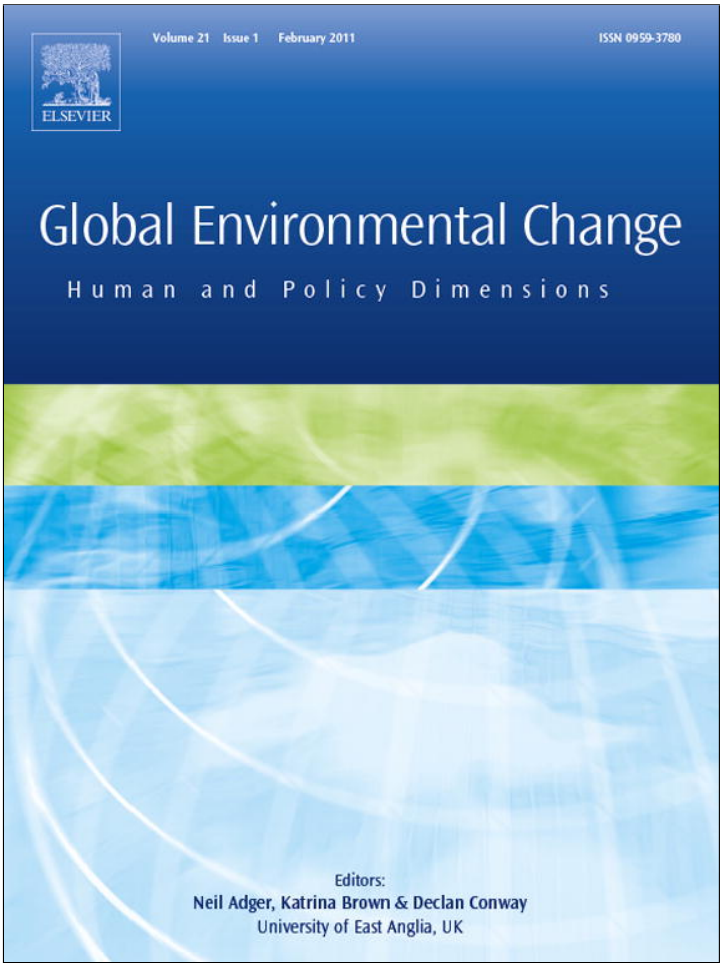
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Mainstreaming local perceptions of hurricane risk into policymaking: A case study of community GIS in Mexico

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ABSTRACT

This article suggests a framework for incorporating and communicating local perceptions of hurricane risk into policymaking through a case study conducted at El Zapotito commune in the State of Veracruz, Mexico. The authors constructed a geographical information system (GIS)-based model to quantify and spatially assess specific household-level vulnerabilities from information generated through interviews. This research developed a household vulnerability index applied to a participatory GIS to map vulnerability to hurricane hazard. The results indicate that infrastructural weaknesses are the most important factor contributing to vulnerability, explaining on their own 72.2% of the variation in the vulnerability patterns. These findings are corroborated by a vulnerability and capacity assessment (VCA), which shows that the community lacks strategies to cope with unsafe housing. It is suggested that linking community participation with modern techniques to analyse risk can empower communities and mobilise their capacities to address very specific vulnerabilities.

1. Introduction

Coastal societies are particularly vulnerable to rapid-onset disasters, such as hurricanes, flooding and drought. Disasters occur from the simultaneous incidence of hazard (the geophysical vulnerability) *and* vulnerability (the human risk) (Alexander, 1998). In the context of climate change, meteorological hazards as well as the potential for greater adverse impacts are becoming more severe (i.e. the geophysical vulnerabilities are increasing) (Pielke, 2005; IPCC WGI, 2007). The environmental management and policy challenges are further complicated as people increasingly settle in coasts (i.e. the social vulnerabilities are also increasing).

It is estimated that as many as 600 million people globally (and 50 million in the Gulf of Mexico) may inhabit hurricane-prone areas by 2100 (McGranahan et al., 2007). The exceptionally high hurricane season of 2005 in the North Atlantic showed the potential impact of climate-related hazards: hurricane activity is expected to increase in the Gulf of Mexico and category 5 hurricane events are likely to become more frequent (SEMARNAT and INE, 2010). At the community level in Mexico, losses resulting from hurricanes have increased over the last 20 years despite government interventions and NGO projects (Saldaña-Zorrilla, 2006). Indeed, the most significant impact of natural disasters is at the local level: there is destruction of human settlements and livelihoods, together with economic losses and injuries or loss of life in the affected areas (Kelly and Adger, 2000; Benfield, 2006). Institutions operating in Mexico, both at the national (federal and local governments) and international (non-governmental organizations) levels, lack sufficient analytical and financial resources to implement disaster policy to tackle household vulnerabilities.

Disaster risk policy has traditionally struggled to balance the tension that can often exist between central coordination and local conditions (Benson and Twigg, 2007). In Mexico, for instance, disaster policy is planned centrally by the federal government (through the Ministry of Civil Protection), but has difficulty accounting for local risk perceptions. Often, this results in a discrepancy between government interventions and the expectations in communities. Thus a significant challenge remains in developing a framework to mainstream local knowledge and experiences to inform disaster policy. In part, this is because of a lack of financial resources to analyse local contexts, but also due to a lack of instruments to allow people to use their experiential knowledge.

Nonetheless, the mobilization and empowerment of local capacities in disaster risk reduction strategies can provide local knowledge and expertise to assist in disaster management decision-making processes (Tran et al., 2009: 152; also Adger,

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1999; BCPR, 2007; Benson and Twigg, 2007; Bryant and Goodman, 2008; Wisner et al., 2004). Community-based disaster risk management (CBDRM) places affected communities at the lead of assessment, planning, design and implementation strategies while also focusing on identifying *local* capacities that can enhance resilience. The benefits of this direct involvement are twofold: first, external monitoring costs are reduced and second, disaster risk reduction is more likely to be effective if the community itself feels motivated to participate in disaster policy (Benson, 2009).

Integration of local knowledge and geographical information systems tools is important for effective disaster management policy for three reasons: (i) a vulnerability map can help in communicating local knowledge through a visual medium; (ii) local knowledge is crucial in reducing disaster risk at the community level; (iii) GIS maps that incorporate local knowledge generate information about very specific (community or household) vulnerabilities in a way that conventional maps cannot (Hatfield, 2006).

Mapping is one of the initial steps in understanding the factors leading to vulnerability and its distribution within a given community (Wisner et al., 2004). Advances in technology have increased the accessibility of GIS-based research, such that community data can be collected with global positioning system (GPS) devices. GIS has become increasingly used in community-based mapping methods (Peters-Guarín et al., 2005; Hatfield, 2006; Kienberger, 2007). There is significant potential for processing local knowledge and communicating *perceptions* of disaster risk through GIS maps. The integration of community perceptions of risk into GIS is a useful first step in the identification of vulnerability and can become a valuable tool in disaster risk reduction (Tran et al., 2009). However, few countries have detailed hazard/vulnerability maps because GIS is a relatively new technology and so access to data is limited (Hatfield, 2006). What little data are available are inconsistent: different government agencies have used different data collection methods and have therefore produced very inconsistent results (Tran et al., 2009). In Mexico, the Ministry of Civil Protection aims to produce detailed State-level hazard maps with a consistent geo-referenced dataset with data from national census and meteorological databases (SEMARNAT and INE, 2010). Such GIS hazard maps can help in (i) focusing disaster policy to assist vulnerable parts of States, and (ii) identifying which communities are most vulnerable (and thus where further research may be beneficial). More recently, participatory GIS methods have become a mechanism to communicate priorities of vulnerable communities for disaster risk reduction. For instance, such mapping techniques have been useful in georeferencing people's knowledge of frequency, intensity, location and impacts associated with frequent hazards such as floods where no official historical hazard records exist (Kienberger, 2007). Participatory GIS analyses can also be used to map social (e.g. caste), economics (e.g. income) and environmental (e.g. land use) differences which might render some households vulnerable and hence help prioritise action (Peters-Guarín et al., 2005). Recognising the potential contribution of participatory GIS in informing disaster management strategies, platforms to discuss limitations and good practices of participatory GIS such as PPgis (http://ppgis.iapad.org/) have been developed. Web-based services such as MapAction (http://www.mapaction.org/index.html), too, have become a source for up-to-date spatial data to assess and aid in emergency situations (McCall, 2008).

This article proposes an approach to include community participation in policymaking by using local knowledge and modern technologies to explain variations of *household* vulnerability at the community level. This is done through the application of a participatory geographical information system (GIS) to produce a household vulnerability map of a community, a vulnerability and capacity assessment (VCA) and a regression analysis. A vulnerability and capacity assessment corroborates other participatory methods, and is used (i) as a *diagnostic* tool to understand vulnerabilities and their context and (ii) to understand community perceptions of risk and disaster management (IFRC, 1999). A VCA considers the range of social, cultural, economic and institutional manifestations of vulnerability, as well as the ways in which vulnerable communities cope with these (IFRC, 2004). Instead of focusing solely on the *problems* (vulnerabilities), a VCA considers people's *skills* (capacities), and can provide policymakers with information on the specific actions needed to reduce risks as well as actions that communities are willing to do.

This three-step analysis illustrates (i) distributional patterns of household vulnerability, (ii) the impact of different risks on overall vulnerability, and (iii) what steps individuals, communities and local governments are ready to take to reduce disaster risks. In doing so, this article models the perceived vulnerabilities of the study site. The advantages and disadvantages of the mapping process are explored through a case study of the community of El Zapotito, located in the hurricane prone state of Veracruz, Mexico.

2. Materials and methods

2.1. Study site and risk characterisation

The research for this study was conducted at the El Zapotito community of the Ursulo Galvan municipality, located in the central part of the State of Veracruz, Mexico (Fig. 1).

Veracruz is an area of high vulnerability to hurricane risk due to (i) its location in the North Atlantic, a region of high hurricane activity and (ii) the extent of population living within 10 km of the coast (CICC, 2007). Much of the infrastructure is located in coastal zones, and 70% of the population lives (approximately 5 million people) within 25 km of the coast (SEMARNAT and INE, 2010; SPC, 2008).

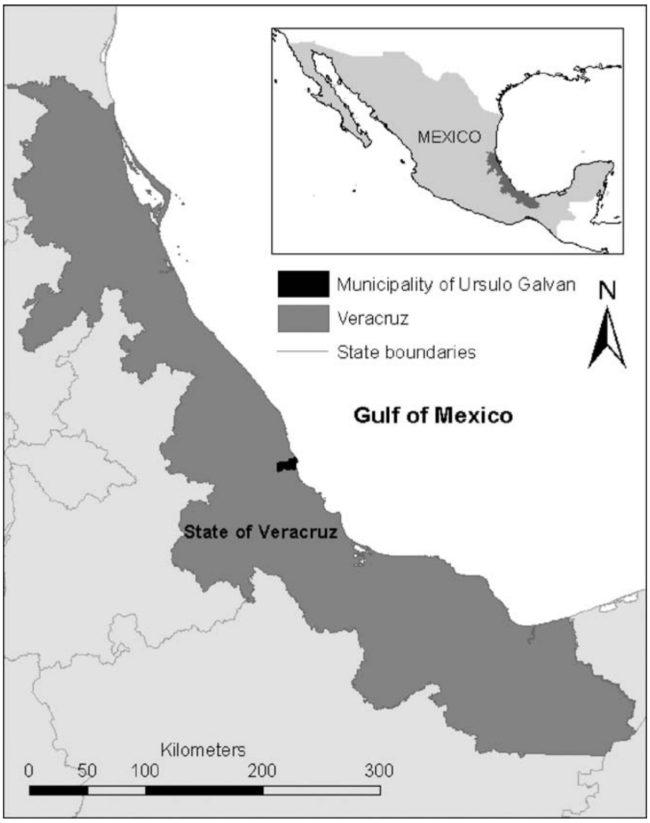

Fig. 1. Location of Ursulo Galvan in Veracruz.

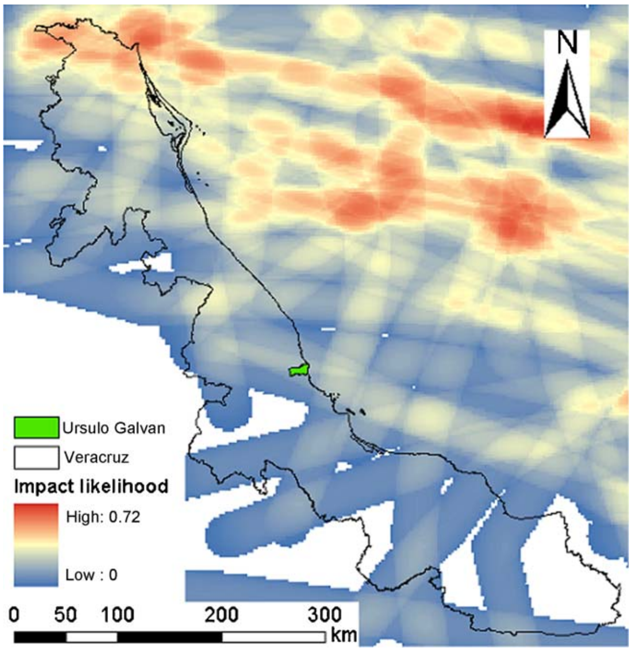

Fig. 2. Hurricane impact likelihood.

Hurricane trajectories in the period 1887–2007 have been mapped by the Ministry of Civil Protection with data obtained from historical records and global databases such as NOAA and EM-DAT (Ramón Pérez, pers. comm.). Based on the hurricane hazard map, Veracruz can be divided into three regions according to hurricane activity: the Northern part is highly vulnerable, the Central part is moderately exposed, and the Southern part has low risk (Fig. 2; SNPC, 2009). Indeed, estimates indicate that 60% of all hurricanes forming in the North Atlantic affect the Northern region of the State; 25–30% affect the Central part, and 10–15% affect the South (Jonathan Pérez, pers. comm.). These probabilities can be interpreted with Fig. 2 below which shows the hurricane impact likelihood, construed in terms of the modelled probability that a cyclone will pass through a given trajectory (areas shown in red are more likely to be affected by either increased wind or precipitation (For interpretation of the references to color in this sentence, the reader is referred to the web version of the article.)).

The municipality of Ursulo Galvan is located in the area of medium to high risk. Areas that are exposed to hurricane risk (measured in terms of flooding) have been identified. Fig. 3 shows the flood risk areas overlain on a transparency obtained from Google Earth; the satellite image clearly shows the difference between the urban centres (near the coast) and the rural areas (further inland). Among the vulnerable rural areas is El Zapotito, a community of 310 inhabitants located 8.2 km from the coast, which is chosen for the present study.

The community of El Zapotito has been affected in recent times by three major hurricanes (categories 4 or 5): Hurricane Janet (September 21–30, 1955), Hurricane Debby (August 31–September 8, 1988) and Hurricane Dean (August 13–23, 2007) (Gobierno Estatal de Veracruz, 2009). The site is selected for this study because it is considered one of the most hurricane-prone areas in the State. The hurricane risks were manifested in terms of high wind-speeds (reaching 280 km/h) and inundations (all households have flooded during major hurricane events). Minor storms affect the region every year, but the impacts are less severe. In these cases, the risks can be explained in terms of rising water levels, with immediate threats only to the households on the riverside.

The detrimental impacts of hurricanes have encompassed a variety of material losses, including loss of domestic goods (ovens, beds), animals for household consumption (chickens, pigs) and damage to infrastructure (especially to houses built out of plastic, cardboard or wood). The main economic activity in the region is monocrop sugarcane agriculture, and it is the main source of

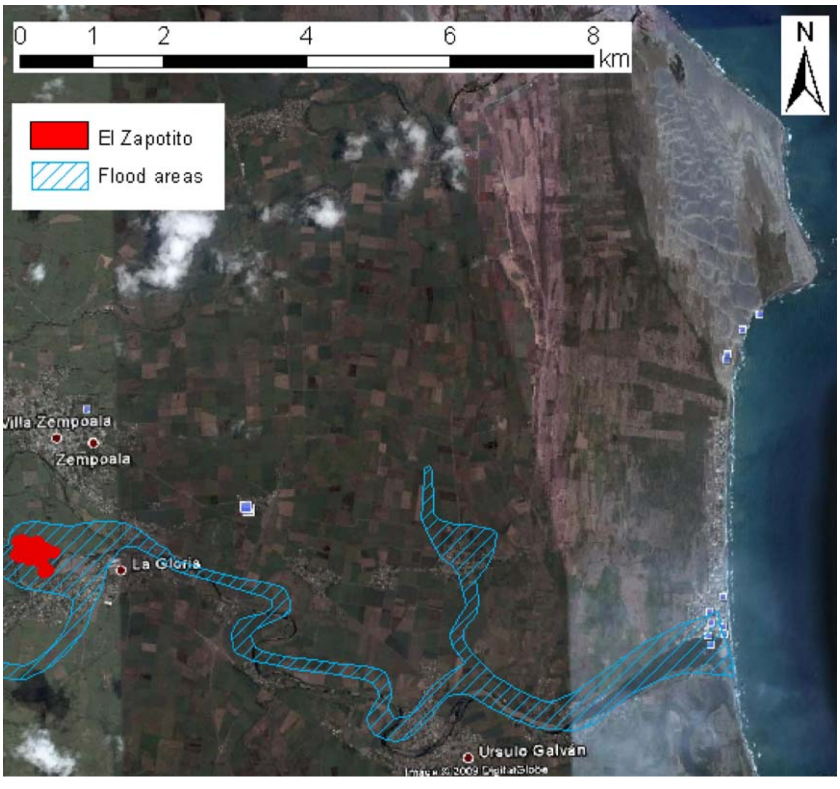

Fig. 3. Hurricane flood risk in the municipality of Ursulo Galvan, showing El Zapotito.

income for over 70% of households in the community (INEGI, 2009b). Sugarcane is the crop of choice due to its resilience (it can tolerate wind-speeds exceeding 100 km per hour and can withstand heavy rainfall and flooding better than any other crops grown in the region). Labour patterns are centred on the crop cycle of sugarcane. Consequently there is a significant shortage of jobs after the harvest period *and* during the hurricane season (due to storm surges and floods). The majority of the workforce (85%) is composed of landless labourers (with an income of 100 Mexican pesos, or approximately US$7.65, per day) and therefore there is little job security. Labour is concentrated during an 8-month period and alternative/temporary jobs have to be found for the remainder of the year. According to the interviews, the members of El Zapotito have conceptualised hurricane risks in terms of the detrimental impacts on their livelihoods.

Evacuation in the community is difficult as it lies on a floodplain. During major hurricane events, the roads that link the community with the federal road network are flooded, thus completely isolating the area. For instance, during Hurricane Dean (2007), all evacuation routes were flooded and the community was *incommunicado*. Heavy rains resulted in landslides and strong winds produced waves, making evacuation even more difficult. The lack of purpose-built safe shelter in the immediate surroundings further challenges the implementation of short-term evacuation plans. The Ministry of Civil Protection responded by sending helicopters to assist the population that remained in the site (Jorge Zamudio, pers. comm.). The government has focused efforts on facilitating evacuation by building bridges and roads that can permit the community to escape during a storm surge. This experience shows that there is a discrepancy in the way disaster risk reduction is perceived by communities and policymakers; the former consider vulnerability in terms of livelihood deterioration whereas the latter regard it as a problem of evacuation. The experience of Hurricane Dean highlights the importance of reducing disaster risk by identifying risk areas, warning the population, and diversifying livelihoods as strategies to mitigate disasters.

2.2. Vulnerability mapping

The method used for this paper consisted of two components: (i) community-based GIS mapping of hurricane hazard, and (ii) vulnerability and capacity assessment (VCA); both from information generated through discussions in focus group meetings in the community (Fig. 4).

The aim of the participatory GIS was to involve the community members and to use local knowledge during the entire mapping process. A focus group consisting of 38 voluntary participants from

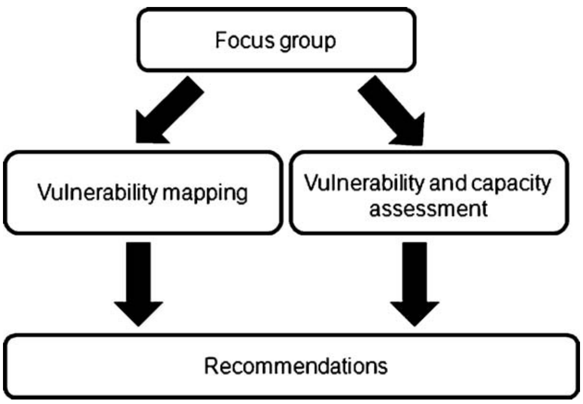

Fig. 4. Methodological flowchart. The flow chart shows the method used (focus group), the outputs (a GIS vulnerability map and a VCA), and the purpose (recommendations to reduce disaster risk) of the paper.

Table 1
Primary data collected for vulnerability mapping.

Factor	Variable	Measure
Exposure	Proximity to river	Metres
Economic risk	Main source of income	Economic activity
Social risk	Children	Number of children
	Women	Number of women
	Men	Number of men
Physical risk	House type	Dominant material of construction
	Roof type	Material
	Floors	Number of floors

the community was organised; the community members were invited to participate through an announcement given by the commune leader at the local chapel. The community members were asked to identify and rank the relative importance of the factors that lead to their vulnerability during hurricane events. From this exercise, the following data were collected: proximity to the Actopan River (exposure); main source of income (economic vulnerability); house type, including material of construction, roof type and number of floors (physical vulnerability); demographic conditions at the household level (social vulnerability) (Table 1). These indicators were identified through participatory methods (focus groups) and are thus used as proxies of community perceptions of risk.

One-third of all houses in the survey (n = 54 of 162) were visited to record the GPS coordinates of the household, to visually identify and classify the house type, to survey the demographic composition and to interview the occupants on their sources of income. Data were processed on ArcGIS (version 9.3), with each household was presented as one point according to its GPS coordinates, based on the attributes in Table 1. The head of the household was registered (to aid policymakers and the community members identify the individual houses) but is not shown in this paper for anonymity; instead, a household identification number is used.

The base map is an overlay of the river network (obtained from data provided by the Ministry of Civil Protection) and an interpolation of household vulnerability using surface spline to show the spatial distribution of vulnerability. All data were projected onto UTM, WGS84, with a latitude–longitude coordinate system. To produce the vulnerability map, the severity of each qualitative characteristic outlined in Table 1 was classified from very low to very high vulnerability based on the experiences of the community (Table 2). The results are subsequently analysed through a regression model to identify the relative impact of each risk on overall vulnerability.

2.3. Vulnerability and capacity assessment

The VCA was conducted during the focus group discussion, where 38 community members were asked to identify household vulnerabilities and the mechanisms used to cope with these. All of these factors were recorded and classified according to four categories (social, physical, economic and environmental) which correspond to the four risks that were used to map vulnerability (social, physical, economic and exposure). The vulnerability and capacity assessment is used in this paper to corroborate the results of the risk mapping exercise.

3. Calculation

3.1. Household vulnerability index

Individual and community vulnerabilities to hurricane events arise from a combination of geographical factors (and their resulting environmental impacts) as well as specific (social,

Table 2
Relative severity for major factors in terms of hurricane risk potential.

Risk severity	Very low	Low	Medium	High	Very high
Proximity to river	>20 m	16–20 m	11–15 m	5–10 m	<5 m
Main source of income	Permanent/pensioner/ multiple sources	Skilled labour (permanent), e.g. taxi driver	Skilled labour (temporary), e.g. plumber	Agriculture (permanent), e.g. small landowner	Agriculture (temporary), e.g. landless labourer
Children	<2	2	3	4	>4
Women	0	1	2	3	4
Men	<2	2	3	4	>4
House type	Solid, e.g. concrete with secure doors *and* windows	Solid, e.g. thick brick with secure doors and/or windows	Reinforced, e.g. reinforced concrete materials with repaired insecure parts	Semi-solid, e.g. some solid materials but with unrepaired insecure parts	Temporary, e.g. cardboard or plastic house, often without proper roof
Roof type	Permanent, e.g. concrete	Solid, e.g. brick	Semi-solid, e.g. corrugated metal or tiles	Temporary, e.g. cloth or cardboard	Makeshift roof
Floors	2	–	–	–	1

economic and domestic) contexts (Alexander, 1998). The interaction of these factors determines the relative vulnerability of a household. Therefore, this research considers vulnerability as the likelihood of loss per household resulting from the interaction of hazard exposures and social, economic and infrastructural risks. The factors influencing household vulnerability can hence be described as follows:

$$\text{Vulnerability} = f(\text{exposure},\ \text{economic vulnerability},\ \text{social vulnerability},\ \text{physical or infrastructural vulnerability})$$

and are further explained in the following model:

$$\text{Vulnerability index} = \left(\sum_{i=1}^{m} a_i E_i\right) \times \left(\sum_{j=1}^{n} b_j EV_j\right) \times \left(\sum_{k=1}^{p} c_k SV_k\right) \times \left(\sum_{l=1}^{q} d_l PV_l\right)$$

where a_i, b_j, c_k and d_l are the weights of exposure i (E_i) (weighting = 5, for proximity to river), economic vulnerability j (EV_j) (weighting = 4, for source of income), social vulnerability k (SV_k) (weighting = 2, for number of children; weighting = 2, for number of women; weighting = 1, for number of men) and physical vulnerability l (PV_l) (weighting = 4, for house type; weighting = 3, for roof type; weighting = 2, for number of floors) respectively; the derivation of the weightings is explained below. And m, n, p and q are the total numbers of hazard, exposure and vulnerability factors respectively. All values are normalised, with 1 as the maximum value for each of the indicators. Indicators are thus expressed as percentages of the maximum value divided by 100. The maximum value of the index is also normalised to 100.

The measurement of exposure (E_i) can be problematic as different hazards require different measures of "impact": for instance, exposure to earthquakes could be measured in terms of distance to the epicentre while flood levels are more useful in assessing vulnerability to flooding (Coch, 1995). Conceptualising exposure in the context of hurricane hazard is a complex process because there are two interrelated risks associated with hurricanes: high wind speeds *and* increased precipitation. Wind might create risks by damaging households and through injuries from flying objects. After a discussion with the community, however, it was decided that wind should not be included in this study because the El Zapotito commune is located on a topographically homogeneous site, rendering all households equally vulnerable to wind speed, *ceteris paribus*. Risk from increased precipitation could be confused with a flood because households affected during flooding events are more likely to be affected by the hydrological impact of hurricanes (Sugi et al., 2002). For the purposes of this research, exposure is defined as the *likelihood* of loss in a hurricane and is measured by the proximity of the household to the Actopan River. The economic vulnerability (EV_j) quantifies the ability of a household to recover from a hazard event. Different measures of economic vulnerability could be used. Such measures include average annual income or the main source of income. For the purposes of anonymity, the latter is considered—this indicator further measures household vulnerability by considering *when* labour and income available. Thus, economic vulnerability is defined in this model in terms of the main source of income in the household. Social vulnerability (SV_k) is an indicator which examines which members of society are more vulnerable to hazards. Social vulnerability is defined in terms of household demographic composition, with children and women being the most vulnerable members. Physical vulnerability (PV_l) refers to the infrastructural characteristics of the household, measuring vulnerability according to the household's physical ability to withstand a hazard. A resistant house can provide security for a family and its possessions during a hurricane event. For this model, physical vulnerabilities are: house type, roof type and number of floors.

The weightings attributed to each of the indicators were defined subjectively on a scale of 1–5, with recommendations of the El Zapotito commune. For this, the community members were asked to rank the indicators collectively and consensually. The discussion highlighted that the poorest families are more prone to settle in densely populated, temporary one-storey households, and often very close to the riverbank. Proximity to the river was considered to be the most important factor (weighting = 5). Economic security measured in terms of income sources was considered to be highly important in determining overall household vulnerability, but less so than distance to the river (weighting = 4). Infrastructural security was considered the third most important factor. Of these, house type was deemed an equally important factor (weighting = 4) followed by roof type (weighting = 3) and number of floors (weighting = 2). Finally, the demographic composition (social vulnerability) was regarded as the least important factor. Children under the age of 5 are considered the most vulnerable members of the community (weighting = 2); women were considered equally vulnerable (weighting = 2); and men are considered to be the least vulnerable members (weighting = 1). Indeed, strong social ties were thought to be the most important *capability* of the community, so social vulnerabilities were considered to be of lesser importance. Values associated with the model were divided into five different ranges using the quintile method, with each range cumulatively representing 20% of the maximum vulnerability.

Table 3
Criteria for hurricane vulnerability of each household.

Vulnerability index	0–20	21–40	41–60	61–80	81–100
Severity of vulnerability	Very low	Low	Medium	High	Very high

Using the composite score obtained from the model devised in this study, each point (household) was assigned a value which allowed for the ranking of its vulnerability to hurricanes. Values were divided into quintiles, with each quintile assigned a qualitative indication of severity (Table 3).

The household vulnerability index is calculated by the following formula (two examples are shown in Table 4):

$$\begin{aligned}\text{Household vulnerability} = {} & 5(\text{proximity to river}) \\ & \times 4(\text{income source}) \\ & \times [2(\text{number of children}) \\ & + 2(\text{number of women}) \\ & + 1(\text{number of men})] \\ & \times [4(\text{house type}) + 3(\text{roof type}) \\ & + 2(\text{number of floors})]\end{aligned}$$

4. Results

4.1. Household vulnerability index

The mean and variance for the household vulnerability index variables are shown in Fig. 5. The results indicate that the average household has a low score for all of the indicators, except for the number of floors (most households have one floor) and the income source (the majority of workers are landless labourers). The smallest variance is for the demographic indicators suggesting that household composition is similar across the community. It is therefore expected that social vulnerability will have the lowest impact on overall vulnerability. The indicators of physical vulnerability have relatively low means (except for the number of floors) and small variance, suggesting that the majority of households are made of similar materials. It is expected that their impact on overall vulnerability will be comparatively small. Further, the indicator of economic vulnerability (income source) has a high mean but small variance (because the majority of farmers are engaged in similar activities). Hence, it is expected that, while economic poverty may have an important impact on household vulnerability (cf. Devereux, 1993), it will not help explain the variations in household vulnerability. The largest variance is for the indicator of exposure (proximity to the river)

Table 4
Example of households with very low and very high vulnerability scores (relative values expressed as fraction of maximum value are shown in [] brackets; weightings are shown in {} brackets).

Household ID number	15 (very low vulnerability)	32 (very high vulnerability)
Exposure	Proximity to river: 117 m [0.007] {5}	Proximity to river: 0.38 m [0.981] {5}
Economic risk	Income source: remittances [0.75] {4}	Income source: landless labourer [1] {4}
Social risk	Number of children: 1 [0.167] {2}	Number of children: 3 [0.5] {2}
	Number of women: 1 [0.125] {2}	Number of women: 1 [0.125] {2}
	Number of men: 1 [0.167] {1}	Number of men: 1 [0.167] {1}
Physical risk	House type: permanent (cement) [0.2] {4}	House type: temporary (plastic) [1] {4}
	Roof type: solid (cement and tiles) [0.1] {3}	Roof type: semi-solid (corrugated metal) [0.2] {3}
	Number of floors: 1 [1] {2}	Number of floors: 1 [1] {2}
Normalised vulnerability index	17 (very low)	93 (very high)

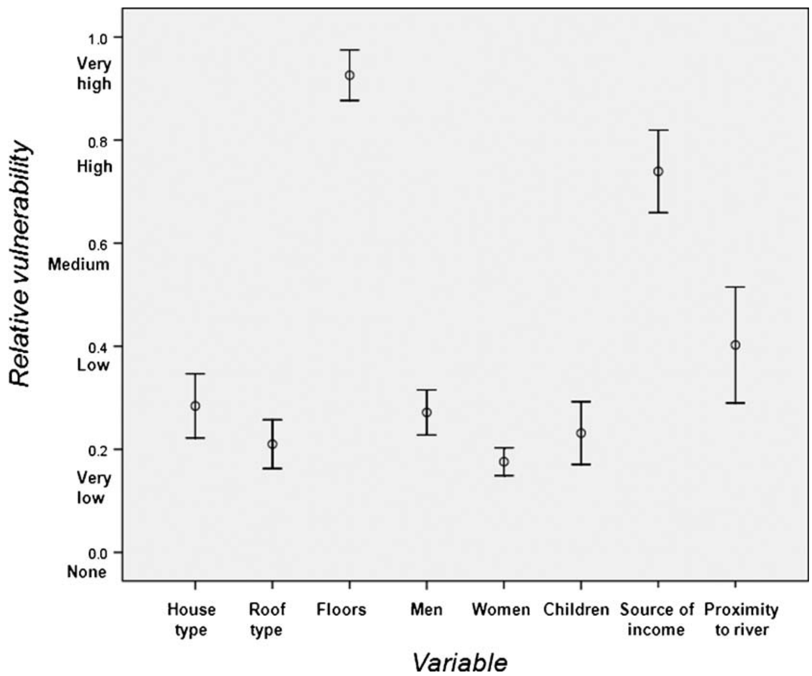

Fig. 5. Normalised mean and variance for the household vulnerability index variables.

Table 5
Hurricane-related vulnerabilities and capacities of different sectors at the El Zapotito community, Veracruz State, Mexico.

Sector	Vulnerabilities	Capacities
Social	• Lack of mobility (absence of evacuation routes) • Occupation of unsafe areas • High-density occupation of households • Vulnerable groups • Low perception of risk • Lack of disaster preparedness • Corruption	• Improvisation of evacuation routes (knowledge of the surroundings) • Designing alternative warning systems • Memory of past disasters and coping strategies • Social capital: communities helping each other • Local leadership
Physical	• Unsafe infrastructure and critical facilities • Buildings at risk	• Resilient constructions/artificial barriers that cope with and resist extreme events Insurance (secure livelihoods)
Economic	Temporary/unstable employment • Monocrop agriculture • Subsistence economies • Welfare dependency	• Financial reserves • Diversified agriculture
Environmental	• Destruction of natural storm barriers (environmental degradation) • Deforestation • Climate change	• Choice of resilient crops • Creation of natural barriers to storms (e.g. agroforestry techniques) • Reforestation (hurricane-resilient crops or plants) • Responsible resource management

suggesting that the geographic distribution of households is highly unpredictable and may be linked to household poverty (cf. Adger et al., 2005). Furthermore, it is expected that exposure will help explain the geographical patterns of vulnerability in the study area.

4.2. Vulnerability map

Households are shown as circles and classified according to the severity of their hurricane vulnerability in a household vulnerability map (Fig. 6). The mapping process shows a skewed distribution of vulnerability across the study area. The households with very high vulnerability to hurricane hazard are located near the Actopan River in the central part of the study area (shown in dark red (For interpretation of the references to color in this sentence, the reader is referred to the web version of the article.)). The majority (70%) of households with medium vulnerability scores are located in the northwestern part of the study area (green and light blue). The households with the lowest vulnerability scores are located in the northern and southernmost parts of the study area (dark blue).

4.3. Vulnerability and capacity assessment

The findings of the vulnerability and capacity assessment conducted at El Zapotito showing vulnerabilities alongside capacities are summarised below, in Table 5. The exercise shows 'weaknesses' and how people overcome them through their interaction with the physical and social environments. The results indicate that the community of El Zapotito has the least capacity in dealing with infrastructural weakness—and indeed, the capacities to deal with infrastructural weaknesses are often improvised. The community also perceives potential vulnerabilities arising from long-term environmental change, particularly in the form of deforestation, land degradation and climate change—capacities to deal with environmental degradation often relate to community-

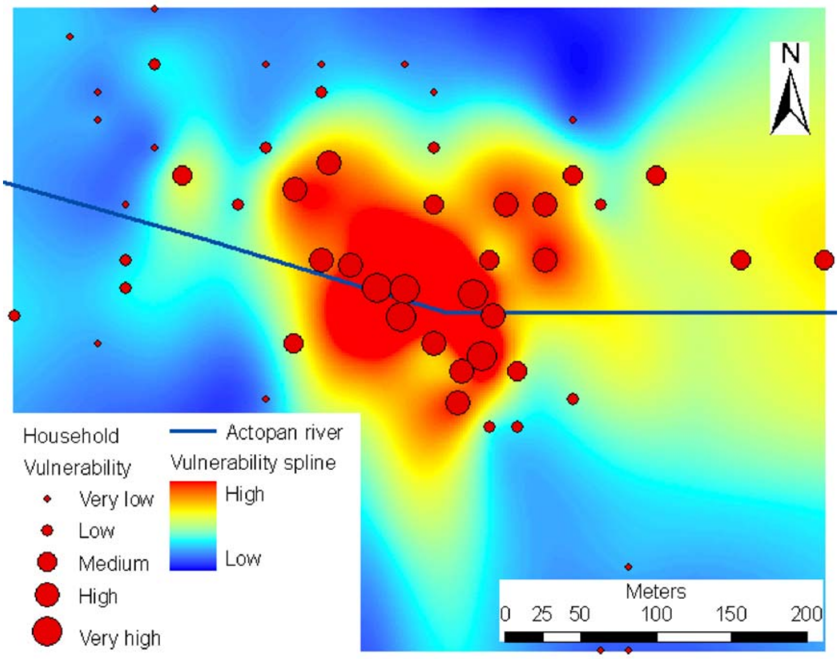

Fig. 6. Household hurricane vulnerability map of El Zapotito commune.

Table 6
Statistical relationships between the risks and household vulnerability.

Parameter (risk)	Regression weighting	*p*-Value	Correlation to vulnerability
(Constant)	−42.617	<0.05	–
Exposure	0.436	<0.05	0.361
Economic	0.369	<0.05	0.428
Social	0.196	<0.05	0.347
Physical	0.615	<0.05	0.722

based resource management. Moreover, the community members explained that the two most important capacities to reduce hurricane risk are strong social ties and localised knowledge of the environment. The VCA highlights that a strong sense of connectedness encourages cooperation throughout a hurricane event through early warning, relocation and evacuation of valuables and people from unsafe areas, and through post-disaster recovery. Additionally, knowledge of the locality allows community members to improvise evacuation routes and to select the most resilient income sources (in this case, sugar cane). The outcomes of the VCA therefore corroborate the findings of the risk mapping exercise and are used to identify patterns of vulnerability.

4.4. Relationship between indicators and vulnerability

This study carried out a regression analysis to examine the relationship between the specific risk factors and overall vulnerability. All risks have positive relationships with vulnerability, indicating (as expected) that reducing any of these factors will reduce household vulnerability (Table 6). All risks are statistically significant with a 95% confidence level (model $R^2 = .828$).

$$\begin{aligned}\text{Vulnerability} = & -42.617 + 0.316\,(\text{exposure}) \\ & + 0.369\,(\text{economic\_vulnerability}) \\ & + 0.196\,(\text{social\_vulnerability}) \\ & + 0.615\,(\text{physical\_vulnerability}) + \varepsilon_i\end{aligned}$$

Proximity to the Actopan River is one of the important factors leading to household vulnerability to hurricanes in El Zapotito village (explaining, on its own, 36.1% of the variability in household vulnerability). The poorest families tend to settle near the riverbank (Fig. 7). Further, households located near a river are prone to flash floods, erosion and inundation during a hurricane event (Smith, 2004). The survey found that four households (7.4%) are located in the riverbank (within 1 m of the River). Further, seven of the households surveyed (13%) are very near the riverbank (within a 10 m buffer zone). Families living in these exposed households should be warned of hurricane trajectories that may affect them as early as possible in order to plan evacuation and protection of their goods. A majority of households (59%) are located within 75 m of the River. Preventive measures (such as safe shelters or protective walls) can be put into practice to reduce the impacts of hurricanes.

Fig. 7. Temporary house located in the riverbank in El Zapotito. Temporary households are more exposed and more vulnerable to hurricane activity.

Economic vulnerability accounts for 42.8% of the variance in household vulnerability. Economic power can determine the ability of a household to cope with hazards and recover after a disaster. Moreover, low economic vulnerability encourages investment in long-term adaptation, for example by buying protective walls or better construction materials (Smith, 2004). In the context of the community, economic vulnerability is not the most important variable; this can be explained by the fact that almost all the workforce in the community (85% of the sampled households) works as landless labourers so it is difficult to differentiate their economic vulnerabilities. Remittance income might also serve as a strategy for risk reduction. Unlike other income sources, remittances are constant and therefore allow households to absorb shocks: in other words, migrant labourer income might serve as a form of insurance that can be used in emergencies to buy essential goods (such as food) or to reconstruct a house (World Bank, 2006). Three of the households in the study claimed remittances as their main source of income and also scored low in the overall vulnerability index, suggesting that remittances may play an important role in enhancing adaptive capacities.

Social vulnerability is the factor that contributes least to overall vulnerability ($r = 0.347$). Population density affects the ability of a household to evacuate (indeed, Jones (1991) suggests that, where there are no people, there is no vulnerability). In the study area, the most densely populated households are located in the riverbank, suggesting a link between household composition and vulnerability. However, the relationship between population and vulnerability is ambiguous: social ties were considered the most important capacity in the community. Community members help each other at all times: before (by warning others and helping to relocate valuable items and documents in safe shelter), during (by helping in evacuating the unsafe areas) and after (by helping to rebuild affected houses) a hazard event.

The regression analysis shows that physical vulnerability is the most important factor, explaining 72.2% of variability in overall vulnerability. Hence, although infrastructural weaknesses are important factors in determining vulnerability, other such risks as economic or social insecurity have a significant impact on vulnerability (Pelling, 2001).

The majority of houses with high physical vulnerability scores are located very near the riverbank (within 10 m). These temporary houses are inhabited by the poorer families and are often densely populated (one of these households was occupied by 20 people). As a result, these families are more vulnerable to hurricane hazard due to the link between (i) exposure to the riverbank and (ii) infrastructural weaknesses which prevent the household from coping with the risks. This exercise highlights *where* additional infrastructure is needed and which households would benefit most from better construction materials.

At the same time, it is important to recognise that social, economic and environmental changes affect household vulnerability to hurricanes. Population pressures (demographic changes) combined with fluctuations in the market (economic change) and long-term environmental degradation (including localised erosion and anthropogenic climate change) all have an impact on the ability of households to cope with hazards. Past trajectories can provide insights on likely trends for the future, but the data are inconsistent. Early surveys (e.g. a 1990 survey; INEGI, 2009a) focused on the demographic composition of households whereas recent ones (e.g. a 2005 survey; INEGI, 2009b) include information on house type and income dependency. It is therefore difficult to model social and economic change, not only due to methodological issues but because it is impossible to know how future generations will behave, and what the impacts of this behaviour will be on the global market and the physical environment.

5. Discussion

5.1. Vulnerability analysis with community participation

In this research, community participation was encouraged for the vulnerability mapping process through focus group meetings, whereby community members were asked to identify and rank the characteristics that increase their vulnerability to hurricanes. The information generated through discussions at these meetings served as crucial input to map vulnerability in the community. The rationale behind this technique is that the local experiences of mitigating and dealing with disasters originate within the community itself. Communities have understood their environments, as well as their vulnerabilities and risks, and have developed local adaptation capacities (Tran et al., 2009). Some of the coping strategies are still in practice but some have become obsolete due to environmental change (Wisner et al., 2004).

Communities often develop strategies to cope with hazard risk, but incorporating this information into policymaking has traditionally been a challenge. A local strategy to reduce the impact of hazards is the development of alternative warning systems. The most devastating impacts of hurricane hazard occur at night, when people are least aware of the potential risks. To overcome this problem, families living near the riverbank have strategically placed rocks between their household and the river so that they are awoken by the sound of crashing rocks when the water-level rises to a dangerous level.

The community has also developed capacities to reduce risks in their agricultural environment. The dominant crop in the community is sugarcane because it is the best suited to tolerate the adverse consequences of hurricanes. One of the community members suggested that mixed cropping can reduce the impacts of hurricane hazard and reduce the vulnerability of the ecosystem (Fig. 8). A total of 189, 882 ha of monocrop farmland were destroyed during Hurricane Dean (SAGARPA, 2007); in contrast, farmers practicing multiple cropping with woody perennials reported significantly lower (or no) losses. Farms with high agrobiodiversity have increased ecosystem resilience (Altieri and Nicholls, 2006). This suggests that (i) knowledge of local conditions is essential in reducing specific risks and (ii) livelihood diversification is an important component of disaster risk reduction (see also Campbell, 1984; Davies, 1996; Little et al., 2001).

The results of the mapping assessment show that poverty and vulnerability to hurricane hazard are linked and mutually reinforcing, corroborating other studies (e.g. Tompkins and Adger, 2005; Pelling and High, 2005; Adger et al., 2003; Brooks et al., 2005). Households located within 10 m of the Actopan River reported losses of domestic goods (such as ovens, beds and even domestic animals) that represent a large proportion of their annual income. As a consequence, the recovery period for these families has tended to be greater than for the others. Moreover, in contrast to the other houses, those located within 10 m of the river are more frequently affected by storm surges and tropical depressions, further inhibiting their capacity to cope with hurricanes. Hence, the poorer members of the community, who tend to live nearest to the river, are more vulnerable to hurricane hazard.

Hurricane Dean—the most intense hurricane of the 2007 season—was the most recent traumatic experience for the community members, especially to those living near the riverbank as their houses were inundated up to the rooftop. Additionally, high wind speeds associated with heavy rains impeded quick evacuation. The event highlighted the importance identifying risk areas, advising households on which actions to take and early warning systems to facilitate early evacuation. In terms of long-term risk reduction policy, the findings of the participatory GIS and VCA highlight that, for the community of El Zapotito, the greatest benefits in reducing the adverse impacts of hurricanes would come from better domestic (construction material) and protective (barriers) infrastructure, particularly near the riverbank. Risk transfer mechanisms, such as insurance, might also help protect households as well as valuables and income sources.

5.2. Developing partnerships to overcome the limitations of GIS-based mapping

A challenge encountered in this study related to the availability of technical resources on the field. GIS mapping requires sophisticated software and hardware as well as technical expertise to upload and analyse data (Dash, 1997). Furthermore, the process of collecting field data with GPS devices and uploading the information on electronic databases and formatting the information so that it is compatible with GIS can be time-consuming. These technical problems can be overcome by developing partnerships with local universities, where the software and technical support are available. Partnerships with universities can facilitate the process of updating data, because vulnerability changes over time and space.

Three possible approaches can be implemented in order to address potential problems that policymakers and researchers might encounter. First, the spatial resolution of the analysis could

Fig. 8. Ecosystem resilience as a result of increased agrobiodiversity.[Photograph sources: CONACYT, 2007 (left); Krishnamurthy, 2008 (right)].

be increased (for instance, the analysis could be carried out at the municipality level). At larger scales, vulnerability changes over a longer period. Second, the process of updating GIS data could become the responsibility of communities through the development of an e-governance system (Tran et al., 2009). This can be problematic because access to Internet is limited in some rural communities; furthermore, the community as a whole has limited knowledge on how to use computers and how to manage cartographic data. Thus, devolving responsibilities to the El Zapotito and other comparable communities is not feasible at this stage. Third, there is potential for developing a web-based database that is expanded and updated by policymakers and researchers. An outcome of this study is a website developed in collaboration with staff from the University of Chapingo, which aims to carry out further similar analyses for the most vulnerable communities in the Gulf of Mexico. The website is in construction on the following link [http://www.chapingo.mx/cads/]; instructions in Spanish and English are included to facilitate uploading data, obtaining maps *and* interpreting the results.

5.3. Policy implementation and recommendations

A discrepancy between government and community perceptions of hurricane risk results from the structure of local governments and the community, as well as the interactions between these. Historically, little interaction between the community and the local government existed due to a tradition of prescriptive policy. Disaster planning in El Zapotito commune has traditionally been coordinated by the informal leaders (who are also the older and more experienced members of the community) (Jorge Zamudio, pers. comm.). However, institutional change brought about by the recent creation of the Ministry of Civil Protection has resulted in a national strategy for disaster risk management that encourages community participation in the decision-making process (Saúl Miranda, pers. comm.). Accordingly, the shift in institutional strategy requires sub-national civil protection offices to provide a strategy for disaster management which highlights how communities are being involved in policy, and whether the participation is active (through managing and evaluating projects) or passive (by identifying local vulnerabilities). Mapping risk perceptions through participatory GIS is therefore an important step in targeting policy strategies.

A household vulnerability map can has two particularly useful applications. First, it can identify the risks that increase vulnerability to hurricane risk (in this case, exposure, economic, social and physical vulnerabilities). Thus it can recommend a holistic policy approach to reduce vulnerability to hurricane hazard in the community. Structural policies (reduced exposure to the Actopan River through building walls) in combination with economic policy (such as financial assistance or agricultural subsidies to reduce poverty) as well as infrastructural measures (such as building safer houses) would complement each other and contribute to reducing vulnerability (Gaillard et al., 2007). Relocation of families is infeasible for three interrelated reasons: proximity to the place of work, sentimental attachment to the place, and connections to the community; often, however, in highly vulnerable settings, the challenge of relocation is economical (cf. Eakin and Bojórquez-Tapia, 2008). Consequently, disaster risk reduction strategies should focus on addressing vulnerability to hurricanes by dealing with spatial (exposure), economic, social and physical problems. Second, a household vulnerability map can be used to signal which households require the earliest warning possible to protect their goods and evacuate if necessary. For example, households that are located in the riverbank should get the first warnings. By providing an early warning, it is possible to reduce damage and lower physical losses (both material and human).

An additional issue relates to whether populations who live in unsafe conditions choose to settle in hazard-prone areas, or whether they are forced to live there. The participatory GIS corroborates that the most at-risk households (i.e. the most densely populated, the ones with the least resilient income sources, and the ones constructed with the least resistant materials) are located in the most vulnerable areas of the community, near the riverbank. These households are also the ones with the least material capacities to deal with hurricane risk. In this context, Hewitt (1983) emphasises the role of economic and social structures as a *cause* of vulnerability rather than a *contribution* to hazard mitigation (Adger, 1999). The focus is therefore shifted to access to resources (or lack thereof) as the main indicator of vulnerability: poverty increases endogenous stress and reduces the ability to cope with exogenous stress and hence the solutions involve adjustments in macro-economic policy (poverty reduction strategy papers). The political ecology literature has further contextualised vulnerability in terms of power relations whereby powerless groups are marginalised into hazardous areas (floodplains, eroded coastal zones and riverbanks) (cf. Wisner et al., 2004). Further research is necessary to analyse the complex *historical* circumstances which have led to the specific manifestations of vulnerability (exposure, economic, social and physical) studied in this paper.

6. Conclusions

This paper demonstrates the needs, rationale and procedures for integrating local perceptions of hurricane risk into policy making. This information has been interpreted through a vulnerability map and a vulnerability and capacity assessment, both of which outline the factors that contribute to household vulnerability in the community of El Zapotito. By developing a method which includes participatory GIS mapping, statistical analysis and a vulnerability and capacity assessment, this paper proposes a framework for communicating local perceptions of risk to policymaking which can be replicated elsewhere. Here, it is important to note that modelling human systems is not necessarily universally robust: the model used for this research is based on the perceptions of the local community and should be seen as a visual representation of local risk perceptions in both time and space. However, the incorporation of community perceptions of risk in the mapping process can illuminate the vulnerability within the social and physical environments (as well as the ways in which these interact) to situate the context in which vulnerabilities to hurricane hazard emerge, as well as feasible coping mechanisms. This knowledge can be conveyed to policymakers to develop disaster management strategies that focus on specific vulnerabilities. Framing vulnerability within a local context can help improve knowledge of the social, environmental and institutional situations which enhance (or reduce) the ability of a community to cope with hazards.

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