

Slum socio-ecology: an exploratory characterisation of vulnerability to climate-change related disasters in the urban context

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Glossary of terms

Bio-physical environment- Relating to or concerned with the interaction of biotic and abiotic surroundings of a population

Climate Change- A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Disaster - A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

Disaster risk - The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.

Ecology - The study of relationships between living organisms and their physical environment.

Ecosystem services - The benefits that people and communities obtain from ecosystems, including regulating, provisioning, supporting and cultural services.

Environmental degradation- The reduction of the capacity of the environment to meet social and ecological objectives and needs.

Feedback loop -The output of a situation is used as a new input.

Hazard- A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Informal settlement- Areas where groups of housing units have been constructed on land that the occupants have no legal claim to, or occupy illegally; unplanned settlements and areas where housing is not in compliance with current planning and building regulations (unauthorized housing).

Macro- Large scale or overall, here used to denote country-scale aggregation of data.

Megacity -Metropolitan area with a population of more than 10 million people.

Micro -Small scale, here used to denote city- or local-scale data.

Multiscalar -Relating to multiple scales, here used to mean data which is usefully collected at country, to city, to local scale.

Resilience -The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Slum -A slum household is defined as a group of individuals living under the same roof in an urban area who lack one or more of the following: durable housing of a permanent nature that protects against extreme climate conditions; sufficient living space which means not more than three people sharing the same room; easy access to safe water in sufficient amounts at an affordable price; access to adequate sanitation in the form of a private or public toilet shared by a reasonable number of people; security of tenure that prevents forced evictions. A neighbourhood is classified as a slum if more than half of the households in the area suffer from one or more shelter deprivations.

Socio-ecological system -The interactions and feedback loops between humans, the bio-physical environment and other non-human biological units, which together create a system.

Socio-economic -Relating to or concerned with the interaction of social or economic factors.

Sustainable development -Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Threshold -The magnitude or intensity that must be exceeded for a certain reaction, phenomenon, result, or condition to occur or be manifested.

Vulnerability- The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Abstract

Context: As cities, especially coastal megacities, continue to grow often through rapid unplanned urbanisation, populations are increasingly concentrated in climate change-affected hazard-prone spaces. How these populations interact with their environments will ultimately influence their vulnerability to climate-related disaster. Yet the interdependence between human and environmental systems, especially in the urban slum context, is under-researched and represents an important gap in our understanding. Using a socio-ecological system approach provides a holistic framework to understand vulnerability.

Aims: This paper has three main aims: 1. Characterise slum socio-ecology; 2. Identify urban socio-ecological indicators; and 3. Geospatially map available socio-economic and biophysical vulnerability indicators of Metro Manila, Philippines as a proof-of-concept.

Methods: Literature review search terms used were: “socio-ecolog* system* OR human-environment*”, “urban ecology”, “environment urbanisation”, “slum”, “slum ecology OR slum*environment*”, “metro manila slums”, “metro manila environment”. Applied in the abstract, title or keyword, without limitation on date, using Google Scholar, HOLLIS+ and Web of Science. Geospatial mapping for Metro Manila using the *barangay* as the unit of analysis was completed using ArcGIS10.3.

Results: 1. The socio-ecology of slums is characterised by a heterogeneous group of urban poor, united by their exclusion from municipal services, relying on a degraded environment. Hazards disturb an already fragile system, leading to a downward spiral of increasing disaster risk; 2. In total, 19 urban socio-economic and 12 biophysical indicators were identified; 3. Geospatial mapping is a useful and powerful visual means of communicating vulnerability.

Conclusion: There is urgency for more interdisciplinary research and data collection in slums.

Key words: socio-ecological system – vulnerability – climate change – slums – urbanisation – disaster risk

1. Introduction

1.1. Background

The role the environment and climate change play in disaster risk has a renewed emphasis in the political agenda. The unprecedented rapidity of regional and global environmental changes is precluding the adaptation of millions of people worldwide (1), contributing to impoverishment, vulnerability and suffering, and necessitating greater government involvement. Key international agreements including the Sendai Framework for Disaster Risk Reduction, the launch of the Sustainable Development Goals and the prospect of a new global comprehensive climate agreement, CoP Paris, mark 2015 as a crucial year for addressing the intersection between disaster risk, climate change and the environment. Already, more “dedicated action” is being called for to tackle climate change, unsustainable uses of natural resources and declining ecosystems, which are recognised as significant underlying disaster risk drivers (1).

This paper aims to pull together research on climate change, disaster risk and environmental degradation to understand vulnerability in the urban context. Vulnerability needs to be understood holistically, which means understanding its drivers and how actions and behaviours exacerbate these drivers. The interdependence between human and environmental systems, especially in the urban context, is under-researched and represents an important gap in our understanding. The Environmental Vulnerability Index (2004) specifically does not “address environments that have become dominated by human systems, e.g. cities” (2), despite the environment still playing an important role in the functioning of a city. Whether natural or man-made, the impacts of disasters have human and environmental dimensions and often reveal the underlying problems both in society and the environment (3). Assessing and understanding how humans (social factors) interact with their environment (ecological factors) as an integrated system – a socio-ecological system – will go a long way towards managing vulnerability and disaster risk.

Understanding the “bundle” of multiple interacting socio-ecological stressors which influence vulnerability and risk is complex (4). Focussing on the urban context adds a further layer of difficulty as most climate-change literature focuses on developmentally diverse regional and/or specifically rural areas (5) and data on urban environment-human links are lacking (6). However, cities are major contributors of greenhouse gases (and therefore causes of climate change) as well as some of the leading victims to climate change; consider in particular the coastal megacities (7). There is thus some urgency to understand urban vulnerability in a framework of multiple stressors so

that determinants of vulnerability can be addressed and the constraints and windows of opportunity for disaster risk reduction can be explored (5).

This introduction is divided into three main parts: 1. Climate change, which provides a general outline of climate change predictions and associated impacts; 2. Socio-ecological systems, which introduces this concept and previous research; and 3. Urbanisation and slum socio-ecology, which provides an overview of the challenges of urbanisation.

1.1.1. Climate change

For long term sustainable development to succeed, the links between climate change, the environment and disaster risk must be understood (1). Many development goals surrounding poverty, health and livelihoods are climate-sensitive. The trends in global disaster occurrence show an increasing frequency of climate-related disasters (8). As disasters can undo years of development by destroying costly infrastructure, eroding living conditions and deepening poverty, it would appear that future development progress may be undermined at an accelerated pace if the world continues to “perpetuate a disconnect between disaster risk reduction, sustainable development and climate change” (9).

The Intergovernmental Panel on Climate Change (IPCC) predicts that climate change will “heighten/amplify other risks already present and might create new risks for natural and human systems, including cascading events” (10). Predictions with high confidence include, amongst others, abrupt and irreversible changes to terrestrial and freshwater ecosystems; submergence, flooding and erosion of coasts; and heat stress, air pollution, inland flooding, landslides and extreme precipitation in urban areas (10). However, not all people are at risk to the same extent. Uneven development practices mean that some populations – often the poor and marginalised - are more at risk of these environmental changes than others (10). People in many settings may already be “approaching the biophysical and social boundaries of adaptation, beyond which climate change compromises their sustainable development”, and continued existence (11). Understanding the dynamic relationships between social, environmental and climatic phenomena is vital to make appropriate disaster management decisions.

1.1.2. Socio-Ecological Systems

Ecology studies the relationships of organisms to one another and to their physical environment, which together make up an ecosystem. The concept of socio-ecological systems (SES, also referred to as human-natural systems or human-environment systems (12-14), is simply that humans systems cannot be separated from the environmental systems on which they rely. The interactions and

feedback loops between the human condition and environmental condition are necessary to understand the dynamic, complex and adaptive nature of this system as a whole, especially under the influence of climate change and disaster risk (14-17).

These are complex relationships that are easier to conceptualise than to quantitatively assess (18). A socio-ecological systems approach considers the capacity of the system to respond to hazards as well as the origin of hazard from within and outside the system (15). In general this approach is interested in causal sequences, the dynamic interactions across scales, and the tipping points and thresholds of the system (17). Several socio-ecological systems frameworks exist (13-16,19) to look at how human impacts on environmental systems may lead to degradation and collapse of the environmental system which in turn could further compromise the adaptive capacity of human systems or contribute to a disaster(15). For example, Southern Yucatan peninsula in Mexico experiences water stress and hurricanes. Significant human-induced deforestation, for cultivation and pasture, has led to landscape fragmentation. Hurricanes, which are predicted to increase with climate change, also knock down large stretches of forest, as well as damaging crops through strong winds and floodwater. A fragmented landscape means less of a natural buffer from hazards (e.g. the hurricanes) and a resultant reduction in yields. Farmers therefore intensify their use of available land, which increases vulnerabilities to other hazards such as crop pest, and continue to cut down the forest as they seek new pastures (15). The continued use and degradation of the environment, in combination with each hazard event, is compromising the adaptive capacity of these farmers. While the short-term repercussions of disasters on human and environmental conditions are relatively well understood, the long-term consequences of the feedback loops are less well researched - especially in the *urban* context.

1.1.3. Urbanisation and Slum Socio-Ecology

As more than half the world's population now live in urban areas (21), humanitarian crises in an urban context are an increasing reality of the present, and will certainly be the reality of the future. The devastation in Port-au-Prince, Haiti, Tacloban City, Philippines, and Kathmandu Valley, Nepal, reveal the consequences of combining poverty, high population density and inadequate infrastructure and governance in hazard-exposed settings. Rapid and unplanned urban growth has led to the proliferation of informal settlements and slums which home close to one billion of the urban poor (22). These populations, through absence of alternative options, frequently live in dangerous locations liable to the effects of climate change, in poor-quality settlements of close proximity (23), lack protective infrastructure and the means to cope with the impacts of a disaster(4,5) – whether

biological, natural or man-made in origin. The urban poor/slum dwellers thus represent some of the most vulnerable populations in the world.

Research on slum settings, such as their specific socio-ecology, demographic composition, unique economy and livelihoods, and culture of thinking is lacking. The number of inhabitants in, and location and existence of, many slums are controversial and disputed making comparisons problematic (24), not least because no common definition of what constitutes an urban settlement exists (25). “Slum” dwellers typically lack in any one of five factors: durability of housing, access to safe water, access to sanitation, sufficient living area and secure tenure, and are considered the most deprived of the urban poor and the most likely to suffer in an urban emergency (22). Settlement layouts restrict where floodwaters can go, densely settled roofs, roads, and pavements obstruct natural channels, a lack of systematic attention to household waste collection blocks drains, and poor and inadequate maintenance of drainage channels increases the risk of flood from even minor storms (4). Such factors are true of urban contexts more generally, yet the marginalisation, hostility, blind-eye turned to slum settings and the degree to which these milieus feel overwhelming, mean that populations do not have the provisions to deal with the impacts of environmental degradation and climate change.

1.2. Research proposal

Based on the assumption that human (social) systems are inextricably linked via feedback loops with the environmental (ecological) systems on which they rely - and that these feedback loops can exacerbate or reduce disaster risk - this research will build on previous conceptual frameworks which have sought a holistic, socio-ecological systems approach to the understanding of vulnerability.

Previous socio-ecological systems approaches to vulnerability have *described* how human impacts on environmental systems may lead to degradation and collapse of the environmental system which in turn could compromise the adaptive capacity of human systems (15). This research aims to go further and geospatially map and spatially analyse the socio-economic and biophysical vulnerability indicators—taken together as socio-ecological indicators—which through interactions, generate vulnerability in an urban system.

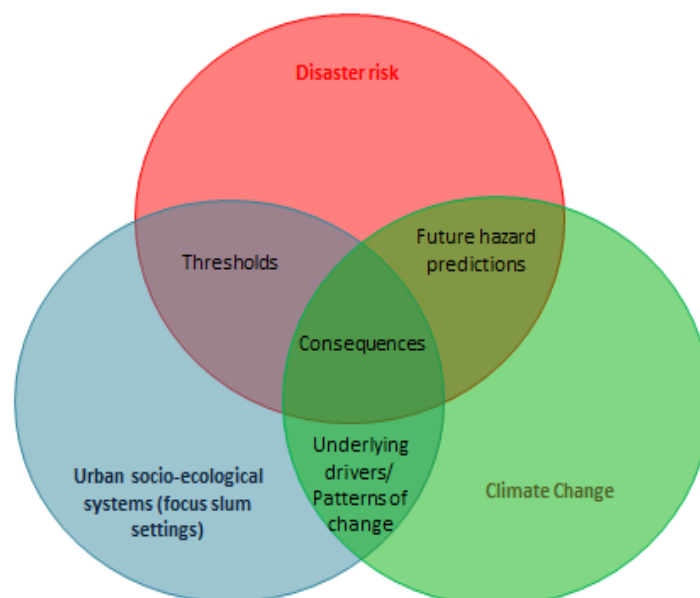
The future of humanitarian crises is going to be in the urban context, where the poorest people, i.e. those living in informal/slum settlements, are likely to be disproportionately affected. Trends in global disaster occurrence show an increasing frequency of climate-related disasters. As cities, especially coastal megacities, continue to grow often through rapid unplanned urbanisation,

populations are increasingly concentrated in climate change-affected hazard-prone spaces. How these populations interact with their environments will ultimately influence their vulnerability to climate-related disaster.

As shown in Figure 1, this paper will thus draw together research on disaster risk, climate change and urban socio-ecological systems, with a focus on slums. Climate change will increase the frequency and intensity of various hazards in the future (such as extreme temperatures and weather, unpredictable rainfall patterns and sea level rise) and thus increase disaster risk (10). The amount of disturbance, in the form of a disaster event, a given socio-ecological system can take, and the associated impacts and losses, can be conceptualised as thresholds. Climate change and the urban socio—ecological system will interact to drive change and contribute to underlying drivers of risk. All of which when taken together will create unique consequences in a given system.

Working on the basis that Metro Manila is a megalopolis at known risk of climate change and contains large slum/informally settled constituencies, I will use it as a proof-of-concept and case study for this research. I will combine the known risk of climate change with the vulnerability assessment of its socio-ecological system to assess the consequences of a disaster risk, such as a flood.

Figure 1. Venn diagram representing intersection of research themes.



1.3. Research Aims

To create a holistic geospatial representation/assessment of vulnerability this research aims to:

- Define slum socio-ecology from the literature
- Identify appropriate dynamic socio-economic and biophysical vulnerability indicators from the literature
- Gather appropriate data for the given context and case study: Metro Manila
- Geospatially map the indicators under current risk and future climate-induced risk
- Layer the indicators to create a climate change-hazard socio-ecological vulnerability map
- Discuss the applications of this approach to other urbanized informal settlements considered at risk from extreme climate events

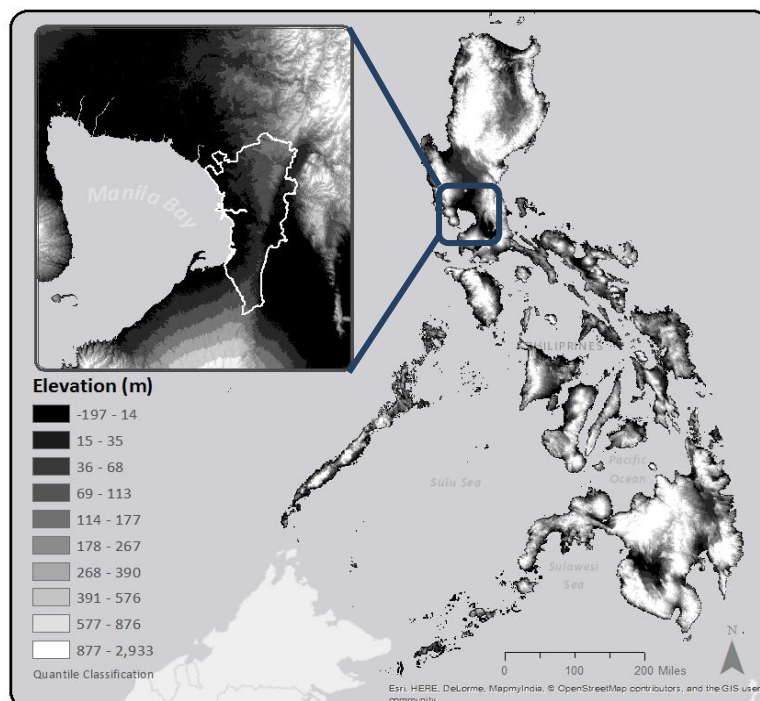
1.4 Settings: justification of Metro Manila as a proof-of-concept

The Philippines is the fourth most at-risk country in the world in terms of climate-related natural disasters, such as typhoons, sea level rise, flooding and extreme temperatures (8). Since 2000 it has experienced 245 natural disaster events (an average of 16 disasters a year), which have caused over 23,000 deaths, with damages in excess of \$17 billion (8). The capital - Metropolitan Manila, officially the National Capital Region – is the second most disaster prone city in Asia and one of the largest urban agglomerations in the world (26). Home to 12.764 million inhabitants (11.9% of the national population) (27), Metro Manila is a rapidly urbanising region, with a high density of people and assets exposed to meteorological hazards (8).

Metro Manila is a coastal megacity with Manila Bay to the west and Laguna Lake to the East (see Figure 2). Several major rivers crisscross the megalopolis and form the Pasig-Marikina basin system. Through a combination of a) being built largely on alluvial plains and soft sediments along the Pasig River delta, b) having an average low elevation (Figure 2), and c) experiencing intense rainy seasons, Metro Manila is extremely vulnerable to flooding. For example, in 2009 during Tropical Storm Ondoy (Ketsana), 455mm of rain fell in 24 hours affecting five million people across Metro Manila and causing significant mortality and morbidity (464 dead, 529 injured)(28).

Most importantly, Metro Manila has a large constituted slum population. A 2007 estimate put the number of slum households at 199,398 (29), an estimated 37% of the metropolitan population (or more than 4 million) (30). As a population, they are typically the most exposed, more impacted when exposed, less able to cope and then adapt to reduce future risk (5). Metro Manila is thus a useful proof-of-concept case study as it: 1) is at high risk of natural disasters and 2) is a megacity with a significant slum population.

Figure 2. Map of the elevation (m) above sea level for the whole of the Philippines with enlarged view of Metro Manila and Manila Bay. Source: Raster files from the GIS department LGU Muntinlupa.



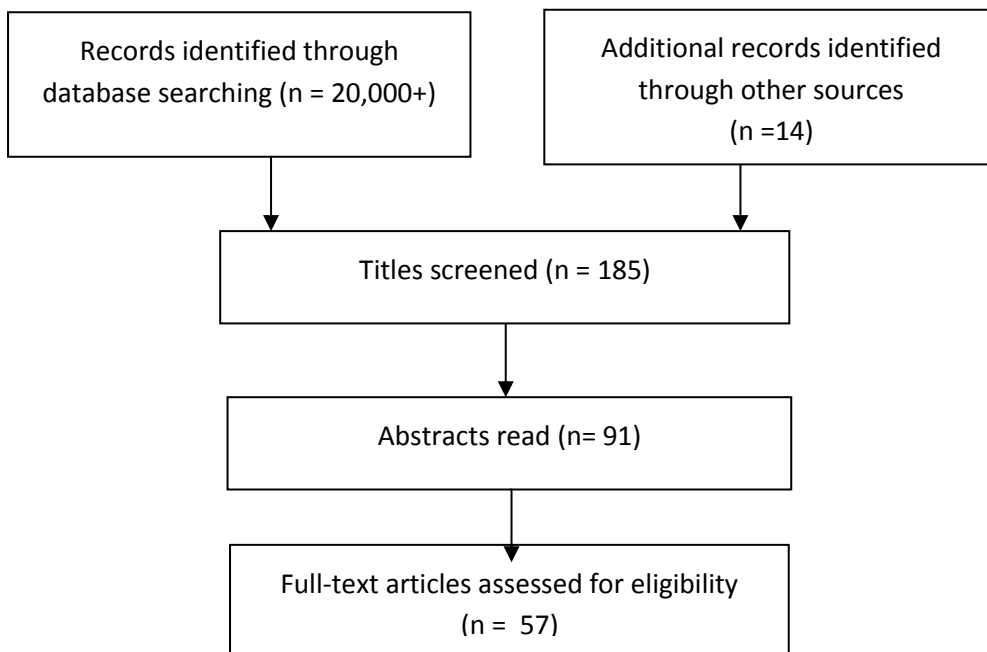
2 Methodology

2.1 Literature review: “urban/slum socio-ecology”

The literature review was conducted to include peer-reviewed journals as well as grey literature, as a substantial amount of relevant information is known to be contained in this format. A number of different search terms were used for two main reasons: 1) there is, as of yet, no consensus on what “urban” or “slum” is, therefore they needed to remain relative terms, and 2) generating a holistic picture of the interactions with humans and their environments would require inputs from a variety of disciplines, including development, urban studies, ecology, and health.

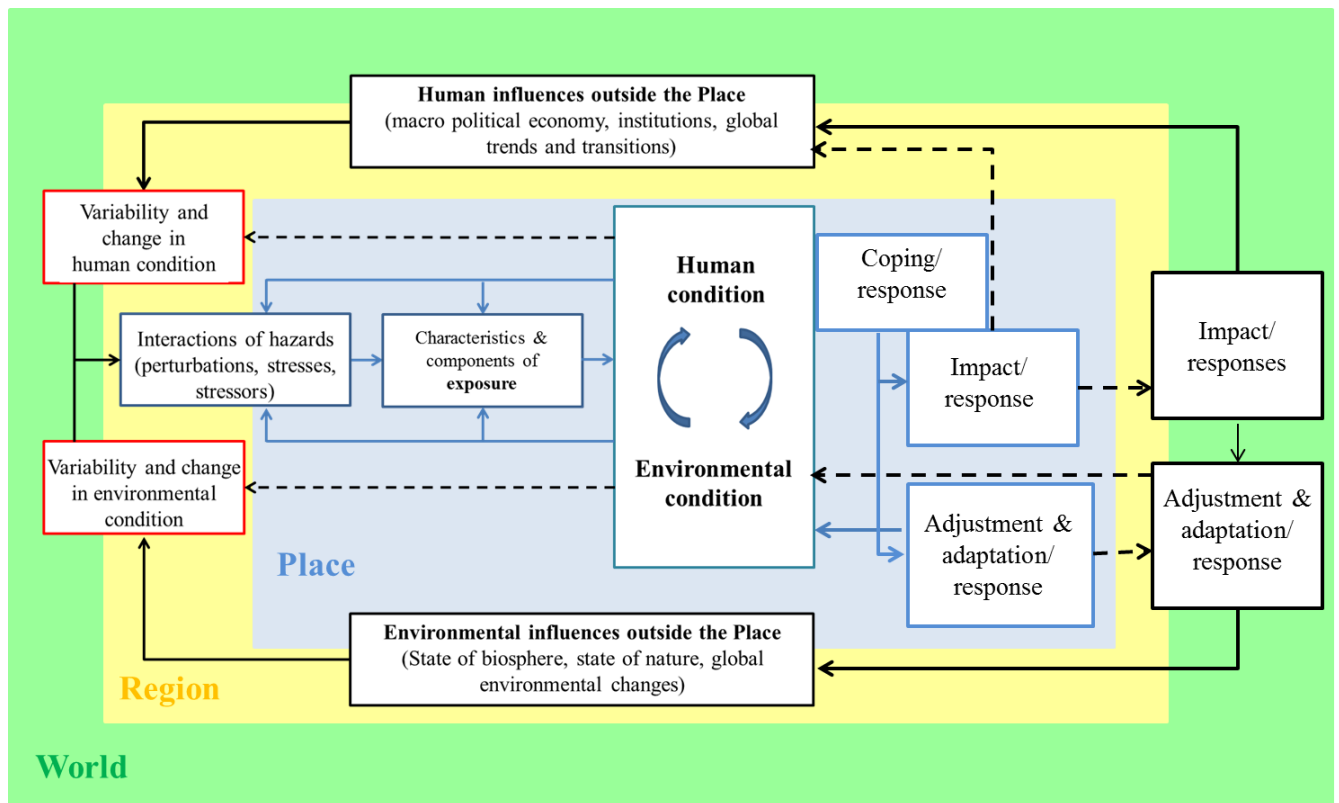
Consequently, search terms used were: “socio-ecolog* system* OR human-environment*”, “urban ecology”, “environment urbanisation”, “slum”, “slum ecology OR slum*environment*”, “metro manila slums”, “metro manila environment”. The search terms were applied in the abstract, title or keyword. There was no limitation on date and type of article. International search engines used were Google Scholar, HOLLIS+ and Web of Science. The titles and abstracts of these articles were reviewed to assess those that potentially addressed slum ecology, and these article’s abstracts were then further assessed. Of these abstracts, articles which seemed relevant were read in detail. Snowballing techniques included reference list checking to ensure relevant literature was gathered (see Figure 3).

Figure 3. Flow diagram of search strategy used for literature review



Identifying vulnerability requires a clear definition (see the glossary of terms for key definitions) and conceptual framework. Vulnerability here follows UNISDR terminology of “*The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard*”. From the identified vulnerability frameworks, that of Turner, et al 2003, was chosen to guide the framing of the urban socio-ecological definition. This was because it did not have predefined indicators and was the most flexible conceptual framework in terms of providing “broad classes of components and linkages that comprise a coupled system’s (socio-ecological) vulnerability to hazards” (Figure 4 is a redrawn version of framework). Resilience formed part of the vulnerability definition; therefore indicators in both vulnerability and resilience literature were used. Resilience in UNISDR terminology is taken to mean “*the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions*”. Explicit in the framework is that the interactions between the human condition and the environmental condition represent the place of analysis and that hazards hold the potential to affect this coupled system. The urban condition was the place of analysis of interest in this research, therefore, this framework was deemed most appropriate.

Figure 4. Redrawn conceptual framework from Turner et al 2003 to assess vulnerability holistically. Solid black lines refer to interactions and feedback loops beyond the place of analysis. Solid blue lines indicate interactions and feedback loops occurring within place of analysis. Dashed black lines indicate cross-scale dynamics.



2.2 Indicator Selection

Pre-identified socio-ecological frameworks and frameworks identified during the literature review were both used as sources to compile the list of indicators. Eleven papers proposed biophysical and social indicators. The Environment Vulnerability Index was excluded as it explicitly stated that the indicators are not applicable in the urban context. Only quantifiable socio-economic or biophysical indicators which were related to disasters and climate-change were gathered. Indicators without an accompanying measurable explanation were excluded.

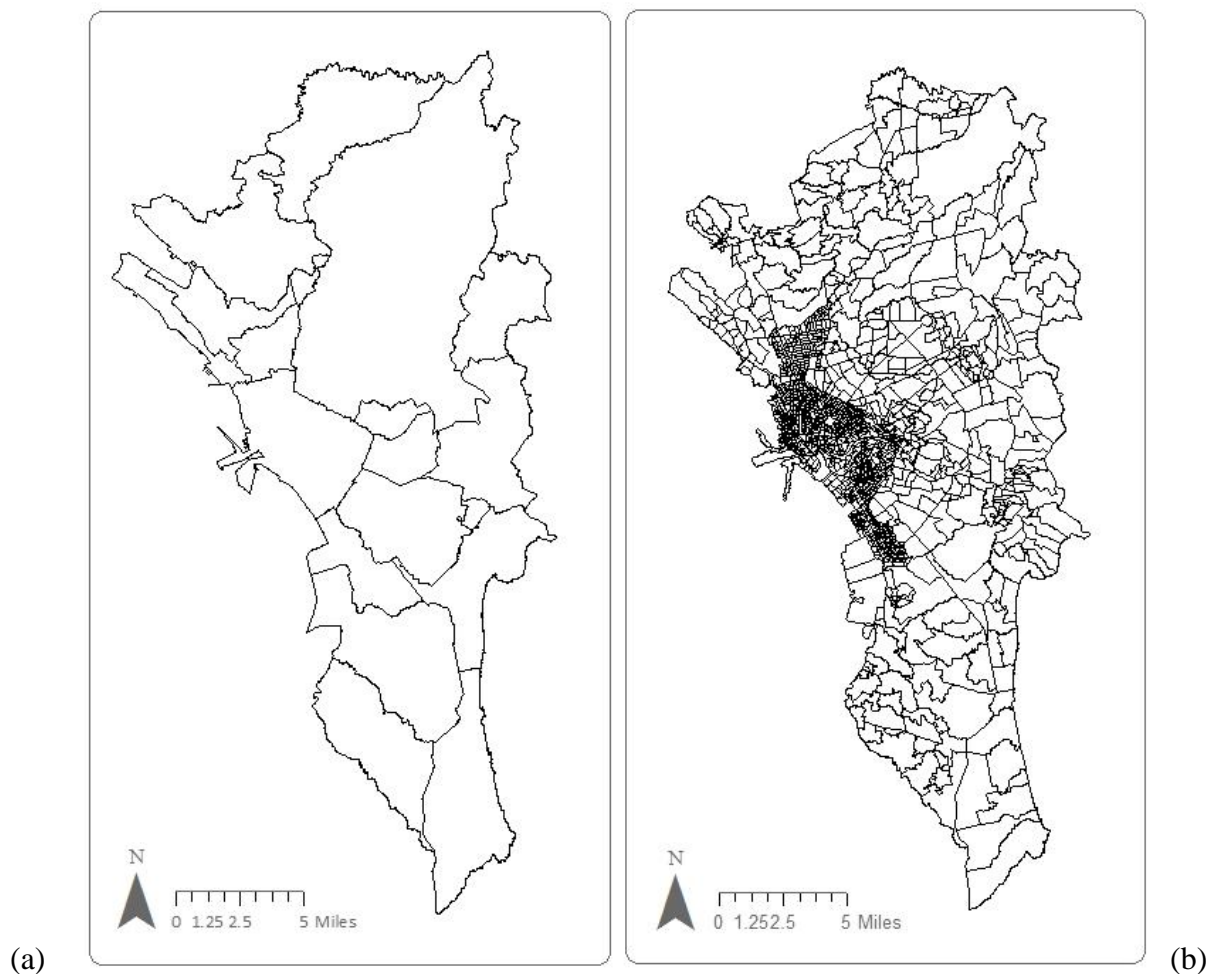
In terms of indicators chosen for geospatial mapping of Metro Manila, these were informed by literature review but were limited by indicators which had geospatial information that was publicly available.

2.3 ArcGIS Mapping and Analysis

Exploratory mapping of Metro Manila was dependent on information publicly available. The *barangay*, the smallest political and demographic unit (26), was chosen as the unit of analysis as this would yield the most meaningful comparison since it “serves as the primary planning and implementing unit of government policies, plans, programs, projects, and activities in the community, and as a forum wherein the collective views of the people may be expressed, crystallized

and considered, and where disputes may be amicably settled”(26). The alternative was to use the municipal level, but it was felt that this level of aggregated information would mask too much variability within the municipality. Figures 5a and 5b shows the relationship of municipalities and *barangays* in Metro Manila.

Figure 5a) Map of the 17 different cities and municipalities in Metro Manila. Figure 5b) Map of the *barangays* in the different municipalities in Metro Manila. Source: Polygon shape files from the GIS department LGU Muntinlupa.



2.3.1 Mapping

ArcMap10.3 (ESRI, Redlands, CA) was used to manipulate the administrative boundary shape files and conduct the geospatial mapping. The population size of each *barangay* was taken from the 2010 census in CSV format and joined to the polygon *barangay* shape file using ArcGIS inbuilt features. Once the polygon and CSV data had been ‘joined’, by using the ArcGIS geometry function to calculate the area of the *barangay* polygons, the population density was calculated using the attribute table, area and calculation function. This variable was then mapped in 10 categories, via a logarithmic transformation (as the data ranged from 0 to >240,000 inhabitants), in a quantile

distribution for all Metro Manila *barangays*. A polyline shape file of the rivers running through Metro Manila was then layered over the top of the *barangay*-population density map.

2.3.2 Geo-coding slums

An image of the Risk Analysis Project (RAP) Flood Modelling Team 2013 map for 20% flooding return rate was used to map potential urban slum locations at risk of flooding. The 20% flooding return rate refers to a flood that would be expected to occur every five years. This was used as the hazard event in the model because it is the type of flood that regularly disturbs the city and one that, due to its frequency, could be expected under the influence of climate change. Using the georeferencing toolbox in ArcMap10.3, the PNG image of the RAP Flood Modelling Team 2013 Risk Map was over-laid with the *barangay* polygon shape file. The *barangay* shape file and image were displayed in the same general space using “zoom to layer” and then further visually aligned and orientated using the rotate, shift and scale tools. Control points were then added between the image layer and the shape file to link the same place in the world in both layers.

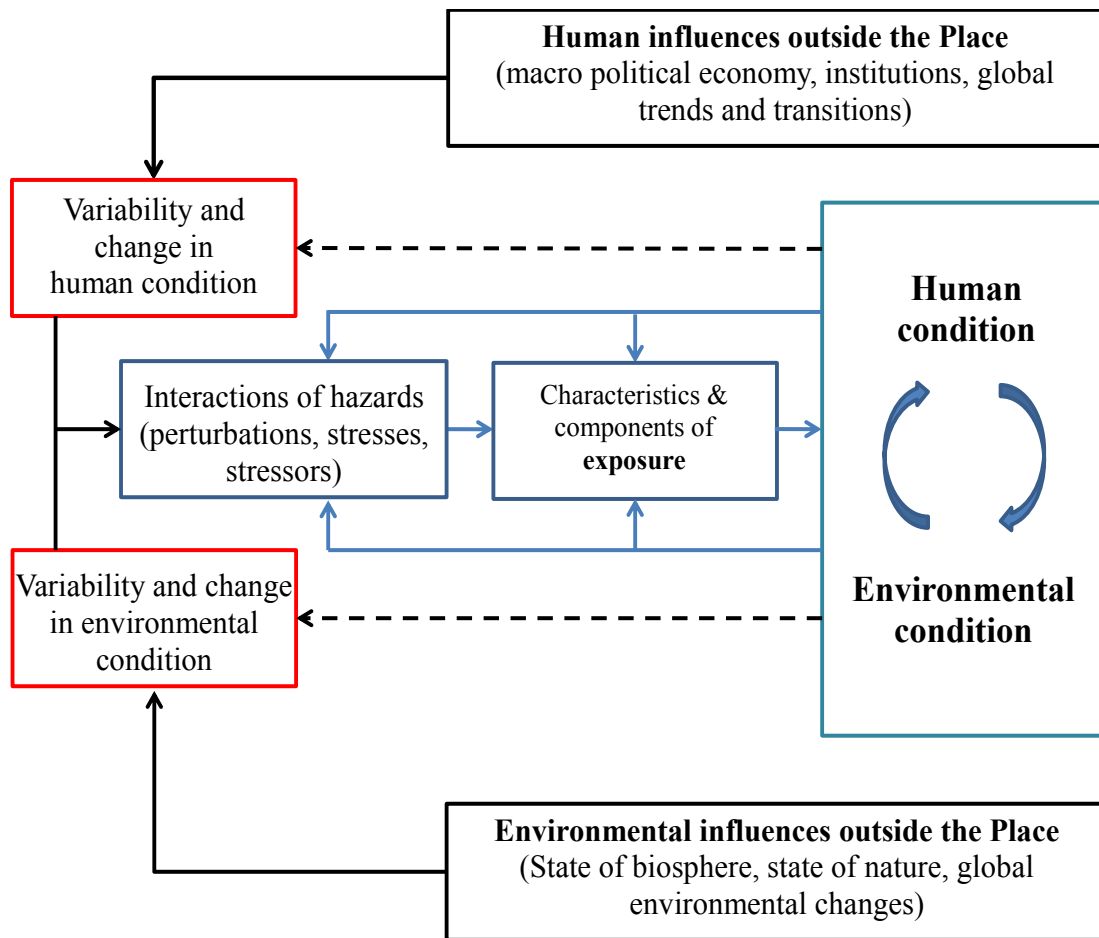
Populations with inundated homes where $>100,000$ people/km² live was chosen as potential sites of informal settlements as the average population density in Metro Manila was 62,977 people/km² (based on authors calculations). To digitise the locations of populations with inundated homes where $>100,000$ people/km² were affected a new empty shape file was created, with “point” as the feature type. The editing toolbar was used to create new point features. The points of $>100,000$ people/ km² was then used as a layer for other maps.

3 Results

3.1 Characterisation of “slum socio-ecology”

In this section the conceptual vulnerability framework developed by the Research and Assessment Systems for Sustainability Programme (13) is applied to the slum setting, as a means to frame the characterisation of “slum socio-ecology”. The interactions between human conditions and environment conditions is expanded upon and linked with the interactions of climate-change related hazards, external influences and variability (as shown in Figure 6).

Figure 6. Enlargement from conceptual vulnerability framework Turner et al 2003.



The most definitive report on slums to date is the Challenge of Slums Report (2003). It emphasised that slums are a relative concept, rendering universally applicable criteria difficult, and that the complexity of slums resists single parameter simplifications. Instead it provided two broad categorisations: 1. Slums of hope or “progressing settlements” and 2. Slums of despair or “declining neighbourhoods” which are undergoing degeneration. Taking this idea of progress or degeneration, and avoiding creating a rigid definition, this study identified the common interactions, patterns and processes that reciprocally link slum dwellers with their environment in ways other urban dwellers are not linked. Of focus here was the unequivocal strong causal relationship between poverty, a degraded environment and higher disaster risk, compounded by climate change (3), an understanding of which is key to designing the right disaster mitigation strategies.

3.1.1 Exposure and feedback loops between human condition and environmental condition

Slum settlements are typically located on sites which are, or were, considered undesirable or uninhabitable wastelands as these are often the only locations close to economic opportunities that the urban poor can access (31). However, these sites, especially wetlands, river banks, or steep

slopes, are increasingly recognised to have intrinsic disaster mitigation value, which may be eroded through human settlement (32). For example, in their natural condition, wetlands help regulate absorption and release of surface water by acting as a natural sponge (33). If this sponge is either saturated or covered over the results are perturbations of the natural water regulating system. Human activity influences the natural regime of the environmental conditions rendering the timing and intensity of expected natural phenomenon more unpredictable, with ramifications for populations living on the wetland, but also in the wider vicinity (32,34). The insecure residential status of slum dwellers limits their ability to fight for the right to a safe environment and therefore environmental problems generally perpetuate and increase (35). Land that may have been considered “marginal” in reality has under-recognised critical ecological functions which are lost through unplanned, haphazard settlement.

With more than three fourths of global low- and middle-income urban populations living in slums, it is not surprising that the demographic profile, diversity of livelihoods, and size of slums are hugely variable (22). Slums are associated with poverty and are the most evident manifestation of urban poverty; however, while slum dwellers are disadvantaged, they are not a homogeneously impoverished population. The majority of slum dwellers find employment through the informal economy and so deal with irregular incomes based on temporary, low-paying occupations (36). Yet, there are also those who are employed in the formal sector (e.g., as teachers) who nevertheless remain excluded from the formal housing market (36). Further still, there are those who are self-employed, that would not fall into the international categorisations of poor, yet choose to continue living in slum settlements (36). Being multidimensional, poverty encompasses low income, low human capital, low social capital, and low financial capital (22). The severity of deprivation of each depends on a number of variables such as age, gender, health. As a rising share of the poor resides in urban areas, there are especially vulnerable groupings (defined by variables associated with deprivation) within a vulnerable population.

High population density and overcrowding characterises the majority of slum settlements (35). Worldwide, the poor must rely on environmental resources for survival: for instance, a lack of access to an improved water source means that water must be gathered from a well or a river directly; unaffordable durable housing material forces the cutting down of trees to build a home (37). The more people there are, the more pressures there are on limited environmental resources. Slum dwellers are unique in that they have limited natural resources at their disposal simply because of the built-up urban environment. The majority of slum households rely on urban canals or rivers for drinking, cooking, washing and human waste disposal. Where urban rivers and coastal areas may be

a source of livelihoods, fishermen can fall into deeper poverty when their source of income becomes degraded;; many rivers in cities are becoming or already are “biologically dead” (30). Making do with what is available, slum dwellers use garbage innovatively for the foundation and construction of houses (32), or to reinforce dilapidated housing (22). This leads to structurally poor quality, substandard housing with high occupancy rates in all-purpose rooms (22,35). The resources that slum dwellers have at their disposal are unique to the context of their urban environment, location within the city and competition with other urban residents.

Waste generated by human activity (in particular human waste) in contexts of high population density can lead to the rapid degradation of both the environment and human condition. When there is no waste management system in place, as is the case for slum settlements which typically lack sanitation infrastructure, critical water resources can rapidly become polluted. Studies have found that water sources are contaminated by people using them directly to dispose of human waste (34), by groundwater mixing with sewage from open defaecation (38), or through leaching of waste from pit latrines (39). The waste increases the siltation of the river making flooding more common (34). In turn the flooding can worsen the pollution of the river as toilets that do exist become clogged, obliging people to relieve themselves directly in the river, creating a downward spiral of continued deterioration of the human and environmental condition, increasing the risk of transmissible diseases, especially water-borne and vector-borne diseases. (40).

Solid household waste is also a major issue for slum dwellers. Municipal garbage collection does not extend to slum settlements resulting in huge amounts of accumulated garbage which can also leach toxins into the environment and provide refuge to other organisms, such as rats and mosquitoes, which spread disease (41). Very little research has been conducted on interactions of multiple toxins and pollutants in the urban context (41). What is more, garbage generated outside of slums by other urban residents is sometimes disposed of in slums– known as “garbage dump syndrome” (41) – which is a blatant example of social and environmental injustice.

In general slum dweller health is much worse than non-slum urban residents (41). In Nairobi’s slums the under-five mortality rate is two to three times higher than the city as a whole; children living in Manila slums are nine times more likely to have TB than other children (42); and one third of people in slum communities of Dhaka and Chittagong are thought to be ill at any given time (41). Communicable diseases such as tinea (a fungal skin infection), diarrhoea, TB, ARI, rheumatic heart disease, and meningitis are common (43), as well as chronic non-communicable diseases such as hypertension and diabetes (36). The crowded conditions, inadequate housing, poor environmental

context and availability of food on the markets clearly affect the health of slum populations. Significant knowledge gaps remain about the true health profile of slums as data is gathered from clinic, hospital or national mortality registries which are likely to underestimate the true burden of disease and mortality present in slums (35,36).

This section has attempted to provide a holistic characterisation of who may live in slums, how they interact with their slum environment, and how the environment in turn feeds back into affecting the human condition, as a cyclical coupled system. However, there is relatively little information available on the long-term consequences of feedback loops between human condition and environmental condition. Slum dwellers are a distinct urban population, but remain a heterogeneous grouping when considered globally. The context of city and type of slum – favela (Brazil), ghetto, townships (South Africa), jhopadpatti (Mumbai), gecekondu (Turkey) – is crucial to understand the different challenges and pressures its socio-ecology system faces, and whether it is a slum of hope or a slum of despair.

3.1.2 Interactions of Hazards

Hazards cause a disturbance to the system, which can affect the future exposure to that (or other) hazard(s) and also the socio-ecological condition, which in turn feeds back to influence the likelihood of a hazard reoccurring (as shown in blue outline and vectors in Figure 6). Contrary to popular opinion, human activities in urban settings influence the timing, magnitude and frequency of natural hazards (3). For example, inadequate, poorly managed drainage systems which become blocked through indiscriminate disposal of solid waste lead to urban flooding (44). Debris and blockages can get so bad that even normal rainfall results in backlogged water around drains (44).

Perturbations and the stresses caused by hazards influence the coupled human and environmental condition. Post-disaster assessments have found that many slum household members become sick, suffering from fevers, skin allergies, diarrhoea, resurgence of TB, typhoid, and dengue (34,45). Water supplies become buried, contaminated with sewage overflow, or experience increased siltation (34,46). Contamination and siltation in the short-term contribute to worsening the human condition and in the long-term increase the likelihood that the slum dwellers will experience another flooding event. The causal links between intentional inaction (on the part of city authorities) and the way slum dwellers are obliged to interact with their environment increases urban disaster risk for these populations. Slums undeniably form a hotspot of risk which requires more concerted municipal intervention and attention, especially given that climate-change is predicted to aggravate the situation through increased extreme weather events (47).

3.1.3 External factors

External factors control the overall structure of the socio-ecological system acting as drivers of variability and change in the human and environmental condition. Following the framework of Turner et al 2003 (Figure 6), two main external factors are identified: 1. human influences outside the 'Place' (including macro political economy, institutions, global trends and transitions) and 2. environmental influences outside the Place (including the state of the biosphere, the state of nature, global environmental changes). These are both large and complex externalities, and so for simplification in this paper, this section will be based on research from the World Economic Forum Risk Report and Planetary Boundaries, as these represent the two leading bodies of research in these domains.

3.1.3.1 State of biosphere, state of nature, global environmental changes

The concept of 'Planetary Boundaries' provides guidance on the safe operating space within which humanity can continue to prosper and develop (48). Nine key systems covering global biospheric processes were identified: 1. Biogeochemical cycles of nitrogen, phosphorus, carbon, 2. Freshwater Use, 3. Land-system Change, 4. Biosphere Integrity, 5. Climate Change, 6. Novel Entities, 7. Stratospheric Ozone Depletion, 8. Atmospheric Aerosol Loading, and 9. Ocean Acidification. Each has thresholds beyond which non-linear transitions could lead to the functional collapse of the system and related systems. Being planetary in their scale, everyone will be affected; but, unquestionably, the poorest are likely to feel the greatest pressure and suffer disproportionately.

Slum dwellers have contributed least to approaching the planetary boundaries but are likely to feel the greatest impacts should these systems destabilise. For example, slum dwellers have very little absorptive and coping capacity for increased extreme weather events associated with climate change. Urban areas already extract and deplete significant amounts of ground water, so freshwater scarcity will put increased pressures on the multitude of urban citizens. Informal shelters provide little barrier from outside air pollution. Slum livelihoods which are dependent on fishing will be lost with ocean acidification and biodiversity loss.

3.1.3.2 Macro-political economy, global trends and transitions

The Global Risk Report (21) researches the future significance of 28 global risks related to economic, environmental, geopolitical, societal or technological issues. Societal risks which are set to increase include a continued failure of urban planning. This will be due to rapid urbanisation of people seeking employment opportunities as rural environments degrade, the productivity of cropland decreases, and rural incomes drop (22). Rapid, unplanned urbanisation has the potential to

drive other risks, such as unemployment and underemployment, the spread of infectious disease, social instability, water and food scarcity crises (21).

3.1.4 Conclusion: Socio-ecological system of urban slum setting

This section has elaborated descriptively on the socio-ecology of slums. It is one of hazardous locations, whose resource use by a heterogeneous group, united in their disadvantage, increases disaster risk. The density of people generates great pressure on limited natural resources. The exclusion from municipal services means that everyday activities lead to ongoing degradation and pollution of the environment, which creates unhealthy conditions. Hazards disturb an already fragile system leading to the deterioration of the human condition and the environmental condition. These perturbations can lead to a downward spiral of increasing disaster risk. External factors, such as climate change and global economic trends, are predicted to increase urban risk. The deprivation of slum dwellers is not unknown. Yet their problems continue to receive limited attention.

3.2 Socio-ecological Indicators

Indicators provide information on the state or condition of something of interest. When it comes to socio-ecological systems, indicators need to try and capture the complex spatial and temporal scales of the system. For this to be achieved, indicators should be dynamic (i.e. show rates of change), cross-scale (i.e. link local, to global processes) and have clear thresholds defined (49). For example, Miller et al, state that static indicators, such as GDP, should not be used as they cannot capture the changing process of vulnerability. Instead indicators of dynamic processes, such as the percentage of labour force employed, should be used (50). In general, these types of indicators are not always easy to define or to measure.

There is a remarkable amount of interest and literature surrounding the qualities urban socio-ecological indicators should possess, however, relatively few studies propose and test such indicators. Eleven papers were identified which proposed measureable indicators for socio-ecological vulnerability analysis. Table 1 lists the urban socio-economic indicators and Table 2 lists the urban biophysical indicators which were identified during the literature search. Together these sets of indicators could be used to characterise the socio-ecological condition.

In total, 19 urban socio-economic and 12 biophysical indicators were identified. For convenience the indicators have been grouped. Socio-economic indicators are related to development, economics, exposures, health, infrastructure, politics or society. Biophysical indicators are related to climate,

ecology, ecosystem, geography, geology or hazards. The spatial scale at which this information has been, or is proposed to be captured, is indicated by “macro” or “micro”. Macro refers to country-scale indicators which cannot be disaggregated; micro refers to city- or local-scale indicators. The term ‘multiscalar’ is used when the information could be usefully collected at either the micro or macro level. Not all indicators were “dynamic” e.g. HDI, GINI are all static indicators which take a snapshot of time.

Table 1. A compilation of urban socio-economic indicators which could be used in an assessment of socio-ecological vulnerability				
Type	Socio-economic Indicator	Description	Aggregation level	Source
Development	Human Development Index	Composite statistic of life expectancy, education, per capita income.	Macro	(19)
Economic	Gini Coefficient	Measures inequality amongst a population based on income or consumption expenditure.	Multiscalar	(51)
	Human Appropriated Net Primary Productivity	Aggregated statistic of the amount of area used by humans and intensity of land use. A measure of resource consumption.	Macro	(52)
	% living in legal housing built with permanent materials	Value, quality, security of tenure, and density of residential construction affects populations. Proportion of households with formal title deeds to both land and residence, to either one of land or residence, or with enforceable agreements or any document as a proof of a tenure arrangement.	Micro	(6,22,53)
	Increasing population affected by disasters (employment loss)	Potential loss of employment/livelihoods following a disaster contributes to slower recovery from the disaster.	Micro	(53)
	Number of meals per day	When generalized poverty and informal work means per capita income might not be very useful indicator, instead social gradient could be indicated using meals per day.	Micro	(35)
Exposure	Number of people living in disaster prone areas	Proportion of households residing on or near a hazardous site such as: geologically hazardous zones (landslide/earthquake and flood areas); on or under garbage mountains; around high-industrial pollution areas; around other unprotected high-risk zones (e.g. railroads, airports, energy transmission lines).	Micro	(22)
Health	Loss of DALYs (Disability Adjusted Life Year)	DALYs for a disease or health condition are calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years Lost due to Disability (YLD) for people living with the health condition or its consequences:	Macro	(54)
	Burden of environmental diseases	Number of people affected by environmental diseases (pollutants, chemicals) microbial infection, diarrhoea, chronic lung disease.	Micro	(54)
Infra-structure	Proportion of population served with risk-reducing infrastructure	Including: paved roads, storm and surface drainage, piped water <30% = very vulnerable	Micro	(6)
	Structure and quality of housing	Proportion of households living in temporary and/or dilapidated structures, factors to consider include: quality of construction (e.g. materials used for wall, floor and roof); compliance with local building codes & standards.	Micro	(22)
	Adequate sanitation and solid waste management	A settlement has inadequate sanitation if less than 50% of households have improved sanitation, including: public sewer; septic tank; pour-flush latrine; ventilated improved pit latrine. The excreta disposal system is considered adequate if it is private or shared by a maximum of two households	Micro	(22,54)
	Access to water	A settlement has an inadequate drinking water supply if less than 50% of households have an improved water supply: household connection; access to public stand pipe; rainwater collection; with at least 20 litres/person/day available within an acceptable collection distance.	Micro	(22)
Political	Worldwide Governance Indicators	Composite statistic of 6 dimensions of governance: Voice & Accountability, Political Stability and Lack of Violence, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption	Macro	(53)
Social	Population density/Overcrowding	Number people/area ² ; Proportion of households with more than two persons per room.	Multiscalar	(19)
	Gender	Women can experience more hardship and exclusion from resources pre and post disaster	Multiscalar	(53)
	Age	Children in general more vulnerable to environmental factors affecting health. Elderly also.	Multiscalar	(53)
	Previous disaster experience	Number of disaster events the person has lived through	Micro	(55)
	Population growth/Urbanisation rate	Typically annual %; rapid growth often leads to a lack of available quality housing, water and sanitation infrastructure; social services network (if it exists) doesn't have time to adapt to increased population	Multiscalar	(19)

Table 2. A compilation of urban biophysical indicators which could be used in an assessment of socio-ecological vulnerability to climate-induced extreme hydrological events

Type	Biophysical Indicators	Description	Aggregation level	Source
Climate	Climate Variability	Including rainfall and temperature. Provides a potential assessment of human vulnerability to environmental change.	Multiscalar	(54)
Ecological	Land-use in natural terms	e.g. flood plain, marshy ground, river bank. This would tell us something about the ecosystem service that the land provided/provides.	Micro	(55)
	Cover density of vegetation barrier separating built areas from sea/river	Moderates extreme environment events e.g. vegetation barriers provide buffering to storms and sea surges	Micro	(51)
	Pollution	Compare the quality of water/soil to the quality standard, gives some indication about leeching.	Micro	(51)
	Ecosystem conversion	Looks at the ecosystem services lost when land is converted e.g. from a floodplain, marshy ground, river bank to something else.	Multiscalar	(54)
	Land-use change	Temporal indicator which monitors expansion, land use change, human activity.	Multiscalar	(19)
	Environmental Vulnerability Index	Comprises over 50 smart indicators but states it is not applicable in cities.	Macro	(2)
Geo-graphical	Elevation	Elevation above sea level (m).	Multiscalar	(19)
	Erosion and soil characteristics	Soil parameters include organic carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry.	Macro	(54)
	Soil infiltration capacity: % impermeable relative to permeable surface	Relates to land cover and built environment.	Multiscalar	(51)
Hazard	Climate Hazard Index	Average annual frequency of occurrence in a given time. A composite statistic of a variety of natural disasters.	Macro	(56)

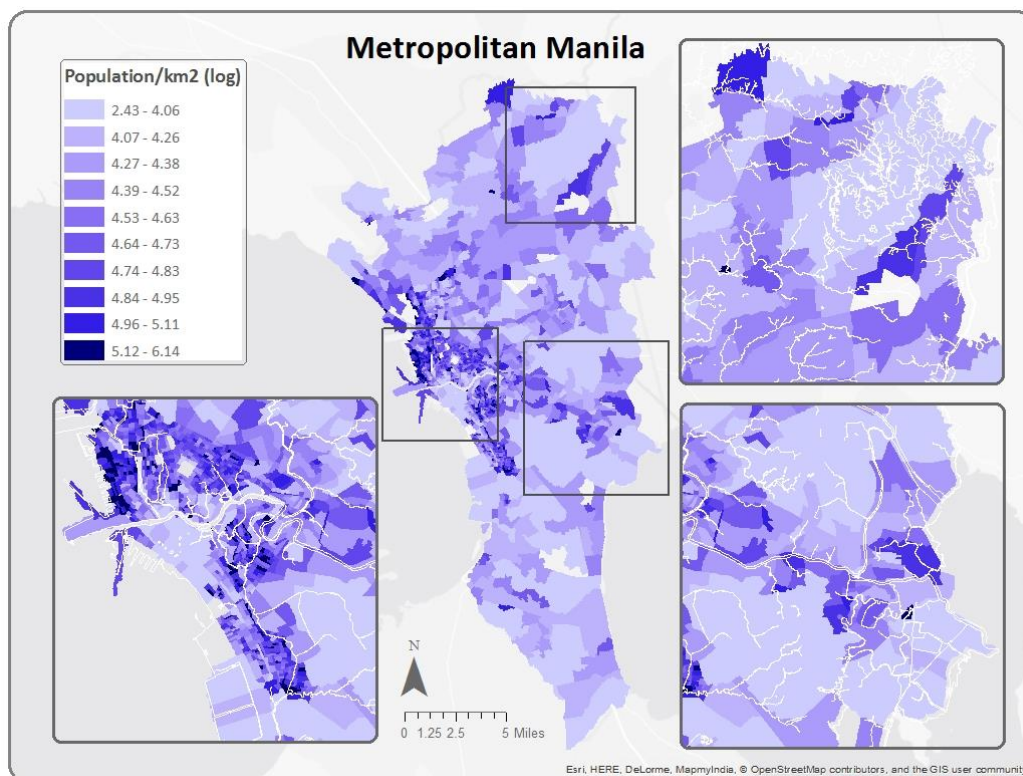
3.3 Proof-of-concept: Metropolitan Manila

Metropolitan Manila was chosen as the proof-of-concept for this research due to its disaster risk and large slum population. The data used in the geospatial mapping included: *barangay* administrative boundaries, population size per *barangay*, river paths and canals, previous disaster impacts, and expected flooding level. Unfortunately, further indicators as identified in literature review and Section 3.2 were not publicly available, or had been gathered only at the municipal level. A geospatial analysis was unable to be carried out as there was not sufficient data to check for spatial correlations or associations at the *barangay* level.

3.3.1 Population density along natural water courses

As shown by Figure 7 the population density in different *barangays* across Metropolitan Manila ranges considerably (darker blue denotes more densely populated *barangays*). From the data the most densely populated *barangay* has 13,776,670 people per km² and the least densely populated *barangay* has 271 people per km². Manila City population density, in general, is highest along the coast and high along the drainages off the Pasig, Marikina and Parañaque rivers. The densest areas of Metro Manila are therefore located in potentially risky zones.

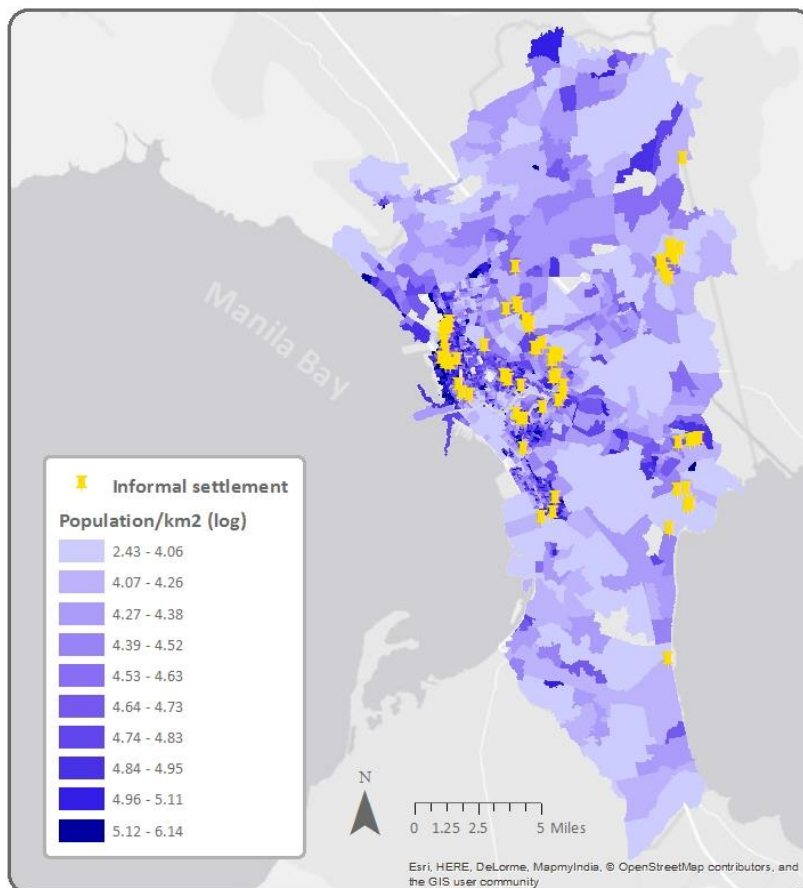
Figure 7. Population density by *barangay* in Metropolitan Manila with enlarged sections showing population density along rivers and canals. Source: Philippines Census 2010; ESRI maps.



3.3.2 Informal settlements in hazardous locations

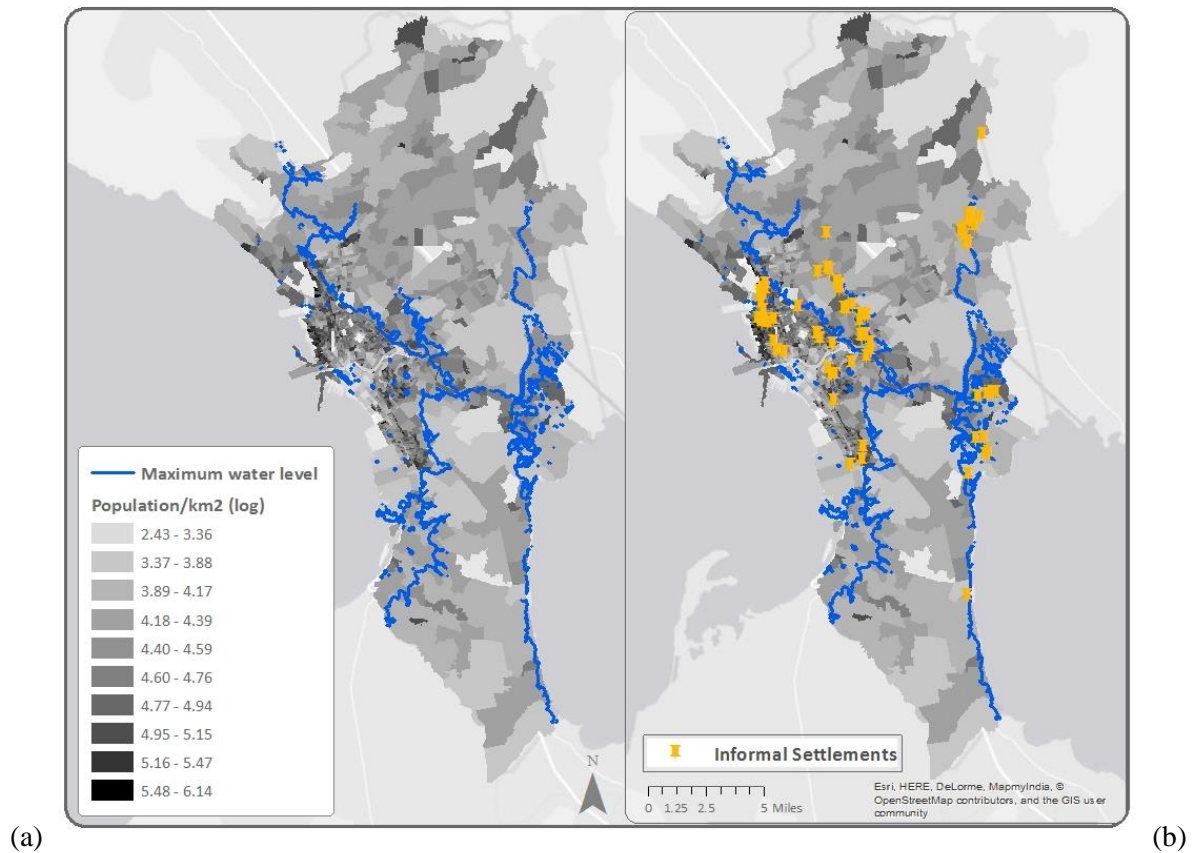
There was no publicly available information on where informal settlements were located in Metro Manila, despite the existence of a national resettlement programme for informal settlements found in hazardous locations (57). As a proxy, potential informal settlement sites were identified using flood risk maps. The majority of informal settlements at risk of a flood that could be expected to occur every five years were located in the City of Manila where population density was highest (Figure 8). They were also located near the Marikina River and along the east towards Laguna Lake.

Figure 8. Geocoded locations of potential informal settlements (yellow pins) over-laid on population density by *barangay*.



Combining the potential locations of informal settlements and the maximum water levels reached during Typhoon Ketsana revealed that slum settlements lie very much within risk of flooding impacts of a typhoon (Figure 9). The slum locations would have been affected by the Typhoon Ketsana flooding all along the western coast of Metro Manila as well as along the Marikina River system and in the east by Laguna Lake.

Figure 9(a) Maximum water level experienced during Typhoon Ketsana (2009) on a map of population density by *barangay*. Figure 9(b) Location of potential informal settlements (yellow pins) relative to the maximum water levels of Typhoon Ketsana (2009). Data source: Philippines Census 2010, Typhoon Ketsana max water level from GIS Department of Local Government Unit, Muntinlupa.



4 Discussion

This paper had three main research aims: 1. Characterise the slum socio-ecology 2. Identify potential indicators to be used in a socio-ecological assessment of vulnerability 3. Attempt a proof-of-concept mapping of climate-related disaster risk in Metro Manila using GIS techniques. The following section looks at the findings and limitations of the results for each of these aims.

4.1 Generalizability of slum socio-ecology characterisation

Research on socio-ecological systems is still in an exploratory phase. Its application to, firstly, the complex urban setting and, secondly, the chronically under-researched slum context, was therefore challenging. Nevertheless some broad patterns, processes and interactions of what might be considered the socio-ecology of a slum of despair were able to be drawn. Just as a woodland in the United States has a comparable ecology to one in England, so too, do slums globally share similar socio-ecological principles: a degraded

environment in which inhabitants rely on unimproved water systems and whose ordinary actions, by virtue of many people relying on limited resources, leads to pollution and unsanitary conditions, with consequences for human and environmental health. The resources available, hazard and external factors, size, governance and culture of the urban milieu (for which there was insufficient information in the literature) will influence the exact impacts and responses in the system. Aside from these broad generalisations, the exact socio-ecology is likely to be more heterogeneous when different ethno-specific urban contexts are taken into account.

How can we go further than these broad generalisations? Unfortunately, data and research is very limited, and perhaps represents one of the key defining characteristics of slums. How different demographics interact with the environment would provide a more nuanced understanding of the socio-ecology of slums. For example, if women typically collect the water, do they also experience a higher burden of environmental disease? The underestimation on almost all aspects of slum life will remain unchanged while data continues to be gathered from health care registries and these populations remain invisible in the eyes of official census collection. As a minimum, information on age structures, burden of environmental diseases and known communicable diseases in locality, livelihoods, water sources and quality, and number of people living in hazard exposed areas is vital to ensure an adequate disaster response.

The extent to which feedback loops and the dynamic, adaptive nature of the system has been characterised is limited, especially with respect to climate change. This may, in part, be due to the disconnect - both temporal and spatial - between actions and the system's feedback and a lack of understanding amongst disciplines. The socio-ecological model requires a multidisciplinary approach to fully understand all the factors in the feedback loop. It is almost certainly also related to the difficulties of predicting future economic and climate change events. Furthermore, establishing causal sequences may be problematic as slums are embedded within urban systems that may have collapsed a pre-existing natural system e.g. a river/wetland cannot reasonably be attributed solely to the actions of the slum dwellers. Therefore, the history of the urbanisation process for a given context must also be considered when trying to understand the disaster risk from hazards induced by human action and the vulnerability of a given socio-ecological system.

4.2 Socio-ecological indicators

The literature review uncovered 31 potential indicators which could be used in combination as a starting point for research focussed on the interaction between humans, their environment, and disaster risk. These should be validated through consultation with local stakeholders, bringing multiple disciplines together, and in field studies. The co-production of indicators is extremely important, especially if the research is conducted at the micro-scale, such as a city or a specific slum. This would ensure the relevance of each indicator to the given context.

Theoretical interest in the qualities socio-ecological indicators should possess has been mounting in the literature (50). Some of the indicators in the table could be considered static i.e. HDI, GINI coefficient, whereas theory suggests that indicators should be dynamic in nature. The reason for this may be that theory has progressed more quickly than the practical research and more research will be needed to verify how relevant the different indicators are in day-to-day disaster planning and management. As this area continues to gain more attention, more indicators will be devised which are able to capture the dynamic nature of a complex socio-ecological system.

4.3 Utility of geospatial mapping

The geospatial mapping could only be as strong as the geocoded data available, which proved a substantial limitation. Aside from the population size per *barangay* data (from 2010 census), the majority of publicly available information was at the municipal level. A mechanism which is capable of capturing granular demographic and socio-economic data, both of the *barangay* and specific slum populations, is urgently needed to understand the reality of urban vulnerable populations. As municipalities in some cases contain 70+ *barangays*, it was felt this level of aggregated information would mask important variations. Using the *barangay*, the smallest political unit, would have been the best way to draw meaningful comparisons, but, unfortunately, was restricted. Given more time and access to data at the *barangay* level (such as gender, age, poverty incidence, health, improved water source access) the information could be re-mapped and yield stronger results in terms of (spatial) correlations.

The extent to which the data from the census accurately captured the population density of each *barangay* was also an unavoidable limitation. Official census collection typically ignores slum settlements and therefore the real population density might be higher than the

data here showed. For instance, data from the National Housing Authority has reported higher numbers of informal settler households than the census data (29). This is an inevitable consequence of relying on publicly available official data. Nevertheless, the municipal government has a moral obligation to be aware of this population just as much as any other.

Using GIS techniques to visualise spatial data is a powerful means to communicate information. This paper showed that dense pockets of people do indeed inhabit what might be risky zones i.e. close to rivers and coastlines. In addition, the results showed that potential informal settlements sites, at risk of urban flooding, would also be at risk of storm-surges associated with typhoons. The use of geospatial mapping can be expanded upon to capture more geocoded indicators and locate more sites of hazard exposure. For instance, flooding and typhoons are only two climate-change related disaster risks predicted to increasingly impact Metro Manila; sea level rise as well as increased extreme temperatures could also usefully be mapped.

Ideally, this research would be conducted in partnership with local stakeholders (such as community groups) and slum dwellers themselves, with clear lines of communication to relevant policy decisions. Participatory mapping would empower slum dwellers by giving them influence over the design of the research, access to the findings, and evidence to use to help promote their rights. Devising indicators and mapping vulnerability to a certain event, is only the first step, but it omits the agency of the populations themselves. This work has great potential to move forward by looking at the environmental health needs and priorities of populations most at risk; trying to understand slum dwellers knowledge, action, and practice in relation to climate-change risk depending on their location in the city; and how slum dwellers interpret risk and risky behaviours and investigating when they would choose to take action.

5 Conclusion and Recommendations

This paper has characterised slum socio-ecology, defined potential urban socio-ecological indicators and, as a proof-of-concept, geospatially mapped vulnerable populations exposed to climate-induced hazards in Metro Manila. The synergistic relationships between poverty, a degraded environment and higher disaster risk are clear: reliance on limited natural resources by large numbers of people generates pressure on the natural functioning of ecosystems; everyday activities without associated basic municipal services (such as sanitation provision) leads to ongoing degradation and pollution, and resultant unhealthy conditions; deteriorated

natural and human conditions undermine coping capacity and influence the impacts of a disaster, presumably leading to greater loss of life and assets for the poorest.

The trilemma of rapid urbanisation, climate change and increasing inequality is set to continue. Given that cities are likely to be the norm of living in the future, it is imperative that governments focus on sustainable urban development – for *all* urban citizens. Local and city municipalities have a moral obligation to slum populations the same as any other urban population. It is thus important that the urban poverty and socio-ecology of slums is understood to design the most appropriate and context-specific, long-term disaster mitigation and sustainable city strategies.

The deprivation of slum dwellers is not unknown, yet their problems continue to receive limited attention and as such defy adequate quantifiable markers. More targeted exploration of slums is needed to rectify this. What may currently appear as an overwhelmingly complex milieu can only become comprehensible with dedicated research. As a starting point, the indicators found in the literature and compiled in this report should be validated. Wherever possible, information should be geocoded so that geospatial mapping and analyses can be employed, as these techniques are both useful to visually communicate information and to assess spatial correlations of phenomena to the physical environment. Further indicators created in participation with local communities and slum populations through focus group discussions should also be generated to ensure locally relevant data is captured for a given context. An exploration of the perceptions of vulnerability and risk by the communities in concern is vital to ensure their engagement and participation in future disaster risk reduction interventions.

As a minimum, information on age structures, burden of environmental diseases and known communicable diseases in locality, livelihoods, water sources and quality, and number of people living in hazard exposed areas should be collected regularly by municipal governments. This information would provide a vital baseline to ensure an adequate disaster response. Further research is needed on how to capture and quantify the feedback loops over time between the human condition and the environmental condition, in the pre-disaster context and also how these will change in the post-disaster context.

Slums are complex, heterogeneous systems and as such locally relevant data from a number of different disciplinary perspectives, including ecology, urban planning, health, disaster management, governance, and sociology, is needed. Not all people are at risk to the same

extent – often it is the poor who disproportionately suffer the consequences of a disaster. Understanding how their risk and vulnerability manifests itself in the context of being embedded in a much larger socio-ecological urban setting is a challenging task and requires a multidisciplinary approach to fully understand. The collaboration between academia, government, civil society and the vulnerable populations themselves is necessary to achieve the healthy, inclusive, protective, and sustainable urban contexts we envision in a climate-changing world.

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