest percentage (approximately 40%) of micro-credit accessibility, leading the Golpahar community to be economically least vulnerable to landslides in comparison to the other two communities based on this indicator.

Vulnerability assessment from PRA surveying

Initial, draft PRA maps were drawn in consultation with each community's people on A1 size papers during fieldwork followed by the final drafts after triangulating the information generated and checking back with the people. The final maps were colored and digitally reproduced by this paper's first author for better visualization. Selected PRA maps, diagrams, tables, and descriptions are provided in the Supplemental Material.

Calculating PRA scores and weights

Nineteen indicators representing community scale landslide vulnerability have been selected from the PRA tables, maps and diagrams. The researchers assign the indicator scores after analyzing the tables, maps, and diagrams (Table 5). For example, a lower vulnerability score is assigned for a community with better risk perception. From the vulnerability and dream maps (Fig. S2 and Fig. S3), risk perception in Golpahar appears to be better than Motijharna. Hence, for the 'lack of risk perception' indicator, a relatively lower score (i.e. 0.5) is assigned to Golpahar and a higher score to Motijharna (i.e. 0.9) (Table 5). As with Table 4, the community people through focus group discussions developed the weightings in Table 5 subjectively where the first author acted as a facilitator.

Vulnerability index and sensitivity analysis

After selecting indicators, calculating scores, and assigning weights, associated composite vulnerability indices were divided by total weights to obtain the final vulnerability index values (Table 6). The household questionnaires led to a vulnerability index on a scale of 0–1 of Motijharna (CCC_1) as 0.66, Batali Hill (CCC_2) as 0.65, and Golpahar (CCC_3) as 0.57. Batali Hill (CCC_2) is found to be the most vulnerable community (0.65) based on household-level questionnaires and Motijharna (CCC_1) is found to be the most vulnerable (0.86) as per the results obtained from the community-based PRA surveying (standard scenario in Table 6). Providing equal weighting for each method, the overall vulnerability indices (on a 0–1 scale) of CCC_1, CCC_2, and CCC_3 are calculated as 0.75, 0.68, and 0.56, respectively. Overall, Motijharna (CCC_1) can be considered to be the most vulnerable community to landslides in CCC. Based on the equal interval vulnerability scaling, Motijharna (CCC_1) and Batali Hill (CCC_2) communities are categorized as 'high vulnerability' and Golpahar (CCC_3) is categorized as 'medium vulnerability' to landslides in CCC (Table 6).

The process of constructing a vulnerability index follows several stages: conceptual framework and research design, delineation of social scale and boundary, indicator selection, analyzing measurement errors, transformation and normalization, data reduction and factor retention, weighting, and aggregation (Tate 2012). Given the number of factors used to calculate the index, a divergence in the value of the overall index amongst communities does indicate a consistent pattern of higher landslide vulnerability in some communities than others. Further work includes conducting a sensitivity analysis, toggling the number of indicators or respective assigned weightings, modifying the vulnerability scale range, and exploring error bars for the data. This way, different scenarios could be examined to determine the impact on the final vulnerability index value, such as (i) if a weighting factor changes, (ii) if the number of indicators vary, (iii) if one of the collected variables had a systematic error, or (iv) if an assumption about thresholds in the questionnaire, such as for income, needs to be revisited.

To address these uncertainties, to justify the robustness of this proposed method, and to verify that ostensibly small differences in the index value do actually represent real differences in vulnerability, a sensitivity analysis with four different scenarios was conducted (Table 6): (a) considering equal weighting for all the indicators; (b) ignoring the PRA transect, vulnerability, and dream maps; (c) randomly ignoring half of the questionnaire indicators; and (d) randomly ignoring half of the questionnaire and PRA indicators.

In all cases, the results show changes in the overall vulnerability index calculations but not in the rankings and with only limited deviation from each of the standard scenario calculations (Table 6). As such, the method itself has been shown not to influence extensively the overall results. The overall vulnerability indices can only be influenced if the indicator scores are changed; that is, only if conditions in the community are different. However, the significance or priority ranking of an indictor changes by varying the indicator weights. For example, in the standard scenario case, the top two indicators responsible for increasing community vulnerability were identified as ‘Illiterate and less educated population’ and ‘People travel to attractions on foot’; conversely, ‘Availability of sanitation facilities’ and ‘No training on landslide DRR’ were the top two indicators for the equal weight scenario (Table 7). It illustrates that the indicator scores can have significant impact on the overall vulnerability index, whereas the indicator weights can alter the priority ranking (in terms of more vulnerable or less vulnerable) of an indicator. The proposed method could be useful to identify a matrix of significant indicators that can be beneficial for the community people and stakeholders in setting priorities for action.

Critical reflections and future research

There is no well-accepted technique for selecting the sample size for household-level questionnaires to conduct research on measuring community vulnerability (Bankoff et al. 2004; Tate 2012; Bryman 2016) although a desirable level of statistical significance often suggests a minimal sample size (Shah et al. 2013). During the fieldwork here, it was not possible to enter some places due to community protests and some people tried to hide the truth while answering the questions, as they feared eviction. Positionality, reflexivity, and power relations during fieldwork can play roles while conducting participatory research (Cooke and Kothari 2001; Mercer et al. 2008).

Other components such as culture, differing cultures, indigenous knowledge, ecological degradation, political willingness, coping capacity, administrative intervention or lack thereof, governance, and other hazards and hazard drivers (including earthquakes and climate variability) need more scrutiny and careful observation. Additionally, vulnerability scenarios can differ for each context, culture, environment, and timeframe, with monitoring changes of community vulnerability over time usually not conducted due to funding and project limitations (Lindell and Prater 2003). Longitudinal studies, including revisiting the communities studied here, should be explored for future research.

Another issue is minimizing the uncertainties while scoring and weighting the indicators for both the quantitative questionnaire and the qualitative PRA surveying. For instance, uncertainties associated with interpreting the indicators (e.g. what is the exact hill slope, what is risk perception, and what is the drainage facility) emerge frequently. Mixed methods and cross-checking approaches, as used here, assist in overcoming implications of and sensitivities of the results from the uncertainties, as demonstrated by the sensitivity analyses. Nonetheless, it is always accepted that the numbers have elements of subjectivity and contextuality.

Future research, especially towards seeking improved accuracy and precision in the results, would involve incorporating more indigenous knowledge and cultural perceptions while validating the results through further community and key informant workshops. External influences should also be examined and included more, namely geopolitics, global climate change, migration in and out, and governance at all scales.

Conclusion

Disasters are not caused by environmental hazards, but by vulnerability emerging from social, economic, and political forces (O'Keefe et al. 1976; Hewitt 1983; Lewis 1999; Wisner et al. 2004). Vulnerability assessment to environmental hazards is a complex task considering its multidimensional aspects, contextual features, and local characteristics (Lindell and Prater 2003; Wisner et al. 2004). The purpose of this article is to develop and implement a method for combining quantitative and qualitative data in measuring community vulnerability to environmental hazards. The significance of this proposed method, which can be replicated in other DRR contexts, rests on integrating qualitative and quantitative aspects of community vulnerability that have been developed, applied, and critiqued empirically in a unique case study. To achieve this goal, quantitative information from household questionnaires is collected and qualitative maps and diagrams from PRA surveying are produced. A weight-based vulnerability index model is then applied, providing an original and innovative method for using both quantitative and qualitative data. The vulnerability index calculation is applied in three landslide case study areas or communities in Chittagong City Corporation (CCC), Bangladesh. The overall vulnerability indices of Motijharna (CCC_1), Batali Hill (CCC_2), and Golpahar (CCC_3) communities are 0.75, 0.68, and 0.56 respectively (on a 0–1 scale).

The proposed method follows an index-based approach that is highly dependent on key informant and community judgment for analyzing the local context for indicator selection, for assigning indicator scores for qualitative data, for formulating indicator weights, and for defining the range of vulnerability scales. The dependence on such judgment is a main limitation of this method because it has the potential to modify the overall index results and to alter the order and weighting of indicators. To overcome such limitations and to improve replicability, the results should be validated through regular community-based forensic workshops where the local people and stakeholders actively participate to evaluate, justify, critique, and update the selection of indicators and their scores and weights—which could also help to reflect any changes as communities develop.

This research integrates qualitative PRA tools with quantitative data, thereby contributing to advancing DRR research, policy, and practice through better understanding and addressing vulnerability to environmental hazards at community scale.

Acknowledgements

Bayes Ahmed is a Commonwealth Scholar funded by the UK government. The fieldwork was partially supported by the UCL Institute for Risk and Disaster Reduction. The authors are grateful to the research assistants from the Department of Urban and Regional Planning (URP) of Chittagong University of Engineering and Technology (CUET) and Bangladesh University of Engineering and Technology (BUET), Chittagong Development Authority (CDA), and most importantly to the local people who assisted during the fieldwork in CCC. The authors want to thank the reviewers and editors for their constructive comments that improved the quality of this manuscript.

Supplemental material

Figs. S1–S6, Tables S1-S5, and accompanying text are available online in the ASCE Library (ascelibrary.org).

References

Ahmed, B. (2015). "Landslide susceptibility mapping using multi-criteria evaluation techniques in Chittagong Metropolitan Area, Bangladesh." *Landslides*, 12(6), 1077-1095.

Ahmed, B. (2017). *Community vulnerability to landslides in Bangladesh*. PhD thesis, University College London (UCL), UK.

Ahmed, B., and Dewan, A. (2017). "Application of Bivariate and Multivariate Statistical Techniques in Landslide Susceptibility Modeling in Chittagong City Corporation, Bangladesh." *Remote Sens.*, 9(4), 304.

Alexander, D. (2000). *Confronting catastrophe: New perspectives on natural disasters*, Terra Publishing, Harpenden, England.

Alexander, D. (2004). *Vulnerability to Landslides*. Glade, T., Anderson, M., and Crozier, M. J. (eds) Landslide Hazard and Risk. John Wiley & Sons, West Sussex, England, 175-198.

Antwi, E. K., Boakye-Danquah, J., Owusu, A. B., Loh, S. K., Mensah, R., Boafo, Y. A., and Apronti, P. T. (2015). "Community vulnerability assessment index for flood prone savannah agro-ecological zone: a case study of Wa West District, Ghana." *Weather and Climate Extremes*, 10, 56-69.

Bankoff, G., Hilhorst, D., and Frerks, G. (2004). *Mapping vulnerability: disasters, development and people*, Earthscan, London, UK.

BBS. (2014). *Urban Area Report*. Bangladesh population and housing census 2011, National report, volume 3. Bangladesh Bureau of Statistics (BBS), Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh.

Beccari, B. (2016). A Comparative Analysis of Disaster Risk, Vulnerability and Resilience Composite Indicators. *PLoS Currents*, 14(8): ecurrents.dis.453df025e34b682e9737f95070f9b970

Bryman, A. (2016). *Social Research Methods*, Oxford University Press, UK.

BUET-JIDPUS. (2015). "Landslides in Bangladesh." Bangladesh University of Engineering and Technology—Japan Institute of Disaster Prevention and Urban Safety (BUET-JIDPUS); Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh. <http://www.landslidebd.com/reports/> (Dec. 14, 2016).

Chakraborty, J., Tobin, G.A., and Montz, B.E. (2005). "Population evacuation: assessing spatial variability in geophysical risk and social vulnerability to natural hazards." *Natural Hazards Review*, 6(1), pp.23-33.

Chambers, R. (1994). "The origins and practice of participatory rural appraisal." *World Dev.*, 22(7), 953–969.

Cooke, B., and Kothari, U. (eds) (2001). *Participation: The New Tyranny?,* Zed Books, London, U.K.

CRED [Centre for Research on the Epidemiology of Disasters] database. (2017). URL: https:// www.emdat.be (accessed on 13 February 2017).

Cutter, S. L., Boruff, B. J., and Shirley, W. L. (2003). "Social vulnerability to environmental hazards." *Soc. Sci. Q.*, 84(2), 242-261.

Ebert, A., Kerle, N., and Stein, A. (2009). "Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data." *Nat. Hazards*, 48, 275–294.

Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., Winter, M. G., Mavrouli, O. C., Fotopoulou, S., Pitilakis, K., Baills, A., Malet, J.-P., and Kaiser, G. (2014). "Assessment of socioeconomic vulnerability to landslides using an indicator-based approach: methodology and case studies." *Bull. Eng. Geol. Environ.*, 73, 307–324.

Gerlitz, J. Y., Macchi, M., Brooks, N., Pandey, R., Banerjee, S. and Jha, S.K. (2017). "The Multidimensional Livelihood Vulnerability Index–an instrument to measure livelihood vulnerability to change in the Hindu Kush Himalayas." *Climate and Development*, *9*(2), 124-140.

Glade, T. (2003). "Vulnerability assessment in landslide risk analysis." *Erde*, 134(2), 123-146.

Glade, T., Anderson, M., and Crozier, M. J. (eds) (2005). *Landslide hazard and risk*, Wiley and Sons Ltd, West Sussex, England.

Hewitt, K. (1983). The idea of calamity in a technocratic age. *In*: Hewitt, K. (eds) *Interpretations of calamity from the viewpoint of human ecology*. Allen & Unwin Inc., Winchester, USA, 3-32.

Holand, I.V. and Lujala, P. (2013). Replicating and Adapting an Index of Social Vulnerability to a New Context: A Comparison Study for Norway. *The Professional Geographer*, 65(2), 312-328.

Krishnamurthy, P. K., Lewis, K., and Choularton, R.J. (2014). "A methodological framework for rapidly assessing the impacts of climate risk on national-level food security through a vulnerability index." *Global Env. Change*, *25*, 121-132.

Krüger, F., Bankoff, G., Cannon, T., and Schipper, L. (2015). *Cultures and Disasters: Understanding Cultural Framings in Disaster Risk Reduction*, Routledge, Abingdon, UK.

Kumar, S. (2002). *Methods for Community Participation: A Complete Guide for Practitioners*, Vistaar Publications, New Delhi, India.

Lewis J. (1999). *Development in disaster-prone places: studies in vulnerability*, IT Publications, London, UK.

Lindell, M. and Prater, C. (2003). "Assessing Community Impacts of Natural Disasters." *Nat. Hazards Rev.*, 4(4), 176-185.

Martins, V. N., Silva, D. S. E., and Cabral, P. (2012). "Social vulnerability assessment to seismic risk using multicriteria analysis: the case study of Vila Franca do Campo (São Miguel Island, Azores, Portugal)." *Nat. Hazards*, 62, 385–404.

Mercer, J., Kelman, I., Lloyd, K., and Pearson, S. S. 2008. "Reflections on use of participatory research for disaster risk reduction." *Area*, 40(2), 172–183.

Naudé, W., Santos-Paulino, A. U., and McGillivray, M. (2012). *Measuring Vulnerability in Developing Countries: New Analytical Approaches*, Routledge, London, UK.

O'Keefe, P., Westgate, K., and Wisner, B. (1976). "Taking naturalness out of natural disasters." *Nature*, 260, 566-567.

Pandey, R. and Jha, S. (2012). "Climate vulnerability index-measure of climate change vulnerability to communities: a case of rural Lower Himalaya, India." *Mitigation and Adaptation Strategies for Global Change*, *17*(5), 487-506.

Petley, D. (2012). "Global patterns of loss of life from landslides." Geology, 40(10), 927-930.

Quarantelli, E. L. (1998.) *What Is a Disaster?* Routledge, New York.

Roy, R. C. K. (2000). *Land Rights of the Indigenous Peoples of the Chittagong Hill Tracts, Bangladesh*. IWGIA Document No. 99. The International Work Group for Indigenous Affairs (IWGIA), Copenhagen, Denmark.

Shah, K. U., Dulal, H. B., Johnson, C., and Baptiste, A. (2013). "Understanding livelihood vulnerability to climate change: Applying the livelihood vulnerability index in Trinidad and Tobago." *Geoforum*, 47 125-137.

Tate, E. (2012). "Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis." *Nat. Hazards*, 63(2), 325-347.

UNISDR. (2017). "Terminology on disaster risk reduction." The United Nations Office for Disaster Risk Reduction (UNISDR), Geneva, Switzerland. (https://www.unisdr.org/we/inform/terminology) (Feb 2017).

Vincent, K. (2007). "Uncertainty in adaptive capacity and the importance of scale." Global Environmental Change, 17(1), pp.12-24.

Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T., Bal, H., Bradley, D., Schuurman, N., and Clague, J. J. (2014). "A multi-criteria evaluation model of earthquake vulnerability in Victoria, British Columbia." *Nat. Hazards*, 74, 1209–1222.

White, G.F. (1942). *Human adjustment to floods: a geographical approach to the flood problem in the United States*. Ph.D. dissertation. University of Chicago, USA.

Wisner, B., Blaikie, P., Cannon, T., and Davis, I. (2004). *At risk: Natural hazards, people's vulnerability and disasters*, Routledge, Oxon, England.

World Risk Report. 2016. Bündnis Entwicklung Hilft (Alliance Development Works), and United Nations University – Institute for Environment and Human Security (UNU-EHS), Germany.

Yadav, D. K. and Barve, A. (2017). “Analysis of socioeconomic vulnerability for cyclone-affected communities in coastal Odisha, India.” *Int. J. Disaster Risk Reduct.*, 22, 387-396.

Yoon, D. K. (2012). “Assessment of social vulnerability to natural disasters: a comparative study.” *Nat. Hazards*, 63, 823–843.

Table 1. Justification for selecting the indicators from questionnaires.

Indicator Description	Justification
Settlements started after year 1990.	Newer settlements are located near more dangerous slopes.
Housing type has manufactured materials.	Houses with manufactured materials (fully or semi-built) are generally made of concrete, brick, and cement, along with corrugated iron sheets. These houses are not suitable for construction on the hill-slopes because of sandy soil quality. These houses are highly vulnerable to landslides.
Do not consider landslides as a problem.	Most of the houses surveyed were found located on or near dangerous slopes or foothill, but the locals denied this situation because they were afraid of being evicted. Moreover, landslide hazards are common every year during the monsoon.
Observe landslides in each year.	
Settled for employment opportunities.	The selected communities are located near the city center (Chittagong is the second largest city and biggest port city in Bangladesh). Marginalized and economically vulnerable people from different parts of Bangladesh and other parts of Chittagong are rushing towards CCC in search of jobs. To meet the growing demand, a group of powerful and locally influential people is accommodating them in informal settlements in the vulnerable hills.
Household not owned by the respondent, and built by the landlords.	
Using the house for residential purpose only.	
Availability of water and electricity supply.	Utility services are being provided illegally in the urbanized hill communities. These are informal settlements and are not permitted in the hills as per the detailed area plan for Chittagong Metropolitan Area. By providing utility facilities in vulnerable locations, more people are attracted to come and reside in the vulnerable hills.
Adequate drainage and sanitation facility.	
Availability of gas supply for household use.	
Less literate population.	Those who are less literate and less educated are mostly unemployed, and are assumed to have less opportunity for dealing with landslide emergencies and possible disasters.
People without higher education.	
Monthly income < 10,000 BDT.	Households with less monthly income, with no access to micro-credit, and spending more on house rent are more vulnerable to landslides. These household members struggle to fulfill their basic needs and mostly have no places to go for a standard living. They come to cities to improve their lives, but they are forced to live in squatter or informal settlements. Sometimes they risk their lives while living on the steep hill-slopes.
Need to pay a monthly house rent and the rent is > 2,000 BDT.	
Non-accessibility to micro-credit.	
Face problems after eviction.	
Distance to workplace, marketplace and educational facilities is <= 0.5 km	The existence of community facilities and workplaces near to a hill community can attract working class population to reside in the hills. It works as a city pull factor and promotes urbanization in the hills. Thus or this

Working class population (18–60 years)	kind of external attraction force could make the hills vulnerable to landslides.
No precautions undertaken after getting early warnings.	The household members who do not relocate even after receiving warnings and during heavy rainfall are vulnerable to landslides. Culturally, some people do not want to leave their houses and belongings during emergencies (e.g. fear of theft, of insecurity in the temporary shelters, or of being evicted).
Do not relocate during the monsoon.	
No training on landslide DRR.	Most households do not retain emergency contact numbers and many are not aware of the landslide prone areas that can pose serious threats to lives and property. These households lack training and awareness on landslide disaster risk reduction in CCC.
Without emergency contact numbers.	
No knowledge on landslide prone areas.	

Table 2. Justification for PRA tool selection.

PRA tool	Data obtained	Justification: Relationship with vulnerability assessment
Social and resource map	Living patterns and social/critical infrastructure such as roads, drainage, schools, markets, shops, water points, and playgrounds. Natural resources such as land, hills, water, and forests.	This tool depicts the overall (physical) exposure at community level. The higher the exposure, the more likely the communities are to experience landslide hazards.
Transect map	The topography of the hills, hill forest, housing density, building heights and location of the houses on steep slopes.	This PRA is tool is useful for analyzing the topographic aspects of the hills and their relationship with exiting buildings in the community.
Vulnerability and dream maps	Location of houses, community facilities, and critical infrastructure in areas prone to landslides. The future of the community in terms of, and opportunities for, planning.	The maps identify the areas and infrastructure vulnerable to landslides and other hazards as well as people's hopes and aspirations in terms of building a community and developing livelihoods.
Mobility map	Where people travel, the purposes of the travel; the frequency of visits, the distances travelled, the modes of transport, and accessibility. Peoples' preferences for and perceptions of movement patterns and modes.	The maps highlight reasons why people might move to hill communities and how they access services and infrastructure assessment, thereby indicating how vulnerability to landslides can be created.
Venn diagram	Level of dependency on various institutions or influential individuals, power structures and relations, decision-making process within the power map, different levels of interaction, and the perceived importance of all these parties.	Power plays a major role in creating and perpetuating vulnerability to environmental hazards. As well, influential institutions and individuals, along with interactions with the local people, can make communities attractive, therefore drawing people in and increasing vulnerability to landslides.
Pair-wise ranking	Various problems are identified and ranked	This tool identifies how local people view various problems in their

	according to the local people's perceptions.	community, indicating actual and perceived vulnerabilities.
SWOT analysis	Local perceptions of strengths, weaknesses, opportunities, and threats regarding internal and external factors/forces influencing local vulnerability to landslides.	This tool is useful for scrutinizing: – Capacities to withstand landslides, – Pull factors to the communities, such as job opportunities or increased accessibility to urban facilities and infrastructure. – Reasons why people might not move out. – Perceived areas for improvement dealing with vulnerability to landslides.

Table 3. Scaling of an indicator (average monthly house rent) from the questionnaire. (Shown to two significant figures.)

House Rent	CCC_1	CCC_2	CCC_3	CCC_1	CCC_2	CCC_3
(BDT)	Percentage (%)			Scaling (0–1)		
< 1000	4.5	15	33	0.0	0.1	0.3
1000 – 2000	26	59	55	0.3	0.6	0.6
2001 – 3000	38	20	8.2	0.4	0.2	0.1
3001 – <10000	32	6.1	4.0	0.3	0.1	0.0
Total	100	100	100			

Source: Field survey, July-September 2014.

Table 4. Indicator weights and scores based on household questionnaires.

Vulnerability Dimension(s)	Indicator (Percentage of Households)	Indicator Weight	Indicator Score		
			CCC_1	CCC_2	CCC_3
Physical and ecological	Settlement started after year 1990	3	0.5	0.6	0.5
Economic	Settled for employment opportunity	1	0.3	0.4	0.5
Economic and social	Household not owned by the respondent	1	0.7	0.8	0.6
Economic and institutional	House built by the landlords	1	0.6	0.7	0.4
Physical and cultural	Manufactured building materials	3	0.6	0.5	0.3
Social and cultural	Using the house for residential purpose	1	0.9	0.9	1.0
Physical and social	Distance to workplace <= 0.5 km	2	0.6	0.5	0.5
Physical and social	Distance to educational facilities <= 0.5 km	1	0.8	0.7	0.7
Physical and social	Distance to marketplace <= 0.5 km	1	0.7	0.7	0.3
Physical, ecological, and institutional	Adequate drainage facility	1	0.5	0.4	0.3
Physical, ecological, and institutional	Availability of water supply	2	0.9	0.9	0.8
Physical, ecological, and institutional	Sufficient electricity supply	2	1.0	1.0	0.9
Physical, ecological, and institutional	Availability of sanitation facilities	1	1.0	1.0	1.0
Physical, ecological, and institutional	Availability of gas facilities	1	0.5	0.3	0.2
Social	Working class population (18-60 years)	3	0.6	0.7	0.7
Social and economic	Illiterate and less educated population	3	0.9	0.9	0.7
Economic	Monthly income < 10,000 BDT	3	0.5	0.5	0.4
Economic	Need to pay a monthly house rent	1	0.6	0.7	0.4
Economic and institutional	Monthly house rent > 2,000 BDT	2	0.7	0.3	0.1
Economic and	Non-accessibility to	1	0.7	0.9	0.6

institutional	micro-credit				
Economic and institutional	Will face problems after eviction	2	0.5	0.5	0.5
Cultural	Do not consider landslides as a problem	2	0.5	0.4	0.2
Social, cultural and institutional	No knowledge on landslide prone areas	1	0.6	0.6	0.3
Ecological	Observe landslides in each year	3	0.4	0.6	0.7
Cultural and social	Do not relocate during monsoon	1	0.8	0.9	1.0
Institutional	No training on landslide DRR	1	1.0	1.0	1.0
Cultural and social	Do nothing after getting early warnings	3	0.7	0.7	0.8
Cultural and institutional	Without emergency contact number	1	0.8	0.9	0.8

Table 5. Indicator scores and weights from PRA surveying.

PRA Tool	Vulnerability Dimension(s)	Indicator Description	Indicator Weight	Indicator Score		
				CCC_1	CCC_2	CCC_3
Social and Resource Mapping	Physical and cultural	Density of houses in the community	1	0.9	0.7	0.5
	Physical and institutional	Number of services within the community	2	0.9	0.6	0.3
	Physical and institutional	Extent of road network	3	0.9	0.7	0.4
	Physical and ecological	Level of activities within the community	1	1.0	0.7	0.4
Transect Walk Map	Physical and ecological	Location of houses by steep slopes	3	0.9	0.6	0.4
	Physical	Curvature of existing hills	1	0.6	0.7	0.8
	Cultural	Housing pattern/ building height	2	0.8	0.7	0.6
Venn Diagram	Institutional and social	Number of influential institutions	1	0.8	0.9	0.6
	Physical	Proximity to institutions	3	0.7	0.7	0.5
	Institutional	Overall level of influence	1	0.9	0.8	0.6
	Institutional and cultural	Overall level of interaction	1	0.9	0.7	0.5
Mobility Mapping	Physical and economic	Number of institutions travelled daily	3	0.8	0.7	0.7
	Economic and physical	People travel to attractions on foot	3	0.9	0.7	0.7
Vulnerability and Dream Mapping	Physical and ecological	Areas vulnerable to landslides	3	0.9	0.7	0.6
	Cultural and institutional	Lack of risk perception	1	0.9	0.7	0.5
	Institutional	Lack of landslide preparedness	1	0.9	0.8	0.5
Pairwise Ranking and SWOT	Social and economic	Intensity of socio-economic problems	1	0.9	0.8	0.6
	Physical and institutional	Intensity of landslide related problems	2	1.0	0.8	0.6
	Institutional and economic	Lack of capacities to withstand landslides	1	0.9	0.8	0.6

Table 6. Vulnerability indices of different communities considering various scenarios for a sensitivity analysis. (Shown to two significant figures).

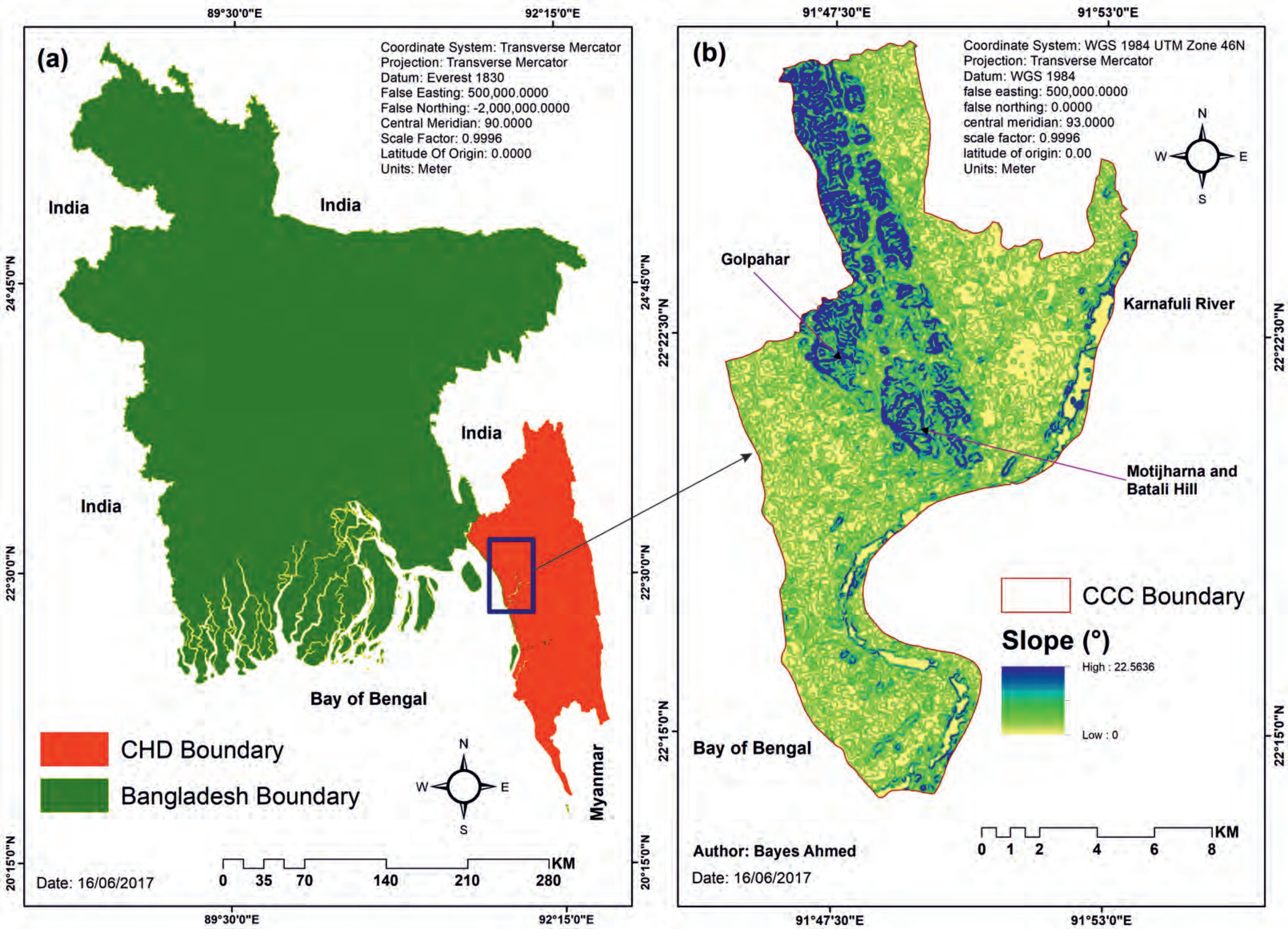
Scenario for Sensitivity Analysis	Vulnerability Index	Motijharna (CCC_1)	Batali Hill (CCC_2)	Golpahar (CCC_3)
Standard Scenario (Proposed Method)	Questionnaires	0.66	0.65	0.57
	PRA survey	0.86	0.71	0.54
	Overall	**0.75**	**0.68**	**0.56**
Equal Weight for the Indicators	Questionnaires	0.68	0.67	0.58
	PRA survey	0.87	0.73	0.55
	Overall	**0.76**	**0.69**	**0.57**
Ignoring Transect, Vulnerability and Dream Maps	Questionnaires	0.66	0.65	0.57
	PRA survey	0.87	0.72	0.54
	Overall	**0.73**	**0.68**	**0.56**
Ignoring Half of the Questionnaire Indicators	Questionnaires	0.69	0.66	0.56
	PRA survey	0.86	0.71	0.54
	Overall	**0.80**	**0.69**	**0.55**
Ignoring Half of the Questionnaire and PRA Indicators	Questionnaires	0.69	0.66	0.56
	PRA survey	0.85	0.71	0.53
	Overall	**0.77**	**0.68**	**0.55**

* 0.00–0.33 = low vulnerability, 0.34–0.66 = medium vulnerability, and 0.67–1.0 = high vulnerability.

Table 7. List of top priority indicators in different indicator weight scenarios.

	Standard Weight Scenario	Equal Weight Scenario
Top Ranked Indicators	Illiterate and less educated population	Availability of sanitation facilities
	People travel to attractions on foot	No training on landslide DRR
	No precautions undertaken after getting landside early warnings	Sufficient electricity supply
	Number of institutions travelled daily	Using the house for residential purpose
	Areas vulnerable to landslides	Do not relocate during monsoon

Fig. 1. **(a)** Location of Chittagong hill districts in Bangladesh and **(b)** Location of Chittagong City Corporation.



(a)
89°30'0"E
92°15'0"E
Coordinate System: Transverse Mercator
Projection: Transverse Mercator
Datum: Everest 1830
False Easting: 500,000.0000
False Northing: -2,000,000.0000
Central Meridian: 90.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
India
India
India
India
Bay of Bengal
Myanmar
CHD Boundary
Bangladesh Boundary
N
W
E
S
0 35 70 140 210 280 KM
Date: 16/06/2017
24°45'0"N
22°30'0"N
20°15'0"N
(b)
91°47'30"E
91°53'0"E
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.00
Units: Meter
Golpahar
Karnafuli River
Motijharna and
Batali Hill
Bay of Bengal
CCC Boundary
Slope (°)
High : 22.5636
Low : 0
0 1 2 4 6 8 KM
Author: Bayes Ahmed
Date: 16/06/2017
22°22'30"N
22°15'0"N

Supplemental Material

For "Measuring Community Vulnerability to Environmental Hazards: A Method for Combining Quantitative and Qualitative Data" by Bayes Ahmed and Ilan Kelman.

Table S1. Justification for selecting the indicators from PRA surveying.

Indicator	Justification [PRA tools used]
Household density.	A community with higher density of houses or infrastructure and other community facilities are highly vulnerable to landslides. [Social and resource map]
Intensity of services and activities.	The higher concentration of commercial and other activities within a community can make it susceptible to landslides. Various activities within a community attract more people to reside and thus increase vulnerability. [Social and resource, and transect map]
Accessibility by road network.	A community accessible by both an internal and external built road network is highly vulnerable to landslides, because it would encourage more people to live in the hills and increase human activities. [Social and resource map]
Location of houses on risky slopes.	The higher number of houses located on steep or dangerous hill slopes increase landslide vulnerability. [Social and resource, transect and vulnerability maps]
Housing pattern (height, hill-cut, design) and areas vulnerable to landslides.	Multi-storied, semi or manufactured, and a house built by cutting hills indiscriminately, increases the probability of landslides. A community with a greater number of traditional or indigenous houses is less vulnerable to landslides. The traditional non-built houses, built by maintaining and preserving the hill slopes, are resilient to landslides. [Transect, vulnerability, and social and resource maps]
Total attractions	A community with more number of attractions (e.g.

Indicator	Justification [PRA tools used]
travelled.	community facilities such as school, market place, playground, bus stand etc.) is more vulnerable to landslides. Easy accessibility to attractions on foot and higher frequency of visits to those attractions encourage concentric settlement development in or surrounding the hills. It increases landslide vulnerability. [Mobility maps]
People travel to attractions on foot.	
Attractions travelled daily.	
Number of influential institutions.	The number of high-influential institutions (e.g. a community leader, school teacher, political or religious leaders, govt. officials, and NGOs etc.) within a community, increase landslide vulnerability. Similarly stronger communications and interactions among them, act as a pull-factor for settlement development in the community. [Venn diagram]
Overall level of influence.	
Overall level of interaction.	
Intensity of socio-economic problems	A community with higher intensity of socio-economic problems is more vulnerable to landslides. They are quite often categorized as the marginalized group of people in Bangladesh and mostly they lack an alternative option to live and continue their livelihoods somewhere safely. [Cause effect diagram and pair-wise ranking of problems]
Capacities to withstand landslides	Communities that are less capable of tackling landslides are more vulnerable to landslides. Those who live in traditional houses, belong to their ancestors land, have local knowledge to deal with extreme hilly environment, have strong social-cohesion, connected internally and externally, and rely on sustainable use of natural resources surrounding the hills for

Indicator	Justification [PRA tools used]
	livelihoods are more capable of withstanding landslides. [SWOT and timeline]
Landslide risk perception	In the context of CHD, risk perception depends on how the community members deal with the natural hazards and perceive the impact of associated threats. A community with lower risk perception is highly vulnerable to landslides. [Dream mapping and SWOT]

Transect walk mapping

The transect map helps to identify the location of houses on steep slopes, the curvature of the existing hills, housing patterns, and housing densities (Kumar 2002). For example, the hill curvature of Golpahar (Fig. S4b) is found to be steeper than Batali Hill community (CCC_2), which is posing greater threats (Fig. S4a). Thus, Golpahar community receives a higher score value (0.8) than Batali Hill (0.7) for the indicator 'curvature of existing hills'.

Venn diagrams and mobility mapping

Venn diagrams of two communities are depicted in Fig. S5. A total of 16 and 14 institutions were identified in Batali Hill and Golpahar communities, respectively. Batali Hill is more vulnerable, because the communities linked with more institutions attract more people to settle in the hills, thereby increasing landslide vulnerability. Again, the institutions with higher influence and interactions within a community can aggravate vulnerability. For example, there are nine highly influential institutions in Batali Hill (Fig. S5a) and eight in Golpahar (Fig. S5b). If community facilities are easily accessible on foot, so nearby, then the location attracts more people which tends to increase vulnerability. This can further trigger degradation of the environment around the hill, exacerbating landslides. People travel to same number of attractions on foot in Golpahar (Fig. S6a) and in Batali Hill community (Fig. S6b), so equal weight (0.7) is assigned for both communities.

Pair-wise problem ranking and SWOT analysis

Using these methods, indicators such as existing problems within the community, intensity of landslide-related problems, and lack of coping capacities for landslide DRR and disaster management can be measured. For example, communities with problems related to the availability of utility services (e.g. water and electricity supply) and fewer job opportunities are less vulnerable to landslides, because they tend to attract fewer people to reside in the hills. Based on this concept, the pair-wise ranking of existing problems is developed and is later compared with other vulnerable communities. Fewer job opportunities, social and political violence, poor economic conditions of the tenants, illegal business activities in the hills, lack of education, and lack of utility services were identified as major problems within the selected communities (Tables S1 and S2). Interestingly, the local people did not mention (or potentially intentionally avoided mentioning) landslides as a problem. They might not wish to discuss this topic because they are concerned about being evicted from their homes.

SWOT analyses group key pieces of information into two categories: internally (i.e. within the community) and externally (i.e. outside the community environment) influencing factors. From SWOT analysis, it is possible to identify the internal strengths of a community for dealing with landslides. After analyzing the SWOT diagrams of Batali Hill and Golpahar communities, it is found that Golpahar people are more capable of reducing landslide risks. For instance, in Golpahar most people live on their own land, but in Batali Hill, people are living in rented houses on illegal land. Batali Hill people are always under threat of eviction making them socio-economically more vulnerable to landslides (Tables S3 and S4). Batali Hill receives higher score values than Golpahar for the SWOT indicator of ‘capacities to withstand landslides’.

Table S2. Pair-wise ranking of problems in Batali Hill community, CCC.

Serial Number	Existing Problem	1	2	3	4	5	6	7	8	9	Frequency	Rank
1	Economic condition	×	1	1	4	1	6	7	8	1	5	3
2	Lack of daily needs	×	×	2	5	6	2	2	8	2	5	3
3	No water supply	×	×	×	4	5	6	4	8	4	3	4
4	No gas supply	×	×	×	×	5	5	8	9	10	5	3
5	Social violence	×	×	×	×	×	6	8	6	10	6	2
6	Illegal business	×	×	×	×	×	×	7	7	10	3	4
7	Lack of education	×	×	×	×	×	×	×	8	10	7	1
8	Poor health facility	×	×	×	×	×	×	×	×	10	1	6
9	Less work	×	×	×	×	×	×	×	×	×	6	2

Source: Community people, field survey, August 2014.

Table S3. Pair-wise ranking of problems in Golpahar community, CCC.

Serial Number	Existing Problem	1	2	3	4	5	6	7	8	9	10	Frequ-ency	Rank
1	Low income	×	2	3	4	1	1	7	8	9	10	2	6
2	Lack of daily needs	×	×	3	4	2	6	2	2	9	10	4	4
3	Political violence	×	×	×	3	3	3	7	8	3	10	6	2
4	No gas supply	×	×	×	×	5	6	4	8	9	10	3	5
5	Limited water supply	×	×	×	×	×	5	5	5	5	10	5	3
6	Load shedding	×	×	×	×	×	×	6	6	9	10	4	4
7	Poor road condition	×	×	×	×	×	×	×	8	9	10	2	6
8	Low capacity of drain	×	×	×	×	×	×	×	×	9	10	4	4
9	Less working facility	×	×	×	×	×	×	×	×	×	9	6	2
10	Poor health facility	×	×	×	×	×	×	×	×	×	×	8	1

Source: Community people, field survey, September 2014.

Table S4. SWOT analysis of Batali Hill community, CCC.

Internal Factors	
Strength	**Weakness**
▪ Voting opportunity ▪ Helpful Ward Commissioner ▪ Better employment facilities ▪ Protected from flood ▪ Less environmental pollution ▪ Social committee solves disputes ▪ Education for children ▪ Strong community bonding ▪ Enough security for women ▪ Early warning system	▪ Local political clash ▪ Hill cutting for housing ▪ Lack of utilities (water and gas) ▪ Low monthly income ▪ Low rate of literacy ▪ No solid waste dumping place ▪ Poor building construction ▪ Low risk perception ▪ Lack of landslide preparedness ▪ Deforestation
External Factors	
Opportunity	**Threat**
▪ Help from City Corporation ▪ NGO activities ▪ Foreign help ▪ Humanitarian assistance ▪ Relocation to safer place ▪ Better job opportunities	▪ Political instability at national level ▪ Hill cutting by outsiders ▪ Encroachment by developers ▪ Forced eviction

Source: Community people, field survey, August 2014.

Table S5. SWOT analysis of Golpahar community, CCC.

Internal Factors	
Strength	**Weakness**
▪ Own property ▪ Local people ▪ Child's education ▪ More women work ▪ Elevated land ▪ Cohesion between the community people ▪ Hill provides wood for fuel and protection from other hazards ▪ Social committee ▪ Mosque committee ▪ Voting power	▪ Narrow and elevated roads (no access for fire service vehicles; ambulances face difficulty) ▪ Poor housing ▪ High density, poor building structure ▪ Lack of utilities (water and gas) ▪ Poverty, less literate people ▪ Poor drainage system ▪ Lack of dustbin and lack of collection of wastes ▪ Lack of facilities (health, education) ▪ Illegal businesses
External Factors	
Opportunity	**Threat**
▪ NGO help ▪ Help from local politicians ▪ Help from the City corporation ▪ Religious financial help (i.e. *Zakat*) ▪ Good transport system	▪ Threat of eviction by Bangladesh Shipping Corporation ▪ Dispute between the locals and powerful outsiders ▪ Rapid in-migration of disaster-affected people resulting in the high density and lower occupancy rate of the houses

Source: Community people, field survey, September 2014.

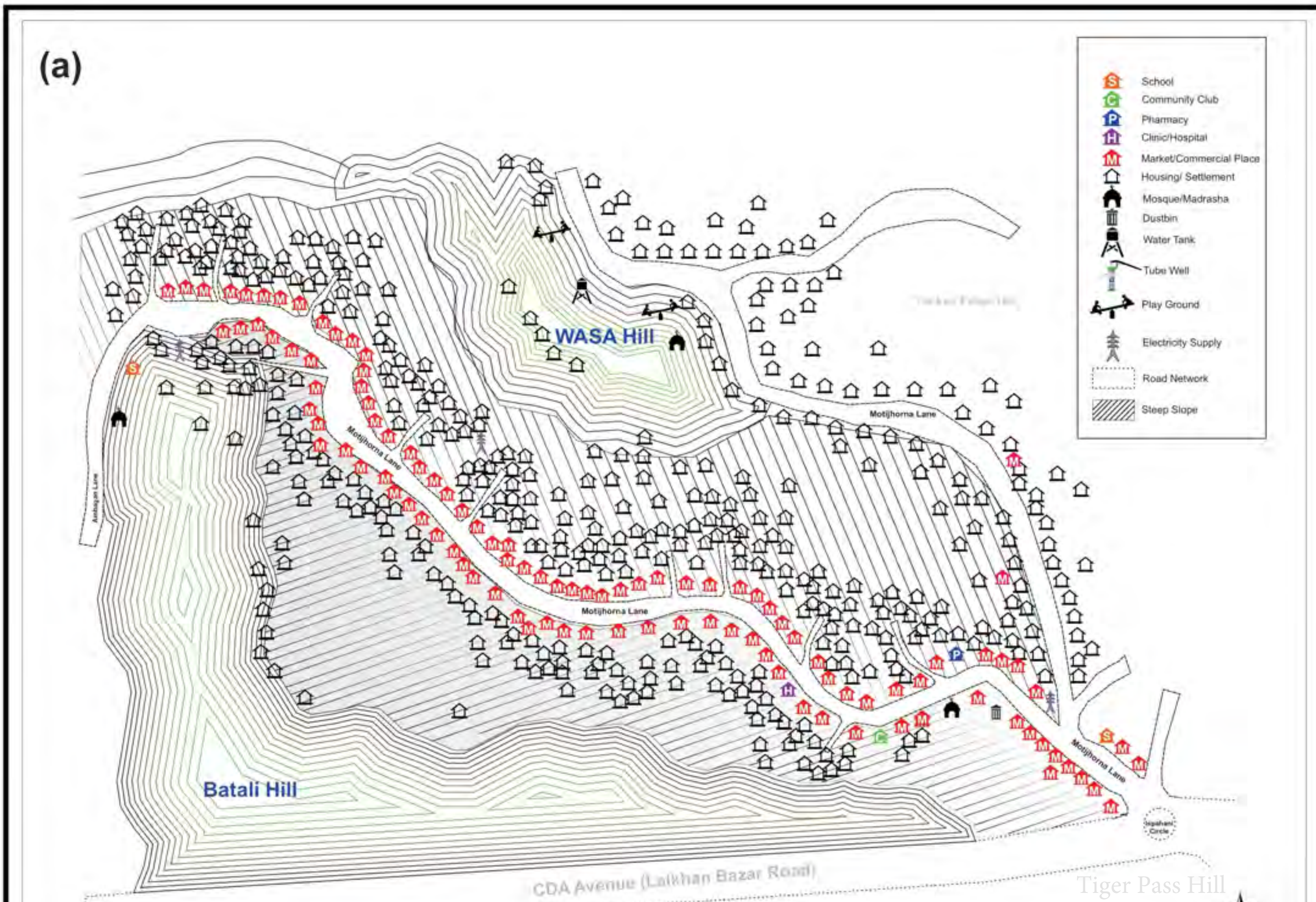
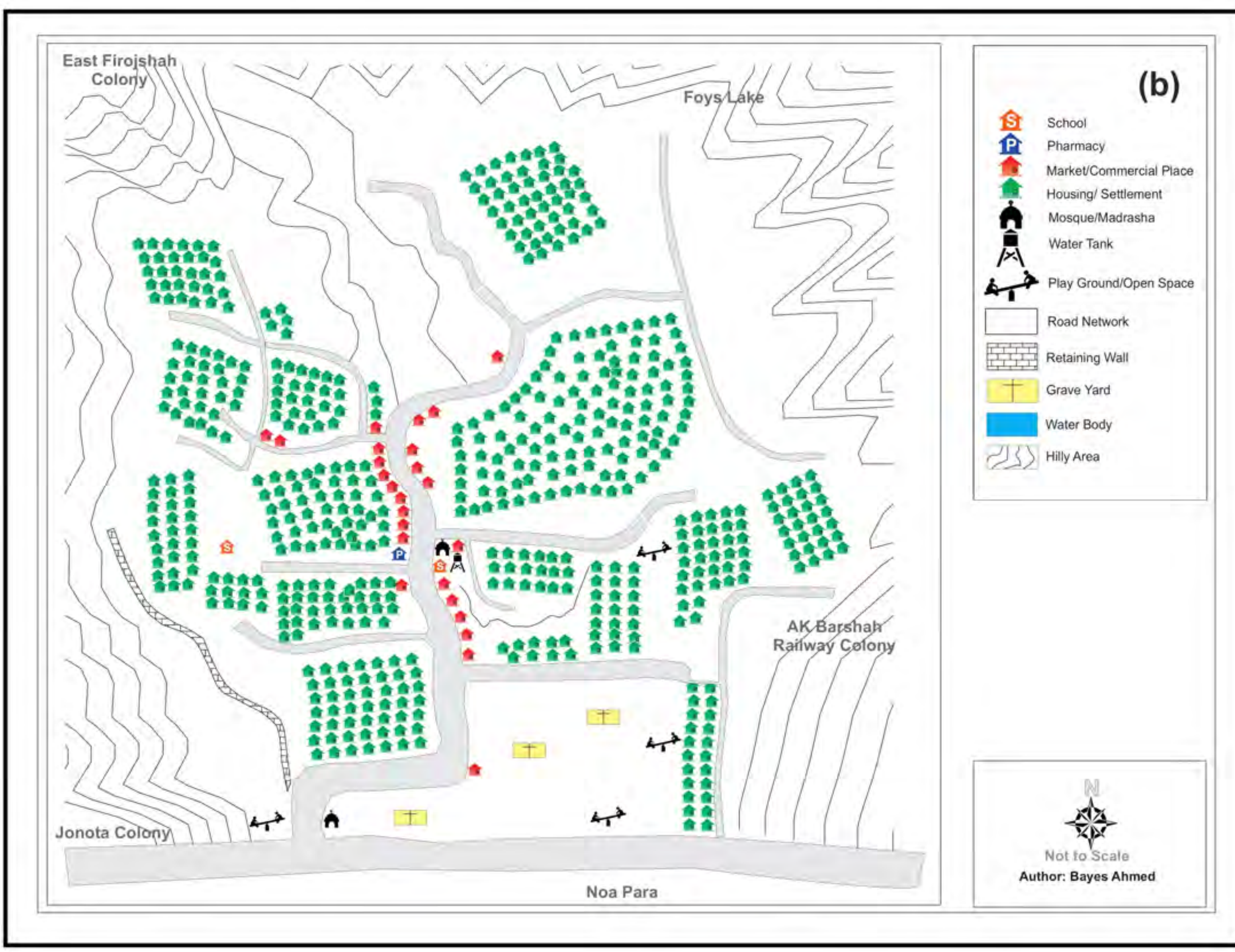


Fig. S1. Social and resource maps of (a) Motijharna (area approximately 0.21 km^2), and (b) Golpahar community (area approximately 0.2 km^2), CCC. Source: Community people, field survey, August 2014.



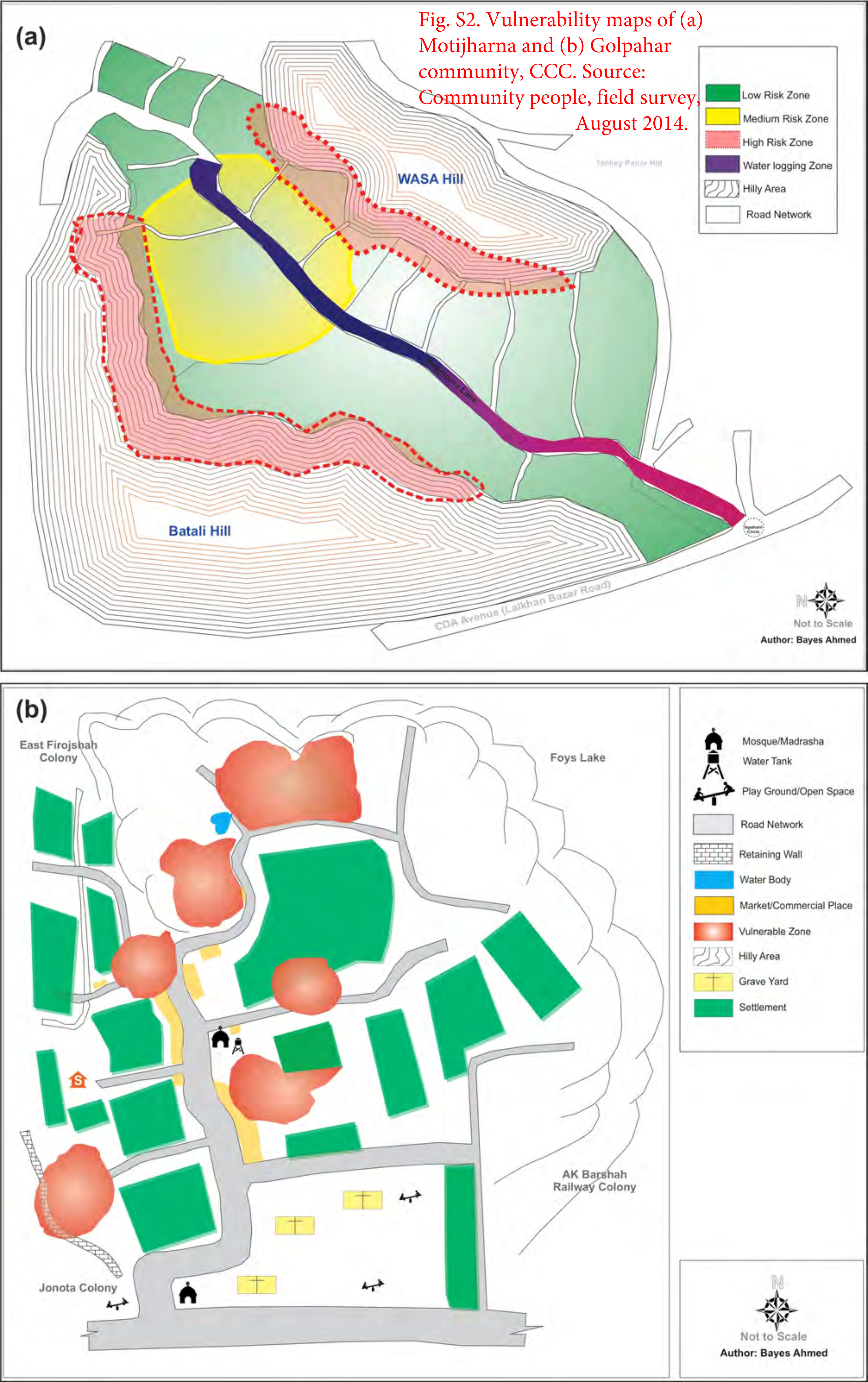


Fig. S2. Vulnerability maps of (a) Motijharna and (b) Golpahar community, CCC. Source: Community people, field survey, August 2014.

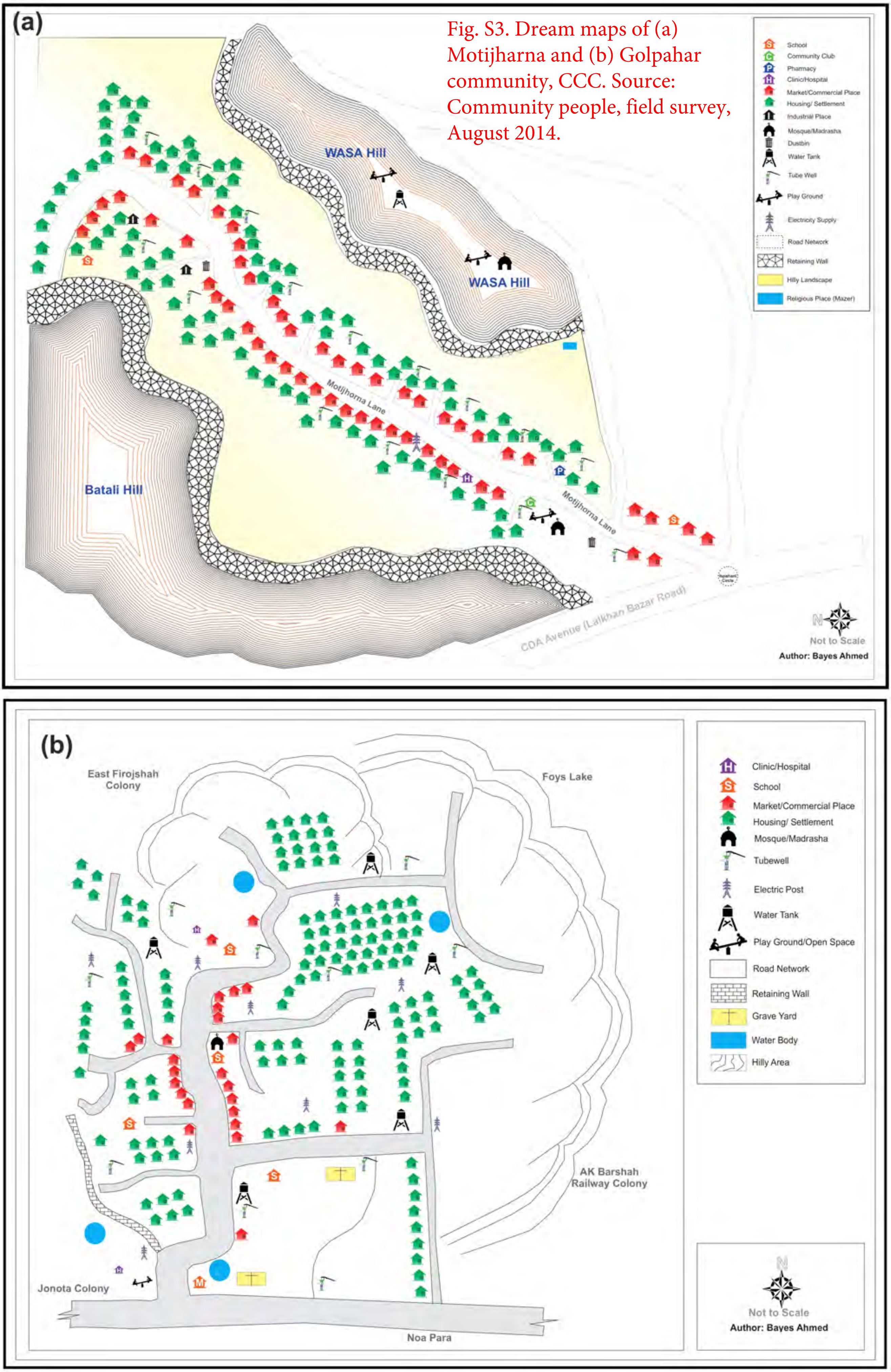
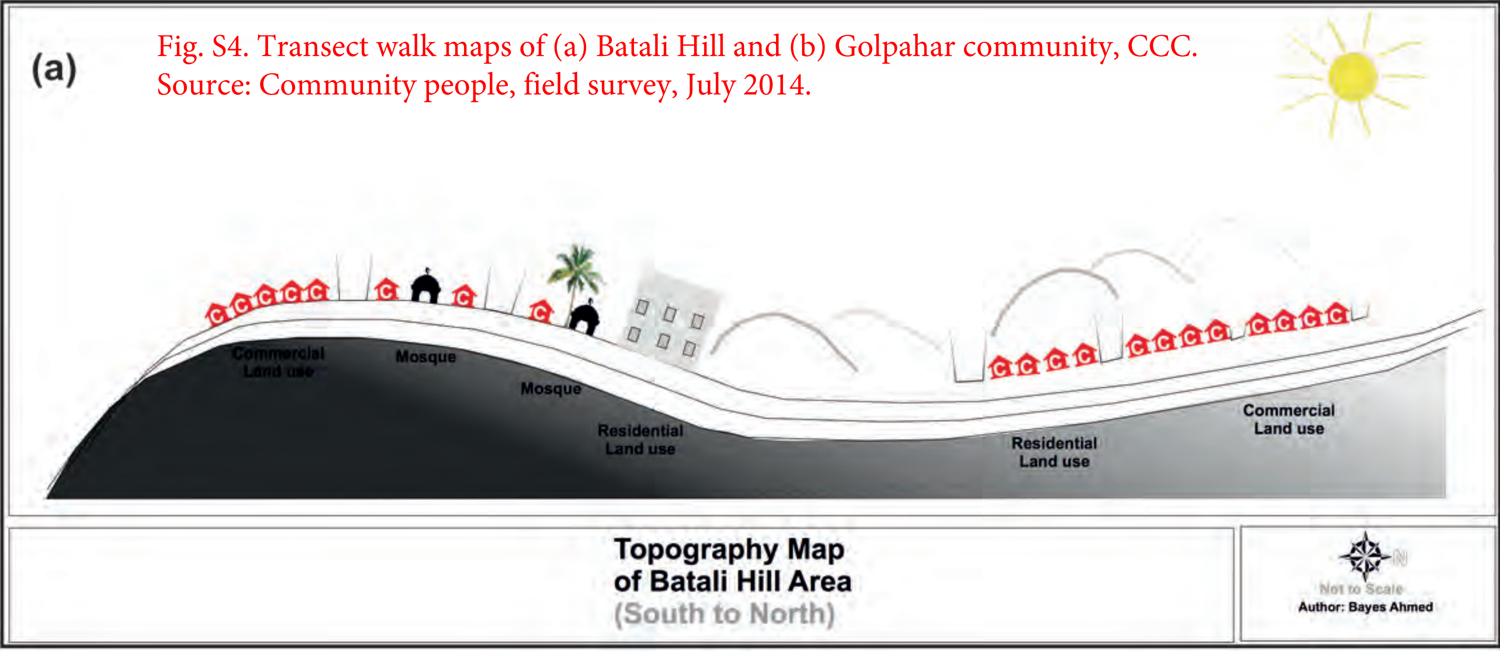
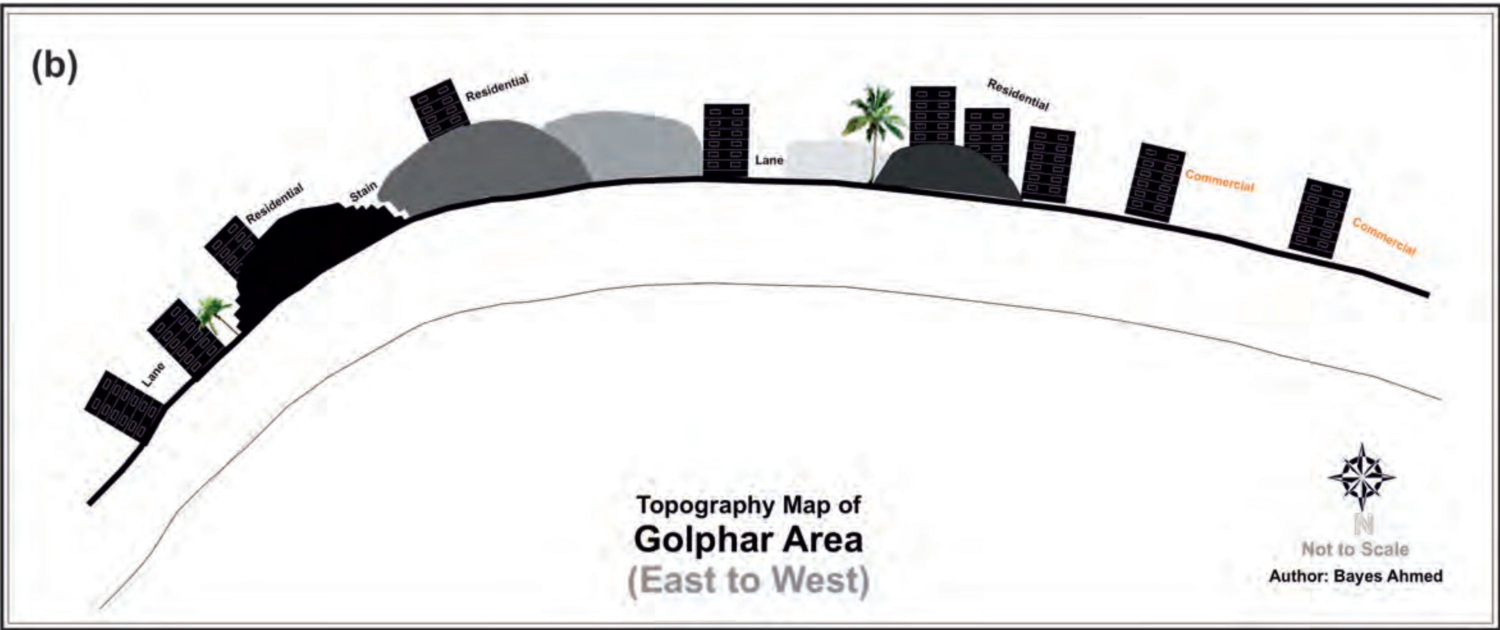


Fig. S3. Dream maps of (a) Motijharna and (b) Golpahar community, CCC. Source: Community people, field survey, August 2014.

Fig. S4. Transect walk maps of (a) Batali Hill and (b) Golpahar community, CCC. Source: Community people, field survey, July 2014.





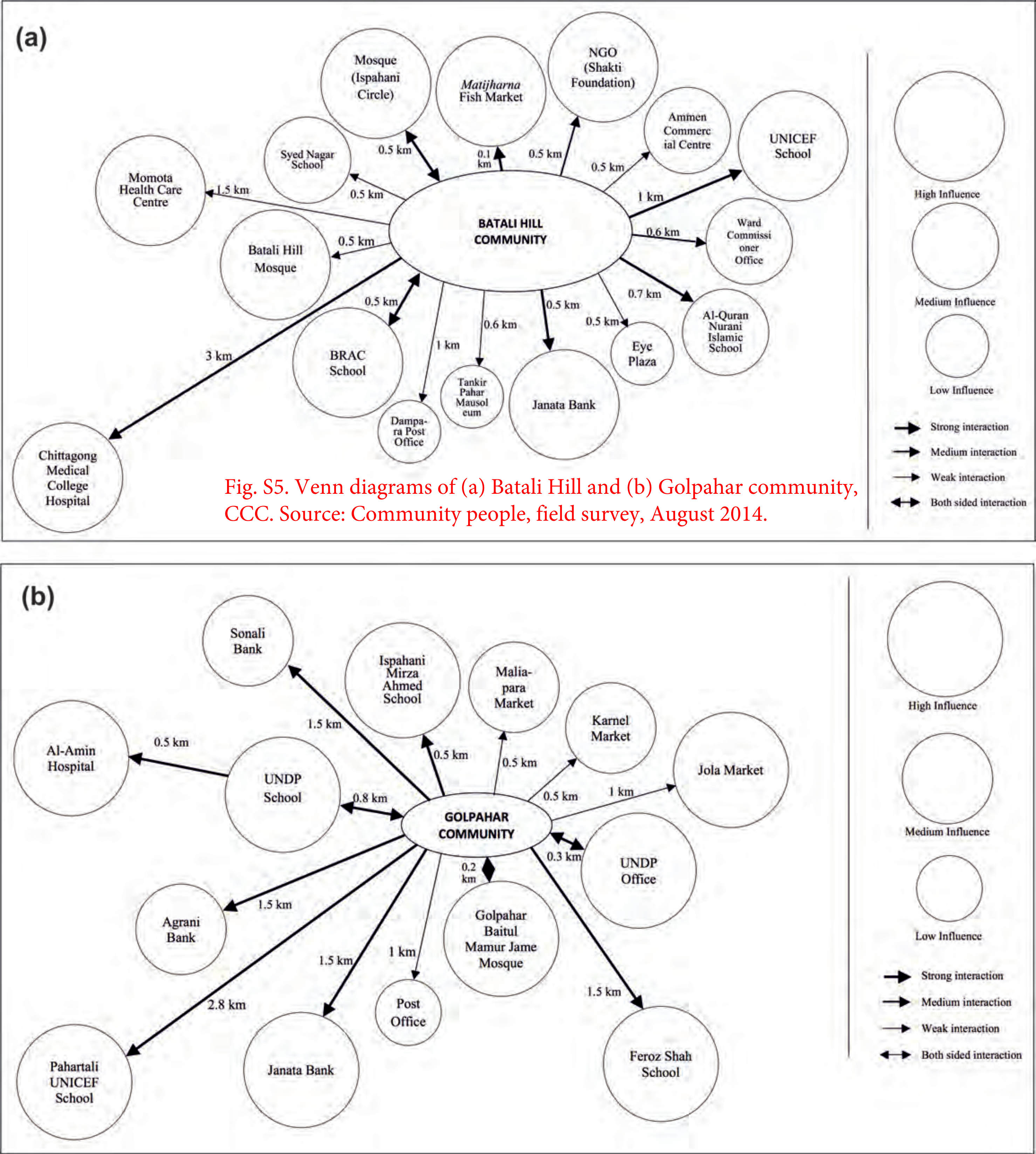


Fig. S5. Venn diagrams of (a) Batali Hill and (b) Golpahar community, CCC. Source: Community people, field survey, August 2014.

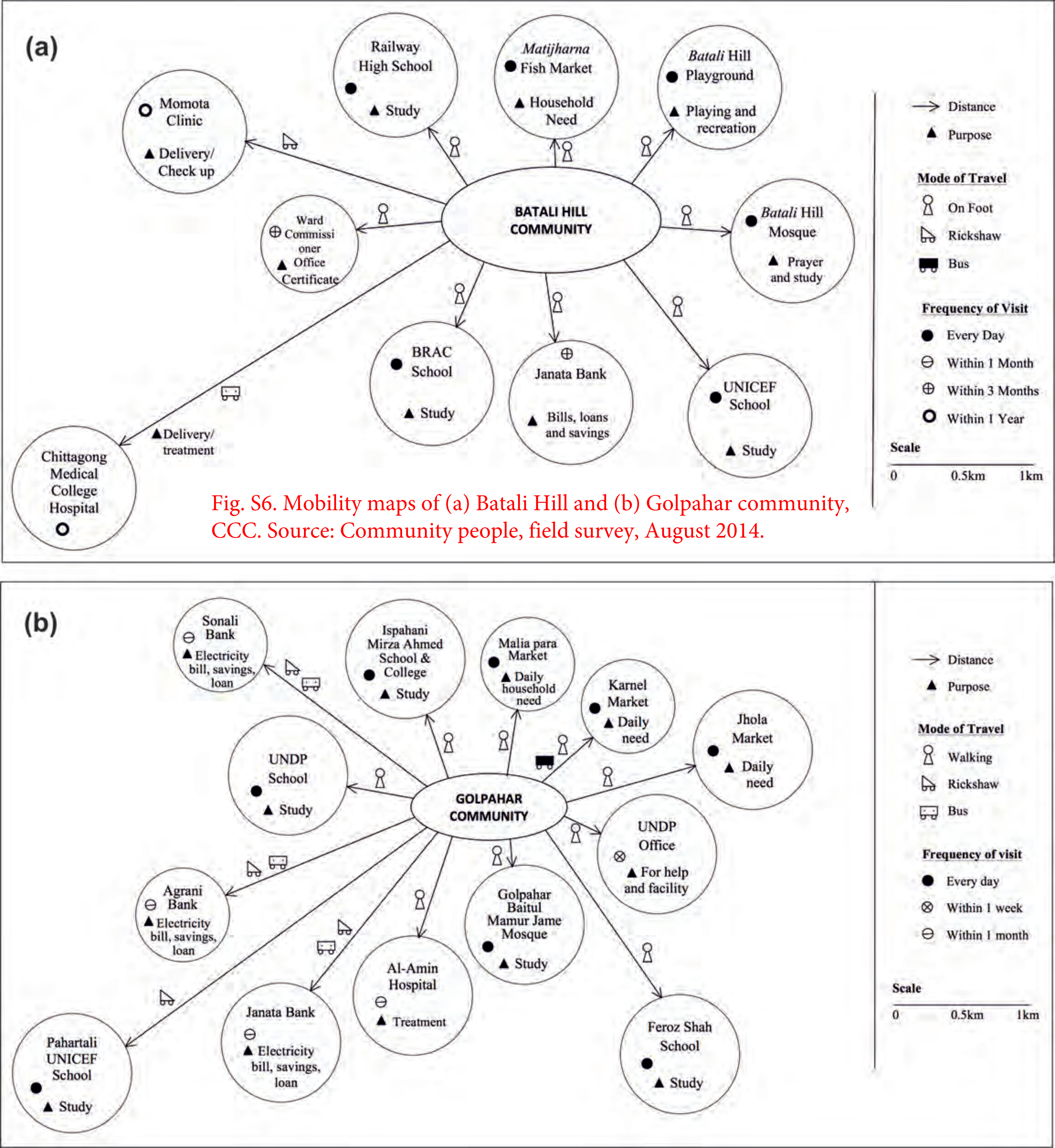


Fig. S6. Mobility maps of (a) Batali Hill and (b) Golpahar community, CCC. Source: Community people, field survey, August 2014.