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# Quantifying resilience to flooding among households and local government units using system dynamics: a case study in Metro Manila

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## Abstract

A generic systems dynamics (SD) model template for resilience is adapted to analyse flooding impacts on household assets and local government assets of Pasig City, Metro Manila. SD simulations are used to quantify the loss of system performance due to adverse impacts, and the recovery of the system due to response measures. The simulation results reflect the decreasing levels of resilience among low-income households, and the reliance of local government on budgeting cycles to replenish assets. The initial model needs to be expanded to include other determinants of resilience, but this exploratory study reflects the potential usefulness of SD simulations as a decision support tool for city policy makers. By quantifying changes in resilience measures over time, simulations can complement qualitative analyses and test policy and programme scenarios.

## Introduction

The concept of 'resilience' is a broad one spanning vast literature in both the social and physical sciences. Researchers from these different fields have defined resilience in various ways (Cutter *et al*., 2008). The traditional engineering and psychological definitions of resilience often involve properties such as flexibility, bending, and the ability to bounce back after a stressful situation (Donoghue, 2007; Norris, 2009). However, when applied to people, groups, and communities, resilience is directly associated with the capacity or ability of individuals, groups, or communities to cope with the adverse effects of a hazard impact (Burton, 2012). For instance, Mileti (1999) argued that resilience refers to the ability of the community to recover by means of its own resources. Norris *et al*. (2008) views resilience as a set of capacities that can be fostered through interventions and policies, which in turn help build and enhance a community's ability to recover from disasters. From an ecological perspective, resilience is also linked to the integrity of ecological systems on which the social systems depend (Norgaard, 1994), with an emphasis on the interactions between and within social and natural systems (Manyena, 2006). Both natural and social scientists have acknowledged that resilience should involve the adoption of multidisciplinary and cross-disciplinary methods in analysis (Cutter *et al*., 2008; Burton, 2012). Further research has sought to characterize whether resilience is a state (i.e. based on inherent characteristics), a process, or an outcome (Pooley and Cohen, 2010).

Haimes (2009) asserts that resilience is time-dependent, and, in the case of systems, requires multidimensional metrics to describe, measure, and monitor it. To enhance resilience, it is important to understand its determinants and how progress, as a result of initiatives to maintain and improve resilience, can be tracked over time (Klein *et al*., 2003; Cutter *et al.*, 2008). Quantitative approaches to resilience can therefore complement qualitative conceptualizations. However, there are currently few methodologies within existing literature that explicitly suggest how resilience should be quantified, as well as how to compare communities with one another in terms of their resilience (Bruneau *et al.*, 2003; Cutter *et al.*, 2010). Bozza *et al.* (2015) propose a framework to quantify urban resilience against disasters that involves defining indicators to measure the efficiency of the city's hybrid social-physical networks, defining indicators to measure the quality of life for the citizens that these networks serve, and then relating these two sets of indicators using a system function. This process can be implemented for different urban management strategies and at different times during the occurrence of a disaster (e.g. pre-shock, then during the recovery phase) to determine the city configurations that provide the best level of resilience. However, different examples or methods to operationalize the framework are only suggested and it has not yet been implemented for a particular city. Shaw *et al.* (2010) developed a Climate and Disaster Resilience Index also utilizing categories of indicators – physical, economic, social, institutional, and natural – rated on a scale from 1 to 5. This index was computed for several cities across Asia, including the Metro Manila area as a whole (with an overall score of 3.77 out of 5) and its component cities and municipality. This index is a static snapshot, however, and does not assess resilience dynamically.

Simonovic and Peck (2013a,b) attempt to quantify resilience over time using systems dynamics (SD). SD is a field involving the analysis of inter-relationships among system components. SD simulation modelling platforms typically allow for a system to be built virtually in terms of stocks, flows, input information, and feedback loops. The structure of the system gives rise to certain behaviours and trends (Ford, 2010). The purpose of this modelling approach therefore is not predictive but descriptive – i.e. it is meant to explore the behaviour of a particular system over time and provide insight into the underlying causes of such behaviour (Meadows, 2008). Simulations are especially useful in capturing and explaining the behaviours of complex systems, and testing leverage points that can result in desired changes in system behaviours. For example, Jin *et al.* (2009) use SD to develop a temporally explicit ecological footprint forecasting model and simulate policy options towards given sustainability targets. Chen *et al.* (2006) explore urban sustainability, particularly in terms of air quality management, and, through SD simulations, find that the preservation of green space may actually be a more effective policy than public transportation facilitation. System dynamics simulation modelling has also been applied to water resources and flood management (Ahmad and Simonovic, 2000; Mirchi *et al.*, 2012). Josol (2013) develops a physical hazard index and simulates changes in the index over time for Metro Manila using an SD platform. The index is based on the status of the physical services (e.g. sanitation and sewerage, municipal solid waste management, water availability and accessibility, water quality, and urban growth) that may exacerbate urban flooding hazards during extreme rainfall.

In the case of resilience, an SD model can help identify and analyse the components of the system that contribute to or detract from its capacity to absorb or recover from shocks. In studies presenting static indices or analyses based on time-slice or one-time data gathering, the characterization of resilience is that of a specific snapshot in both space and time, and it becomes challenging to observe resilience as a process. With the SD approach, researchers can use time-slice data as baseline for defining a system structure, and then model how this structure gives rise to certain behaviour dynamics when subjected to a hazard or disturbance.

The approach described by Simonovic and Peck (2013a,b), which tracks adverse impacts versus adaptive measures in the system over time, draws largely from an engineering background. However, it has the potential to be adapted for systems defined over different spatial scales, for a variety of users or sectors, and in terms of even a few key variables of interest. Moreover, individual systems can be linked together to create feedback loops among sectors and to develop an aggregate resilience measure. Processes that operate on shorter time scales (e.g. hourly, daily, monthly) can also be modelled separately but linked to processes that operate on longer time scales (e.g. annual to decadal). A flooding event triggered by extreme rainfall would be the example of the former, whereas climatic changes and sea level rise would be examples of the latter.

The objective of this study, therefore, is to explore how an SD simulation modelling approach can be applied to describe the resilience of households and local governments as a dynamic state in the case of extreme rainfall and flooding events. This study tests the feasibility of the template proposed by Simonovic and Peck (2013a,b) by adapting it to describe the asset base of households and the asset base of their local governments, and the processes that enhance or erode this asset base during a flooding event. This paper is a component of a larger study, the Coastal Cities at Risk (CCaR) project under the International Research Initiative on Adaptation to Climate Change (IRIACC). CCaR is being implemented for Vancouver, Lagos, Bangkok, and Manila. The project includes the integration of the physical, social, economic, and organizational sectors into a holistic analysis of city resilience to flooding, which will be the basis for development of decision support tools for local government. The models described in this paper are not yet the complete simulation tool for policy makers, but represent initial efforts to operationalize and evaluate a proposed SD model template in the Philippine context for a discrete flooding event.

## Modelling approach

### General system dynamics model

The approach of Simonovic and Peck (2013a,b) uses the concept of system performance in constructing generic SD simulation models (GSDSM). Resilience is manifested in the (1) ability of the system to absorb shocks, reduce negative impacts, and therefore mitigate the deviation from baseline system performance; and (2) the ability of the system to quickly recover from any adverse impacts, re-establish normal system functioning, and, if possible, 'build back better' and improve on the baseline system performance. In the simulation environment, a quantitative resilience measure can therefore be calculated by comparing the system performance as affected by the shock or hazard with the initial or baseline system performance. This measure can be plotted over time at the onset, during, and after the hazard, and in this way, provide a means to track and compare system resilience under different conditions and scenarios.

The general model template representing a system is shown in Figure 1. The simulation platform used is Vensim® by Ventana Systems (Harvard, MA, USA). Stocks, which are variables that accumulate over time, are represented by boxes, while the flows are represented by the arrows with 'spigots'. Flows are connected to stocks and can either add to or take away from stocks over time at a controlled rate. Other text and arrows provide auxiliary information and connections between variables.

Figure 1 is adapted and simplified from the GSDSM template developed by Simonovic and Peck (2013a,b) through the use of a damage profile. In the original template, a key stock that is affected by flooding is identified in each system, and the changes in this stock are quantified through the interaction of hazard, exposure, and vulnerability factors. Examples of key stocks may include the number of injured or sick population, available and/or accessible support services (e.g. hospitals), and the damages to infrastructure (e.g. roads and buildings) and services (e.g. electrical networks or water pipelines) (Simonovic and Peck, 2013b).

Because of the lack of consistent data over time to develop and validate mathematical functions relating exposure to the flooding hazard and vulnerability to quantified amount of impact on the stock, the three are collapsed into a damage profile. This damage profile is applied to the stock to represent adverse impacts. In this study, a Typhoon Ketsana-type damage profile is constructed. Typhoon Ketsana (local name Ondoy), which hit the Philippines on 26 September 2009, caused widespread flooding in Metro Manila as well as in the central and southern parts of Luzon. The amount of rainfall that was recorded by the Manila Observatory station over a 12-h period was 450 mm (World Bank, 2011). The typhoon affected approximately 4 million people in 2018 barangays in the country (National Disaster Coordinating Council, 2011).

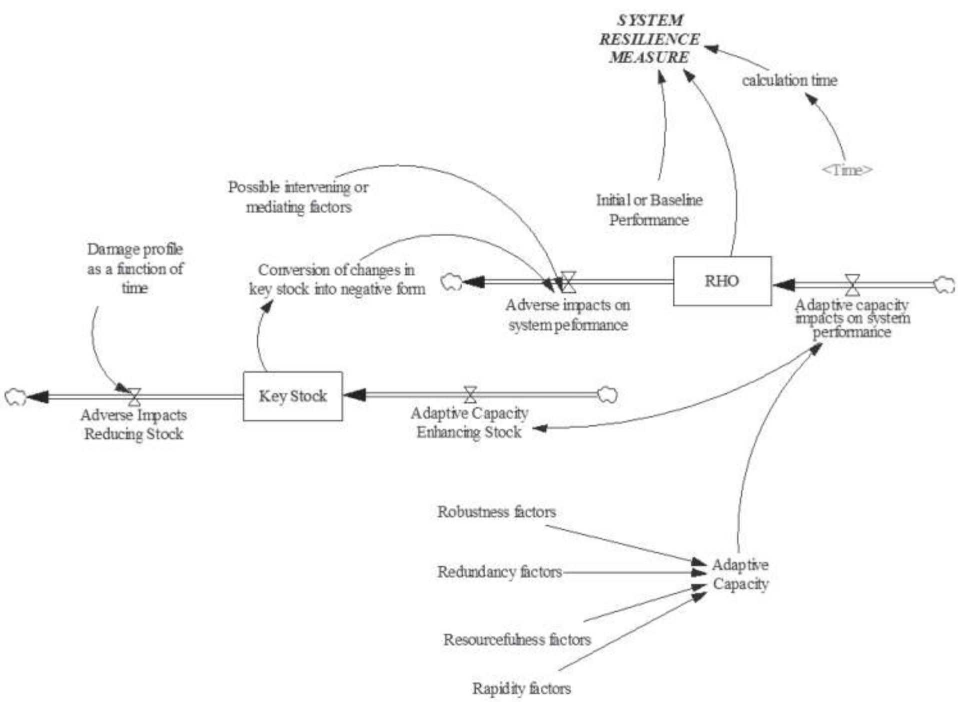


**Figure 1** General system dynamics model template. (Adapted from Simonovic and Peck, 2013b.)

For the purposes of the model, a Ketsana-type damage profile is one in which extreme rainfall occurs and incurs damage over the short span of a day (as opposed to flooding experienced in Metro Manila during the southwest monsoon season in August 2012 and 2013 that involved prolonged rainfall events). This hypothetical damage profile was constructed by distributing the total recorded damages over 1 day of intense rainfall and flooding. Better scenarios of damage may be developed later when functions relating exposure to hazard and vulnerability factors become available.

System performance throughout the progression of a flooding event is calculated from the changes in the key stock, based on the effects of the adaptive capacity measures that counter adverse impacts. Adaptive capacity here is defined in terms of four properties: robustness (ability to resist stress), redundancy (ability to continue functioning i.e. due to presence of back-up systems), resourcefulness (ability to identify options and source out needed resources), and rapidity (ability to respond in a timely manner) (Bruneau *et al.* 2003 as adapted by Simonovic and Peck, 2013b).

The 'RHO' variable in Figure 1 represents the change in system performance during a specific period based on the adverse impacts and the adaptive capacity factors present to help cope with and recover from them – i.e. if there are no adverse impacts, then system performance is unaffected and RHO is equal to 0. The system resilience measure is then calculated as (Simonovic and Peck, 2013b):

$$\begin{aligned} &\mathit{System\ Resilience\ Measure}(t) \\ &= 1 - \frac{\mathit{RHO}(t)}{\mathit{Baseline\ Performance} * \mathit{calculation\ time}} \end{aligned}$$

The measure is typically equal to one before the onset of the shock (because the current system performance is still equal to the baseline performance), then decreases as the flood causes adverse impacts, but then recovers through the implementation of adaptive capacity measures. The measure may surpass one should the new system performance after recovery be better than the baseline. Simonovic and Peck (2013b) propose that this generic approach can be adapted for either long-term processes (e.g. hazards like sea-level rise or policy changes that require years to implement) or short-term processes (e.g. hazards and responses on the order of days to months). The model template is adapted here as a short-term model to track immediate changes in resilience measure in the days during and after the flooding event.

This exploratory study focuses first on the household as a key system representing the socio-economic sector, and the local government unit (LGU) as a key system representing the organizational sector of Metro Manila. The household refers to the family units or to the groups of individuals living in the same domicile. The LGU refers to the governing body of cities or municipalities. In both sectoral models, assets are used as the key stock (e.g. total household assets and total LGU assets, including both income/budget and monetizable assets).

Assets are chosen as the key stock to test the model template for two reasons: the first reason is the practical aspect of data availability and relative ease of quantification for input into the equations of the systems model. The second reason is the basic conceptual assumption that having more assets or resources at their disposal gives stakeholders more options to explore and actions to take in response to hazards. For example, Green *et al.* (2007) defined resilience in terms of access to resources that enable actions for prevention or response. From a social perspective, measures of resilience also often include the income or resource levels (Adger, 2000; Sherrieb *et al.*, 2010), or the stability and distribution of income levels (Adger, 2000). The sustainable livelihood framework, developed by Chambers and Conway (1992), recognizes financial capital as one of the five main types of capital, the others being social capital, physical capital, human capital, and natural capital (Peacock *et al.*, 2010). This framework focuses on improving these capital assets to enhance community resilience. Financial capital specifically refers to the financial resources utilized by populations to achieve their livelihoods (Peacock *et al.*, 2010). It may include the following: income, as well as the access to credit, savings, and investments that increase the ability of communities to absorb disaster impacts and speed up the recovery process. Financial capital can be measured through household income, employment, property values, and investments (Peacock *et al.*, 2010). The household model captures this quantifiable aspect of capital. Physical capital (e.g. house and appliances for households; physical infrastructure for LGUs) is also captured if it is monetized as part of the asset pool. This monetization is carried out to ensure consistency of variable units in the simulation equations. As a consequence, other forms of capital, such as social capital in the form of community networks, are not included in this model (however, it would be possible to adapt the same model template for these variables if they can be quantified).

## Household model

As mentioned previously, the household as one of the smallest units of analysis is chosen in this study as to represent the socio-economic sector as experienced on the ground, giving a bottom-up perspective to resilience. The household model focuses on quantification of, and changes in, household assets. Adverse impacts and adaptive capacity are quantified in terms of losses or expenditures and income, respectively.

Under 'normal' (i.e. no flood) conditions, each household already has expenditures for basic subsistence needs for which they require income from regular jobs and/or other alternate sources. Average household expenses tend to increase should there be children, senior citizens, sick, or differently-abled members in the household. At the onset of flooding, loss of household assets occurs due to direct damages caused by the flood, expenditures to repair these damages or replace lost property, and the reduced of income due to lost workdays. However, there may be additional income from other sources (e.g. donations, loans, alternative livelihoods) that will aid households.

The four properties of adaptive capacity for the household model representing the socio-economic sector are hence defined as follows.

- Robustness – based on income derived from regular occupations of the household's working members. The rationale behind this is that having a stable source of income allows the household to provide for their basic and critical needs, and this in turn allows them to better deal with stressors.
- Redundancy – based on income derived from extra or alternative sources of income such as small, home-based 'sari-sari' stores, backyard agriculture or animal husbandry, and remittances from family members who are overseas foreign workers, if any. Note, however, that these alternate sources might also be damaged (e.g. in the case of small stores) or may become inaccessible (e.g. access to banks or money transfer agencies to retrieve overseas Filipino workers remittances) by the flooding, which may be accounted for in the model through scenario development.
- Resourcefulness – based on the additional help that can be sourced from the LGU or non-government organizations in the form on donations, relief goods, or cash-for-work recovery programmes.
- Rapidity – a measure of how quickly the donations from external sources, specifically the LGU, can reach the affected households.

The initial value of household assets before the flooding occurs serves as the baseline value for calculating deviation of system performance (e.g. loss of assets) and hence, the household's resilience measure. (For more details on the household model diagram and descriptions of specific variables, see Appendix S1.)

## LGU model

In parallel with the household model, the LGU model considers LGU assets both in terms of available funds as well as monetized assets, as the key stock. Adverse impacts and adaptive capacity are also quantified in terms of losses or expenditures and inflows of funds, respectively. The model deals mainly with local resources available to cities during a disaster. The LGU is the highest unit of analysis of the organizational sector at the city level, so this model provides a top-down perspective to resilience as a complement to the households that constitute the LGU constituency.

Although a Ketsana-type damage profile was used, present-day policy structures for disaster risk management were incorporated in the model. Existing policies emphasize the important role of LGUs in disaster risk reduction and management (DRRM) and climate change adaptation. The Philippine Disaster Risk Reduction and Management Act of 2010 [Republic Act (R.A.) 10121] mandate the LGUs to mainstream DRRM and CCA in governance activities such as land-use and urban development planning, socio-economic development planning, budgeting, infrastructure investments, and policy making. RA 10121 reconfigured the previous local calamity fund into a local disaster risk reduction and management fund (LDRRMF) to highlight the paradigm shift from a focus on disaster response and anticipation to that of an integrated approach to deal with risk as a whole. The LDRRMF provides funding in support of DRRM plans created by the LGU. RA 10121 requires an allocation of 5% of the regular income of an LGU. LGU income is usually earned from both national (e.g. internal revenue allotments) and local sources (e.g. business licensing and building permit fees). Under certain circumstances, other LGUs can donate into another LGU's LDRRMF. The LGU may likewise receive additional income, both in cash and in kind-aid from domestic humanitarian organizations.

Local DRRM funds are programmed annually. Seventy per cent of the LDRRMF is earmarked for all equipment, supplies, and activities for disaster prevention and mitigation, response, rehabilitation, and recovery and is normally utilized before a disaster. The other 30% is allocated as 'quick response fund (QRF)'. The QRF is a reserve that can be used for rescue, relief, and recovery programmes needed during a disaster. The QRF may be utilized only upon the declaration of a state of calamity in an LGU by the Office of the President or the LDRRMF.

Based on the aforementioned legal provisions, the four properties of adaptive capacity for the LGU model representing the organizational sector are hence defined as follows:

- Robustness – based on expected inflows of funding, primarily the QRF, on which the LGU can rely on to respond to the hazard and to implement initiatives and activities to help constituents recover and adjust.
- Redundancy – based on the additional resources that can be channelled from the national government or other LGUs, if the latter is available.
- Resourcefulness – based on additional help that can be sourced from local non-government organizations, international non-government organizations and foreign governments.

• Rapidity – a measure of how quickly resources can be made available and mobilized.

At the onset of flooding, loss of LGU assets occurs due to direct damages by the flood to public or government property, expenditures from the QRF, expenditures to repair damages or replace lost property, and expenditures to help the constituency of the LGU with relief and recovery. This is where the household model and LGU model connect – in the capacity of the LGU to provide relief resources to aid households.

Prior to the flooding, the LGU may already be spending their allocated funds for initiatives that help decrease the vulnerability of the city, although it is not within the current scope of the model to explicitly quantify how these preparatory activities affect the LGU resilience measure. This is a point of improvement for the current version of the model as the effect of preparatory activities cannot be tested dynamically together with the effect of response and recovery activities.

In the current version of the LGU model, the external sources of adaptive capacity (pertaining to resourcefulness and redundancy) are first set to zero to consider only the internal capacity of the LGU. Although feedbacks do exist among the 17 cities and municipality of Metro Manila in terms of impacts of flood interventions implemented (e.g. engineering measures implemented along any one of the major rivers will affect neighbouring LGUs), in this exploratory study, the scope is limited to developing models for a city assumed to be independent. This is the first phase in a larger initiative, which, in the future, will be able to capture the more subtle interdependencies among the cities and municipality of Metro Manila.

As with the household model, the level of LGU assets before the flooding occurs serves as the baseline value for calculating changes in system performance (i.e. loss of assets) and hence, the LGU's resilience measure. This baseline value includes public infrastructure as monetized assets. (For more details on the LGU model diagram and descriptions of specific variables, see Appendix S2.)

## Context: the case of Pasig City, Metro Manila

The feasibility and utility of the household and LGU SD resilience models as a decision support tool are explored using the Pasig City, Metro Manila as a case study (Figure 2). Inhabited by nearly 12 million people [National Statistics Office (NSO), 2010], Metro Manila is the financial and economic centre of the country comprising 16 cities and one municipality. It is traversed by several major waterways, such as the interconnected Marikina River, Pasig River, San Juan River, Napindan channel, and Manggahan floodway running through the north and across Metro Manila, as well the Tullahan River and Malabon River to the northwest [United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), 1990]. Metro Manila is a coastal city bounded by Manila Bay on the West, and is also near Laguna Lake in the southeast.

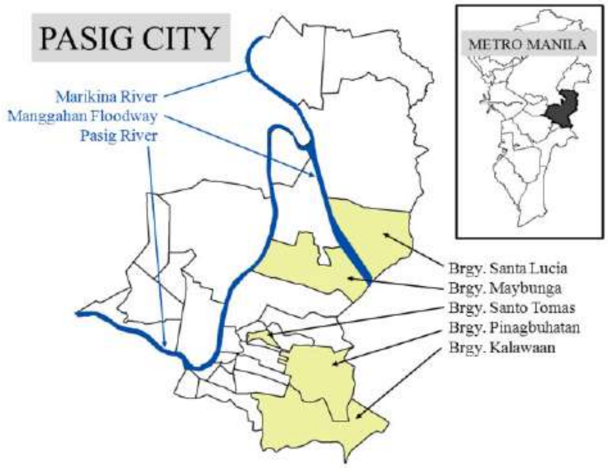


**Figure 2** Map of Pasig City, Metro Manila, showing survey communities used in the household model from the work of Porio (2011; 2014). (Base map of Pasig from Geomatics for Environment and Development, 2009; polygon map of rivers from © OpenStreetMap contributors extracted by Mapzen Metro Extracts (2014); Metro Manila base map from Philippine GIS Data Clearinghouse, 2011.)

Aside from being exposed to typhoons on a regular basis, Metro Manila is becoming increasingly vulnerable due to the stress from a burgeoning population coupled with environmental degradation and diminishing resources. Incidences of flooding have been linked not only to physical variables such as climate and topography, but also to patterns of urban development (Zoleta-Nantes, 2000; Bankoff, 2003). With this in mind, it becomes crucial to develop a suite of tools that can capture not just the physical factors but also the socio-economic and organizational factors that affect resilience and how it changes over time.

The city is used as the spatial unit of analysis. Pasig City is one of the 17 cities and municipality in Metro Manila. It has a land area of 31 $km^2$, only the 10th largest among Metro Manila cities and towns, but is the fourth biggest city in terms of population, as well as the fourth among the highest income earning cities of Metro Manila. Pasig lies within the Laguna Bay basin and is bordered on the west by Quezon City and Mandaluyong; to the north by Marikina; to the south by Makati, Pateros, and Taguig; and to the east by Antipolo, the municipality of Cainta, and Taytay in the province of Rizal (Pasig City, 2010).

Data for the household model of Pasig City were drawn from community surveys conducted by Porio (2011; 2014). The respondents of the household survey reside in low-lying and flood-prone areas in barangay Maybunga, Pinagbuhatan, Kalawaan, Sto. Tomas, and Sta. Lucia (Figure 2). The respondents were mostly female, married, with a median age of 40 years old, and have a median monthly income of Php8000 (less than US$200). They belong to informal settlements, with no security of tenure in their housing and no adequate access to basic services such as water, electricity, sewerage, and drainage systems. The households in these communities regularly suffer from exposure to floods and water surges, in addition to sickness of household members and lack of community security (Porio, 2011). The low income, relative to potential expenditures for basic needs and health, is a key factor in the determination of resilience in the model simulations. Many of these households earn daily wages and depend on the informal economy, which makes the inability to work during days of flooding a crucial factor in eroding their asset base.

The household model focuses on low-income households: meaning, respondents with reported per capita income below the poverty line. The value of the 2009 Philippine poverty line was used. The monthly threshold income that is considered as low-income is Php1600 (National Statistical Coordination Board, 2012). Although the household model is mainly based on data from surveys of low-income households, it can be adapted to affected households at any income level, if data are available. (For more details on the variables of the Pasig City household model, refer to Appendix S1.)

For the LGU model of Pasig City, LDRRMF utilization data were drawn from the Report of LDRRMF Utilization (2012) from the Pasig City Disaster Risk Reduction and Management Office (CDRRMO), and from expenditure reports from the Annual Audit Report on the City of Pasig by the Commission of Audit (2012). Damage profiles were estimated based on an internal report generated by the city after Typhoon Ketsana in 2009, the Pasig City Report on Tropical Storm Ondoy (2012) also from the Pasig CDRRMO. Additional data were also obtained from several consultation workshops and interviews with the Pasig CDRRMO head and personnel conducted in 2013 and 2014.

In the LGU model for Pasig City, it is assumed that the QRF becomes available from Day 1, and is utilized throughout the LGU's days of response operations, which in this case is set at 13, based on the reports after Typhoon Ketsana. (For more details of values used for each variable for Pasig City LGU model as a test case, refer to Appendix S2.)

## Results and discussion

The resilience measure of a representative low-income household from the survey community in Pasig City is shown in Figure 3a. The measure reflects a sharp decrease in the resilience relative to the baseline (a value of 1) as the households incur damages and losses due to the intense Typhoon Ketsana-like rainfall. This decrease is mitigated in the succeeding days by the relief donations given by the LGU. However, starting Day 15, after relief donations cease, the measure begins to decrease again with no indications of recovery within 2 months after the onset of the flooding hazard.

Upon analysis of the input data and simulation results, it is found that this phenomenon is not a result of the flooding hazard itself. Rather, it is the result of untenable conditions already existing beforehand. Even under normal conditions, the expenses of a household are greater than the regular income. Additional sources of livelihood – mostly outside the formal market structure (e.g. the room rentals, small stores, etc. under the Resourcefulness category) – were not substantial based on the survey data. It is suspected that many households avail of informal loans from individual lenders. However, there is currently not enough available data to validate this hypothesis. These particular socio-economic pre-disaster vulnerabilities are not uncommon among these low-income communities in Metro Manila especially those in the survey areas used in the case study. Thus, although the simulation was developed to capture the immediate impacts on households, the changes in the resilience measure also reflect longer term conditions that potentially contribute to the continued degradation of resilience in vulnerable communities.

Furthermore, most households typically suffer impacts (e.g. health impacts, loss of household appliances, housing damage, school, or employment absences), which contribute to losses in assets and also to increases in expenses. House repairs and appliance replacement may be monetized and still be considered as part of the stock of household assets. However, other impacts such as an increase in medical expenses due to injuries or diseases (e.g. leptospirosis, diarrhoea) would create an additional drain from the stock, and cause the resilience measure to decrease further. This increase in subsistence expenses is not yet reflected in the simulation as the data were not available from the community survey and require further data gathering and analysis from the health sector institutions.

The model can be also used to explore and simulate scenarios, such as the impact on the resilience measure of different amount of relief donations from the LGU to the household (Figure 3b). The results show that higher amounts of relief are able to contribute to the recovery of resilience, but only in the short term. Within a month after the hazard onset, household resilience again decreases due to the more long-term systemic conditions regarding the imbalance of income and expenses discussed earlier.

Like the household measure, the resilience measure of the LGU is shown in Figure 4a as experiencing a steep decrease from the immediate damages to public infrastructure during the extreme rainfall and flooding. The QRF becomes accessible, but this resource is a small amount relative to the total

 

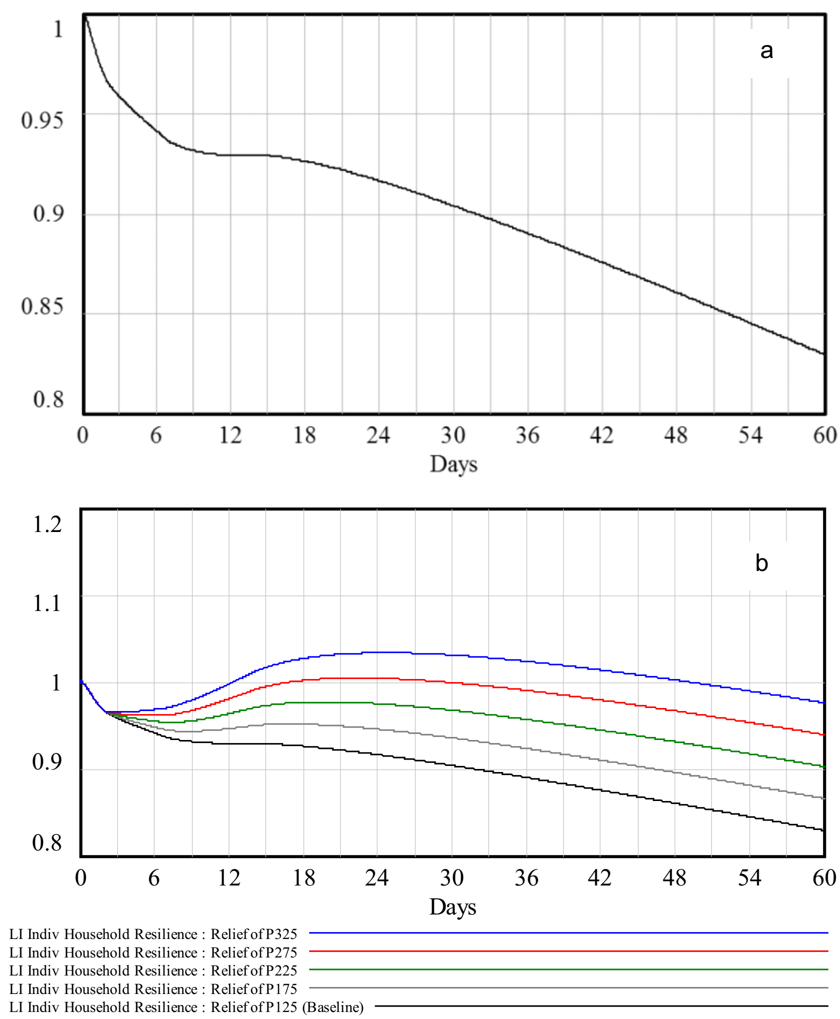


**Figure 3** (a) Resilience measure of an individual low-income (LI) household. (b) Resilience measures of an individual low-income household under scenarios of relief donations.

losses and therefore cannot offset the latter. The effect of the QRF on the resilience measure is not notable. It is not surprising that the measure does not return to the baseline within 2 months as the replenishment of LGU resources is highly dependent on the budgeting cycle. To capture this aspect, a long-term city resilience model (Simonovic and Peck, 2013b) needs to be developed.

The counterpart plots for the LGU given the different scenarios for relief donations to individual families are shown in Figure 4b. This distribution of resources may seem to result in a relatively small loss of resilience for the LGU, but note that only the low-income household of the specific survey communities was included here. In reality, the impact to the LGU would be larger. The important aspect to consider here is the ability of the model to aid in planning for the most efficient use of resources through comparing the relative increase in welfare of the individual households and the relative cost to the LGU.

In addition, there are undoubtedly more interactions between the household and LGUs beyond the relief donations – for example, the LGU plays a key role in the provision of livelihoods and access to basic services that influence the household's asset stock. Separate models, possibly simulated over longer time scales, can be developed to account for these and further link the LGU expenses to the household adaptive capacity factors.

For both the representative household and city LGU, the simulation modelling approach was able to utilize snapshot data as a basis for constructing and parameterizing a systems model to explore and explain trends in resilience for specific determinants. The models synthesized various indicators into a measure that represents the ability to respond and recover from the impacts of a hazard given the available or accessible assets. Sensitivity to and sustainability of factors influencing resilience can be explored by varying input parameters and developing different scenarios in the model.

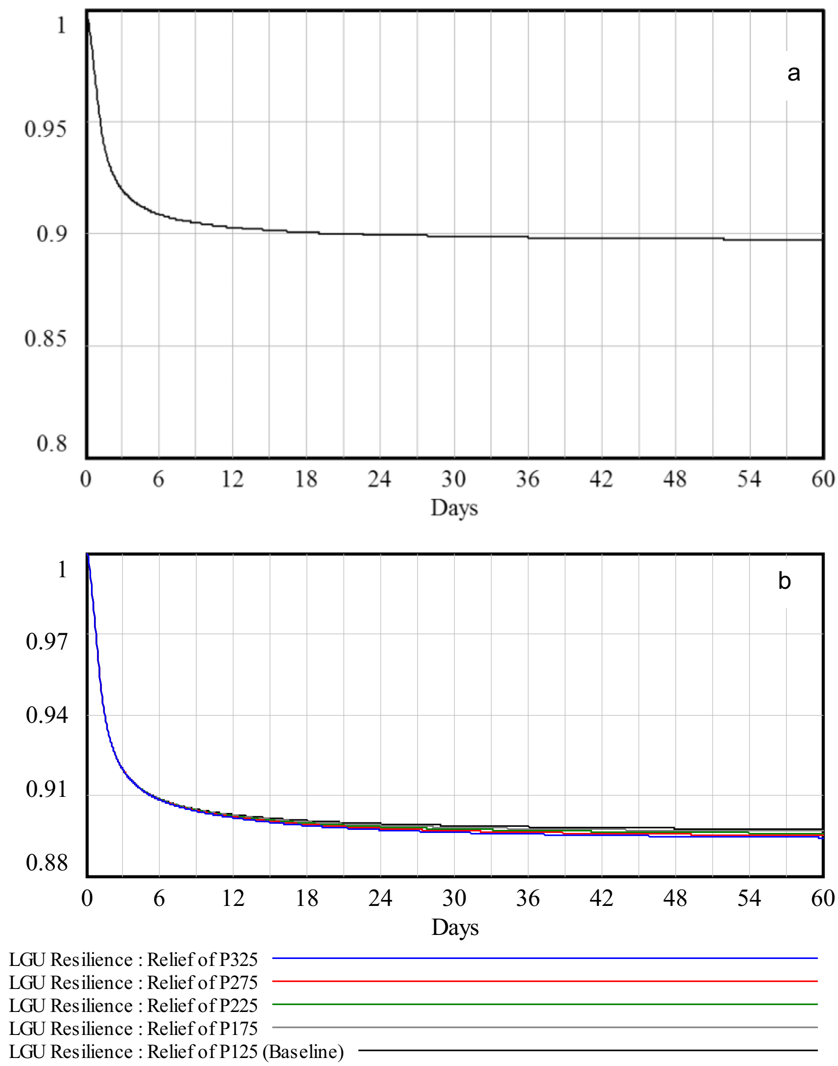


**Figure 4** (a) Resilience measure of the local government unit (LGU). (b) Resilience measures of the local government unit (LGU) under scenarios of relief donations.

This study simulated a Typhoon Ketsana-type damage profile and tested only the effect of the amount of relief donations to low-income households, but the models have a potential to accommodate a wider range of experiments. These may include varying the damage profile to simulate different types of events, increasing wages or reducing the loss of workdays after the event, or reducing the cost of basic subsistence needs. Scenarios to be tested can be identified based on programmes and policies being implemented by the LGUs. For example, decision makers can test the relative impact of livelihood programmes on increasing household resilience.

The resilience measure may also be expanded by developing similar models to account for the other types of capital (e.g. social, human, natural), or other sectors (e.g. the private sector, the health sector) if quantifiable stocks and flows can be established. A health sector model, for example, could interface with the household model to determine the additional costs as a result of disease or injury attributable to a flooding event. It could also be linked to the LGU model to account for the resources that the LGU must direct towards responding to medical needs. A private sector economic model could be connected as well to the household model in so far as the availability of labour is concerned, and to the LGU model for the resources and partnerships that could assist the LGU.

The models were developed to track immediately to short-term impacts on resilience, but were also able to help identify and diagnose underlying systemic conditions or dependencies that operate in the long term through societal institutions. This set of models would therefore be complemented by similar models adapted to reflect longer term processes, such as the budgeting and planning cycles of LGUs, and the changes in the household composition (e.g. increases in the number of earning members over time, or increases in expenses due to advancing in education or in age).

There are certain caveats, however, to the interpretation of the resilience plots. One is that they simply show changes from a pre-determined baseline without making any judgment whether that baseline was a desirable state to begin with. Furthermore, comparisons cannot be made across city LGUs because each city would have its own baseline but all would be normalized to an initial measure of '1' in the model. Even within a city, comparisons cannot be made across income groups for the same reason. Thus, the utility of the model is limited to comparing and tracking the progress of a specific sector, group, or area over time.

## Conclusions and recommendations

The city system resilience models adapted here for the household and the LGU as units of analysis represent a class of tools for quantitative tracking of resilience to flooding (based on specific determinants). This quantitative systems approach is intended as a complement to qualitative characterizations. The simulations can be useful not only for analysing short-term impacts but also for diagnosing underlying conditions that need to be addressed through institutional changes over the long term. It should be stressed, however, that simulation output is not for comparison across communities or for predictions of changes in a specific community. Rather, the utility of this approach lies in helping users understand why and how certain conditions and structures give rise to the trends in resilience that we observe. In this sense, the models can be used as decision support tools for policy makers.

Because the model template is flexible, it can be adapted to represent different units of analysis across different sectors. The success of model development is, however, highly dependent on the availability of the data. In this study, time-slice and aggregate data on stocks (e.g. total losses of household and LGUs, total QRF) from reports on Typhoon Ketsana were used together with simple assumptions on the flows in order to create a dynamic model. This was sufficient to explore the utility of the model template, but the models can further be strengthened for decision support by integrating more key systems and creating feedback loops among them (i.e. to better model inter-sectoral interactions). It is in fact highly recommended that similar models be developed for other quantifiable determinants of resilience in order to broaden the dimensions of resilience that can be explored. These multiple measures can be aggregated into an overall measure as recommended in Simonovic and Peck (2013b).

The models can also be made more useful by addressing the hazard and damage characterization, and the adaptive capacity factors. The hazard and damage characterization can be improved by incorporating time series data (e.g. a more accurate damage profile based on rainfall observations and simulations), and by creating exposure profiles that can more dynamically assess potential damages based on exposure and vulnerability to the hazard. Adaptive capacity factors can be improved by including more resourcefulness, robustness, redundancy, and rapidity factors.

Simulations can also test the effect of multiple events over a given period of time, which is often the case in the Philippines. Adverse impacts would weaken resilience, which in turn means that communities would become more susceptible to future hazards and damages. Conversely, adaptive capacity factors would enhance resilience, which would result in an environment that can better enable further and stronger adaptive measures. These feedbacks will better manifest over a longer simulation time period with multiple and potentially compounding events.

As a further recommendation, the stakeholders themselves can be involved in the modelling process by defining the key variables that are important to them and that they feel contribute to their resilience. Dialogue with stakeholders can also help validate the results of the model by comparison to their experiences on the ground regarding whether and how long it takes for them to recover and to adjust. In this sense, the utility of the modelling process may extend further from decision support to stakeholder engagement.

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## Supplementary Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

**Appendix S1** Household resilience model for Pasig City Communities.
**Figure S1** System dynamics model for the individual low-income household resilience measure.
**Table S1** Variables for household model for individual low-income (LI) households.
**Appendix S2** LGU resilience model for Pasig City.
**Figure S2** System dynamics model for the local government unit (LGU) resilience measure.
**Table S2** Variables for local government unit (LGU) model.

 