Assessment of cascading effects of typhoons on water and sanitation services: A case study of informal settlements in Malabon, Philippines

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ABSTRACT

Urban infrastructures are critical, highly interconnected, and interdependent systems of services that physically tie metropolitan areas, communities, and neighbourhoods together. When such highly inter-related systems are affected by a disaster, cascading effects may result in the failure of infrastructure systems. This paper presents a method to unravel the complexity of cascading effects, which can be applied in situations where documented information of the hazardous event is limited. A service chain management framework is used to examine how services for water supply, sanitation, electricity and solid waste interact. The analysis provides a breakdown of the primary service system into a chain and service elements, which characterises the inter-relatedness of these services. We study the case of Barangay Catmon (neighbourhood) in Malabon, a densely developed urban area, located on Manila Bay that is exposed to various natural hazards. Many of Malabon’s low-income households reside in informal settlements that are prone to flooding from the combined effects of land subsidence, pluvial flooding from the river network and storm surges. Our empirical study reveals the temporal spread of a typhoon’s cascading effects on essential services and the subsequent impact on informal settlers, that may potentially counteract their hope for sustainable improvement through the upgrading of their settlement. Therefore, to complement the ongoing efforts of disaster risk reduction, service chain management framework may further guide the local authorities and other stakeholders to understand the characteristics of cascading effects varying with time and nature of the impact.

1. Introduction

Disasters often lead to cascading effects driven by interdependencies between and within different infrastructure systems [1], when one infrastructure affects another, usually negatively [2] leading to system failure. The interdependent features of infrastructure are defined as the critical points/links which hold the potential of worsening the effects of a hazardous event [3]. Also, failures at the critical points of interdependency may propagate a lag in the disaster recovery process, with a long-term effect on population dependent on service infrastructure [4]. Strong initiatives have been taken by the international humanitarian community to reduce disaster risk to critical infrastructure. The Sendai framework 2015–2030 emphasises in one of the targets, “To promote resilience of new and existing critical infrastructure, including water, transportation and telecommunications infrastructure, educational facilities, hospitals and other health facilities, to ensure that they remain safe, effective and operational during and after disasters in order to provide life-saving and essential services” [5].

The Global Assessment Report on Disaster Risk Reduction 2015, discusses the need of strengthening disaster preparedness by incorporating a new indicator in Hyogo framework, to address the identification of critical infrastructure interdependencies and prioritisation planning, for critical infrastructure recovery operations [3]. In doing so, UNDRR, launched a scorecard to assess the resilience of cities using a set of assessments to monitor and review the progress of implementation of Sendai Framework for Disaster Risk Reduction: 2015–2030 [6]. In 2014, the Swedish Civil Contingency Agency developed a strategy and action plan for protecting critical infrastructure and mapping dependencies between them [7]. The European Union also initiated a programme for the protection of critical infrastructure in member states which included a framework for a coherent and uniform implementation of protective measures [8]. However, disaster risk dynamics in urban settings are poorly understood and, consequently, their root causes are seldom addressed [3].

Disaster-induced cascading effects in infrastructure services often vary on the urban population, based on its socio-economic status, risk...
In fast-growing Asian coastal cities, for example, urban poor living in peri-urban areas and informal settlements are exposed to the high risk of impacts from potential hazards [10]. They often endure complex challenges such as land insecurity, faulty shelters in high-risk areas, high population density, violence and a general lack of economic resilience [11,12]. Furthermore, unhygienic living conditions in informal settlements, such as inadequate sanitation, lack of safe drinking water, poor hygiene practices make affected population prone to public health challenges [13,14]. Zimmerman & Restrepo [2] explained that over time, cascading effects might spreads faster depending upon the vulnerabilities of the community, and the timelines of disaster response support provided. Consequently, when a disaster occurs, informal settlers (especially children, women and elderly) are more susceptible to illness and death from diseases that are often caused by inadequate or disrupted water and sanitation services [15].

Clean water, basic toilets and good hygiene practices are lifelines for human survival and societal development [15]. These services are interdependent systems, which rely on each other to function [13]. When the interdependent features of water and sanitation services are weak, a disaster may trigger the failure of these systems, worsening the impact left by the natural disaster [3]. Failure at the critical points of interdependency will propagate a lag in the disaster recovery process [4]. Cascading impacts may spread quicker in locations causing more damage and secondary hazards by multiple vulnerabilities, i.e., socio-economic, physical and environmental [16].

Piers et al. [17] recommended to consider different levels of vulnerability, determined by social systems and power relations rather than natural forces, to identify the root causes of disaster impacts. They see vulnerability as a phenomenon with multiple layers that depends on the interaction between social networks, economic conditions and unsafe physical conditions. Moreover, socio-economic and physical vulnerabilities are pathways for cascading events and impacts. Pescaroli & Alexander [18] argue that cascading disasters cannot be prevented because of the high complexity and cross-scale dynamics in interdependent critical infrastructures. However, latent vulnerabilities can be understood and addressed before the trigger events occur.

In the urban context, water and sanitation services, when disrupted, increase the likelihood of complex events followed by cascading effects [3]. These effects may or may not be visible immediately after the occurrence of a hazardous event, hence may not be repaired or responded to Ref. [19], thus prolonging disaster recovery. This further strengthens the need for studying the cascading effect in disrupted water and sanitation services. It will contribute to building disaster resilience of the urban population, especially urban poor residing in informal settlements [16].

The purpose of this paper is to apply the innovative approach of the service chain management framework to unravel the complex consequences of cascading effects on informal settlers. It also attempts to understand the spatial and temporal characteristics of cascading effects. Therefore, we have assessed disaster-induced cascading effects of water and sanitation services on people residing in informal settlements. Furthermore, we have investigated the critical points or links interconnecting services responsible for driving cascading effects in a given geographical extent.

The remainder of the paper is structured as follows: Section 2 reviews existing methods to assess cascading effects and explains the methodology applied. Section 3 discusses the results, identifying cascading effects on critical infrastructure and critical points/links interconnecting water and sanitation services. Section 4 discusses the long-term, and lasting consequences of cascading effects on informal settlement population and section 5 presents our main findings and provides further possible research directions. The study examines the cascading effects of typhoon ‘Rammasun’ (2014) on infrastructure services in several informal settlements of Barangay Catmon in Malabon city, Philippines.

2. Methods

Methods for assessing cascading effects in critical infrastructure often emphasise forecasting the cause and effect relationships of disrupted/failed interdependencies either within a web of networks or a single service infrastructure [20]. Krimgold et al. [21] studied how intra-dependencies within critical infrastructure and interdependencies between and among critical infrastructures, affected the operations and serviceability of the infrastructure during and after a hurricane. They interviewed personnel from frontline organisations and reviewed relevant responses, lessons learned and reports, to conclude that integrating such reviews into the emergency management organisations will enhance an understanding of the roles that interdependencies play in improving disaster preparedness, response, and recovery. Several methods to analyse accident-based single events included events and causal factors charting and analysis, barrier analysis, change analysis, root cause analysis, event tree analysis and Sequential Timed Events Plotting (STEP) [22]. Gonzva, Barroca, Gautier, & Diab [23], developed the Functional Analysis, the Failure Modes and Effects Analysis (FMEA) and the Fault Tree Analysis for identification and generation of failure scenarios caused by cascading effects between the components of a rail transport system, facing a flood hazard.

Rinaldi et al. [24] defined four types of interdependencies (i.e., physical, cyber, geographic, and logical) and distinguished three types of failures (i.e., cascading, escalating and common cause failures). Boaru & Bădiţa [25] have defined interdependencies as, spatial, functional, resource and common components interdependencies, relevant for the operation and maintenance of the CI services. Pescaroli & Alexander [18] investigated how the progress of cascading effects of a hazardous event guided by the vulnerability of critical infrastructure, rather than being merely an artefact of high-impact, low-probability, and unexpected events. Their work also found that failure to identify and analyse interdependencies between CIs will lead to wrong or inappropriate policies and decision making during crises or massive infrastructure disruptions. Hilly et al. [26] developed a visualisation based framework, including a causal loop diagram, a HAZUR resilience map, a tree diagram and GIS maps, to analyse cascading effects from floods in the Sukhumvit area in Bangkok, Thailand.

As a consequence of these studies, there is more emphasis on the economic and technical potential of solutions, to reduce cascading effects on physical infrastructure [26]. There is limited research on how various infrastructure services interact with other such services and factors such as utilities, government agencies, community, etc. that co-exist in urban surroundings. This re-enforces the need for a better understanding of disrupted interdependencies and interconnection between specific infrastructure services and after-effects on the community.

2.1. Research design

We have developed a service chain management framework to assess cascading effects in the disrupted water and sanitation services. The framework is based on a conceptual analogy of supply chain management (supply chain of goods to consumers) with infrastructure services as service chain management functions, concerned with the planning and management of activities from support functions to the delivery of end-user services [20]. Any failure or disruption of service delivery has a direct or indirect relation to the delivery process of these services. Therefore, to assess cascading effects in the service chain of water and sanitation, it was essential to understand the service delivery process of the services. For example, the interdependency of infrastructure service components for service delivery and their effect on each other in the wake of a disruptive event.

The schematisation of the service chain management framework developed in the present work is depicted in Fig. 1. It illustrates an integrated framework of distribution and collection based service chain
framework under normal operating conditions, including two dependencies. The dependency link Dep1, in Fig. 1, describes that service distribution infrastructure is dependent on service collection infrastructure to continue delivery (distribution) of service to consumer (Dep 2). The framework here serves as a generic model classifying service chain of infrastructure into of distribution based services (inflow of material/service) to its consumers and collection-based services (outflow of material/service) from its consumers, for example, electricity is distributed to consumers and waste is collected from consumers. The geographic spread of the service chain is defined based on the extent of the study area. The four major service elements of the service chain framework are as follows:

- **Service support function**: A physical facility, supporting the operationalisation of generation or processing the service.
- **Service infrastructure**: Transfer of material/service in the service chain takes place through service infrastructure linked by service support function or another service infrastructure.
- **Service delivery**: Delivery of final product of the service chain which may or may not have a physical shape and size.
- **Consumer**: The consumer is the one who pays to consume goods and services produced.

Fig. 2 shows the occurrence of cascading effects in post-disaster conditions caused by disrupted dependencies. If an event damages or disrupts (Fig. 2) the collection service infrastructure, it will affect the distribution service infrastructure leading to disruption of service delivery, and causing an effect on consumer depicted by Dep2 (Fig. 2). Secondary disruptions caused by a disrupted dependency resulting in failure or disruption of one or more dependencies in a chain takes the form of a cascade, referred to as cascading effects in this study, for example in Fig. 2 (Cas 1 & 2) [24].

### 2.2. Study area

Malabon, a densely developed urban area with a population of 87,808 inhabitants, is highly prone to flooding attributed to its combined topographic and hydrological characteristics (Fig. 3) together with frequent extreme weather events such as typhoons and monsoon rains. Many of Malabon’s low-income households reside in informal settlements that are prone to flooding from the combined effects of land subsidence, pluvial flooding from the river network and storm surges. Such hazards are potential causes of essential service delivery disruption.

Catmon is a highly hazard-prone Barangay1 of Malabon, where flood inundation is frequent due to its flat terrain, reclaimed landfills and encroached riverbed. Catmon consists of 27 informal settlements and is currently home to over 5000 households, which translates to 31,137 as the total population (Fig. 3). Due to land scarcity in Malabon, most of the informal settlements are located in flood risk zones of Catmon (Picture 1). This risk zone includes wetland, land close to the riverbed and waste dumping ground of the city. Most of the occupied land is privately owned who exert a constant eviction pressure on the informal occupants [10]. Such informal occupancy of land is illegal as per the regulation of Malabon administration. Therefore, access to essential infrastructure services is a challenge due to the unauthorised residential status of informal settlers. However, the administration supports informal settlers by providing them with an endorsement letter to obtain access to water and septic tank cleaning services from private service providers on the periphery of informal settlements. Nevertheless, accessibility and availability of quality services is still a significant problem for informal settlers.

Catmon was selected as a case based on an ongoing programme on informal settlement development in Catmon and Tonsuya Barangays in Malabon. At the time of the study, the Human Cities Coalition2 (a Dutch Organisation) was the implementing partner with more than twenty partners and stakeholders from the Netherlands and Metro Manila. Hence, to obtain some synergies and also to contribute to the development of housing and land tenure propositions, Catmon was selected for this research.

During the focus group discussion, participants shared their experiences from typhoon Glenda in 2014, which was chosen as the case to study cascading effects on water and sanitation services in Barangay Catmon. Typhoon Glenda was one of the strongest typhoons to have affected Malabon in recent years. It was active from 13th –17th July 2014 and forced 500–1000 families in Malabon to seek shelter in evacuation centres. Winds of 165 km/h uprooted trees, electricity poles and damaged houses, many of which are made of light materials. The damage was further worsened by heavy rainfall for more than 24 h and the resulting floodwaters. At least 90% of the residents of the metropolitan area of Manila (Metro Manila) suffered power outage starting from 15th July for a week, as electricity poles toppled. Water supply was irregular and was affected by floodwater inundation [27].

Barangay Catmon responded to the typhoon with a standard disaster management plan by extending relief goods and medicines to the affected families. The Department of Social Welfare and Development (DSWD) managed evacuation centres in the affected areas, mainly for families from informal settlements. Barangay Catmon is currently implementing a robust disaster management plan which includes disaster risk reduction and preparedness, disaster response and relief, and rehabilitation and recovery for its residents. This plan consists of well-established disaster response operations, adequate and prompt assessment of needs and damages at all levels, safe evacuation, temporary shelter needs, essential health services provided to affected population whether inside or outside evacuation centre and coordinated, integrated system for early recovery implemented in coordination with other departments such as Housing, City Planning and Development Department, DSWD and the City Environment and Natural Resources Office.

### 2.3. Data collection and analysis

Primary data was collected through focus group discussions (FGD), field observations and expert interviews using different sets of questionnaires. The FGDs were used to collect data on water and sanitation services, its availability and accessibility to informal settlers and challenges for water and sanitation services which emerged after the occurrence of a typhoon/flood. FGDs focused on questions (annexed) based on different stages of typhoon Glenda, e.g. strong winds, heavy precipitation (rainfall) and flood water inundation. Therefore, questions were flexible and modified to dig deeper and bring out additional information when necessary. Forty-five participants from eight informal settlements in Catmon were included in eight FGDs, with 6–10 participants in each group. Each participant was considered as representative of one household and hence for each household, health status (the type of diseases) after the occurrence of the typhoon, was collected, to further support the qualitative narratives of FGD participants.

Interviews were conducted with eight officials from Malabon administration and four with NGO staff working on informal settlement development. The interviews (annexed 1) focused on the mandate of the organisation, disaster response and preparedness plans, inter-

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1. In the Philippines: a village, suburb, or other demarcated neighbourhood; a small territorial and administrative district forming the most local level of government (Oxford dictionary).

2. https://www.icco-cooperation.org/en/newsarticle/launch-of-human-cities-coalition-building-liveable-cities-together (The programme was terminated at the end of 2018, as a result website of Human cities coalition is not functional anymore) (https://www.youtube.com/watch?v=C9edVhe8f0d).
dependency of the department on other departments for service delivery such as electricity and healthcare. Questions also covered events of disrupted essential services triggered by the failure of other supporting services when hit by flood/cyclone. NGO staff answered questions about water and sanitation project implementation and disaster preparedness of informal settlers in Barangay Catmon. Field observations were recorded for the physical condition of infrastructure services of water & sanitation facilities, solid waste management, hygiene management, maintenance of water and sanitation services in Barangay Catmon.

FGD data from eight informal settlements were aggregated into two clusters based on their habitat conditions, to prevent repetitive data on typhoon events (Fig. 4). The physical difference in settlement habitat conditions, i.e. landfill and marine ponds, emerged from the field data and hence was used for clustering. Catmon is located on hydrosol soil series (Fig. 4), which influence the critical physical infrastructure provision as well as its social and economic activities [28]. Hydrosol soil is a conglomeration of clay materials & organic matter originating from the decay of marshy growth. Most of such land areas are reclaimed and developed, except areas used as dumpsites. These dumpsites are gradually turned into landfills and occupied by informal settlers [29]. However, a small part of Catmon is still a marine pond which has now turned into a low lying swamp also occupied by informal settlers with houses on elevated platforms [30].

Cluster 1 (Fish/marine ponds), consisting of three settlements, is
located in a waterlogged low lying area initially used as fish ponds (Fig. 4). Houses have raised plinth surrounded by dirty sewage water, water lilies and solid waste. Whereas, Cluster 2 (Landfill), consisting of five settlements, is located on swamplike fishponds turned dumpsites gradually filled up using garbage and other solid waste material by informal settlers to occupy the land. The landfills are no longer swamplike but are exposed to frequent flooding and land subsidence. The habitat conditions also influence the provision of essential infrastructure services.

Data analysis was an inductive thematic analysis [31], using codes which were developed from field data and organised under specific categories of infrastructure services (Table 1). These codes and categories were further organised as the elements of the service chain framework under distribution and collection-based services. Indicative statements from field data referring to codes and categories are organised into different service elements of the service chain of infrastructure (Fig. 5).

3. Water and sanitation service provision agencies in Barangay Catmon

This section provides an overview of water and sanitation service provision by private and public agencies in Malabon city. A private agency, Maynilad Water Services Inc., manages water supply service in Catmon, drawing water from a supply station facility in neighbouring Barangay Dampalit. This facility processes and transfers water into the distribution network of the pipeline to individual houses [32]. The agency manages routine repair and maintenance of distribution pipelines. The spread of pipeline is mostly underground except in areas where placing underground pipe is difficult, especially in a swamplike area, landfills or near drainages. Water supply pipelines are protected with an asphalt lining and concrete to prevent contamination. Water consumers avail the services with a metered connection at the household level with the monthly charge of 118 pesos/month (approx. 2.25 USD). A legal residential address is essential to obtain a water meter connection at the household level [33].

Sanitation services are analysed for faecal and solid waste management services. As per city regulation, it is mandatory to construct a septic tank or connect with sewage line for residents of Catmon, which is also applicable to informal settlements. Maynilad manages the faecal waste in Catmon in the form of sewerage services. Maynilad also offers cleaning/desludging services for houses not yet connected with sewage line as a free service, scheduled every five-seven years. Solid waste is managed by the Department of City Environment and Natural Resources Office (CENRO) in Catmon. The Barangay has been allotted with waste disposal locations, waste collection vehicles, human resources, and equipment to manage solid waste. Each location has specific collection time daily/weekly, followed by transfer of waste to a sanitary landfill in the neighbouring city for processing and final disposal [30].

Water supply service is dependent on electricity managed by a private agency, Meralco, in collaboration with the Malabon City
In this context, electricity is required at Dampalit water supply station to process and transfer clean water through a network of pipes to customers in Catmon. Similarly, clean drains are essential to maintaining the quality of water supply in the pipe distribution network, which is often close to drains or even crossing through them. Drain cleaning is managed by the Engineering Department of Malabon City [33].

4. Results

A schematic representation of the water and sanitation service chain for informal settlements (cluster 1 & 2) was developed for the pre-disaster condition (Figs. 6 and 7) where no disruption has occurred based on service chain framework (Figs. 1 and 2) and codes in Table 1. Service chain elements of water and sanitation services are the outcome of thematic coding from primary data obtained from expert interviews and official documents. The resultant schematic representation of the pre-disaster status of water and sanitation service (Figs. 6 and 7) is used for further visualisation of ‘post-disaster’ conditions. It describes the disruption of water and sanitation services that have taken place after the occurrence of the typhoon (Figs. 8 and 9). Cascading effects are assessed in post disaster stage using the outcome of disrupted elements of the service chain and the resultant effect on the community of informal settlements.

4.1. Pre-disaster water and sanitation service chain in informal settlements

Water supply services in both Clusters of informal settlements is supplied (Fig. 6) by Maynilad from the deep well facility (W1-3) in Barangay Dampalit. The facility is dependent on electricity (E) to stay operational to supply water through the network of water distribution pipelines (W2) in Catmon. Majority of informal settlement households have a water meter connection at the periphery of the settlement (W3), further connected with individual supply pipes (W4). Informal settlements are not provided with protected water pipelines. Therefore, the community opted for plastic ‘hosepipes’. The cost of placing water pipes is incurred for the community. It was observed that most of the pipes are damaged due to its low quality. Pipes were poorly masked with plastic rags to prevent leakage.

Individual water supply pipes reach its respective households through heaps of garbage, drainage, swamp, dirty and stagnant water within the settlement, which frequently results in water contamination. Sufficient quantity of water was available and accessible to informal settlers. However, due to the poor quality of water, it is not used for drinking purpose.

Consumption of water causes diseases such as diarrhea, stomach ache and dysentery. Residents purchase drinking water from local vendors at the cost of 400–500 peso/month (7–9 USD) for 5 gallons/day (18–19 L), for a household size of 4–5 members. The amount of water purchased is dependent on the financial capacity of the household. Some photographs (Picture 2) depict the water supply status from water meter to individual houses in Cluster 1. Water meters (image 1) are located next to a solid waste disposal facility and connect to hosepipes which cross swamp water (image 2) under floating houses (image3 & 4) clogged with solid waste and faecal waste. Some parts of Cluster 1 have raised pathways (image5) to walk within the settlement. Image 6 presents the water collection process at the household level.

The sanitation service chain delivers services in the form of a collection of waste from the consumer which is further transferred via different service chain elements for safe disposal or treatment to maintain a safe and hygienic environment for improved public health. The two types of sanitation services are: 1) Faecal waste and, 2) Solid waste management services. In the context of faecal waste, field data indicated two different waste capturing modes in the two Clusters of informal settlements. Cluster 1 is a low lying waterlogged swamp with heaps of solid waste floating on the water surface. People live in shelters with a raised platform. Septic tanks for toilets cannot be constructed in this area. Thus, waste is released below ground in swamp water, using a wide pipe connected to the raised toilets, to capture waste safely (FW1). Majority of families have access to a toilet, but few families with no access to toilet opt for open defecation or disposing of faecal waste along with domestic garbage. Therefore, the service chain for Cluster 1 ends after service element FW1 as sewage waste cannot be collected from the swamp water. Toilets (FW1) are dependent (Dep1) on the water supply to flush out the faecal waste for safe disposal (Fig. 6).

In Cluster 2, households (Fig. 7) have access to toilets with septic tanks to capture waste (FW1), as landfill provides a relatively strong surface for construction. Maynilad cleans septic tanks (FW2) for households having an endorsement letter approving that informal settlers can avail septic tank cleaning facility irrespective of land title issue. Waste is further transferred (FW3) to waste treatment (FW4) facility managed by Maynilad. Toilets (FW1) are dependent (Dep1) on water supply for flushing out the faecal waste for safe disposal. The practice of solid waste segregation before disposal (SW1) is not common among the residents of informal settlements. People dispose off mixed waste including plastics, clothes, scrap iron, glass pieces, kitchen and faecal waste. A disposal facility (SW2) has been allocated to each settlement with a specific time for the collection trucks to collect waste (SW3). Waste disposal facilities are located on the periphery of the settlement. All collected waste is then transferred to a sanitary landfill in the neighbouring city of Navotas for waste treatment (SW4).

4.2. Post-disaster status of water and sanitation services

This section presents an assessment of cascading effects on water and sanitation services in informal settlement clusters, after the occurrence of typhoon Glenda in July 2014. In Cluster 1, strong winds brought down by typhoon Glenda triggered the disruption of services. The widespread disturbance (Dep4) of electricity (E) in Catmon (Fig. 6) resulted in the intermittent water supply, which led to insufficient access to water (Dep4). Due to disrupted Dep4, it resulted in a cascading effect (Cas1 to Cas3) on service elements W1 to W3. Twenty-four hours of intense winds were followed by heavy rainfall, and floodwater inundation raised the water level of swamp water bringing up sewage (FW1)
and solid waste (SW1) on the surface of floodwater. Solid waste clogged the natural flow of water out of the community. High tides from river Tullahan brought in more water and solid waste in the community, through the small water channel. Cluster 1 is a low lying area; it was inundated with floodwater for more than two days resulting in contamination of water hosepipes (W4). Toilets became non-functional due to lack of water supply (Dep1). In some cases, toilets were submerged in floodwater, and sewage waste was pushed back in the toilets, making them non-functional.

The water supply pipes (W4) in Cluster 1 got clogged and contaminated (Dep1) due to the heaps of solid waste and sewage water. In Cluster 1, toilets became non-functional due to clogging. Therefore he community opted for open defecation and disposal of waste in floodwater, resulting in the contamination of water supply from hosepipes (Cas4). Similarly, a vast amount of solid waste (SW1) got accumulated (Cas5) in and around Cluster due to the lack of waste collection by the administration (SW2). This further led to clogging of natural drainage (Cas 6) within the settlement, resulting in an increased level of floodwater inundation. Clogged natural drainage prevented floodwater from subsiding through river water (Map1). The community was inundated with floodwater for more than two days. Drainage clogging not only blocked hosepipes (Dep3) but also contaminated water supply (W4). For Cluster 1, the impact of the typhoon and the cascading effect was majorly on hosepipes (W4), pipe toilets (FW1), waste disposal (SW1) and waste disposal facility (SW2) service elements of the water and sanitation service chain (Fig. 8).

In Cluster 2 (Picture 3), electricity (E) failure due to the typhoon led to intermittent water supply affecting all the elements of the water supply service chain (Fig. 9). Informal settlers received insufficient water supply (W4) due to disruption of water supply from W1. Water supply (W4) was also dependent (Dep3) on drainage (D). The service provider stopped water supply to prevent water contamination and damage to pipes from the clogged drainages, especially, for pipes passing through concrete drainage on Governor Pascal Avenue road. All the informal settlements in Cluster 2, have septic tanks attached to the toilets that were functional during typhoon Glenda. However, due to intermittent supply, participants shared that they had to store water to use it for toilets during heavy rainfall and flooding.

Accumulation of solid waste (SW1) within the informal settlements emerged (Picture 3) as a significant challenge, as it clogged drainages (D) close to the settlement, resulting in contamination of hosepipes (W4). Accumulation of solid waste was mainly due to delay in the waste collection by the administration (SW2) and unorganised disposal of waste by the informal settlers (SW1). After typhoon Glenda, the quality of the water supply was affected due to unorganised waste disposal, which further led to the contamination of water via damaged hosepipes. Solid waste disposal during and after typhoon Glenda (Cas5) also affected (Cas6) drainage system (D) in

| Service chain management framework | Existing service chain in Barangay Catmon | Status of service chain in informal settlements |
|------------------------------------|------------------------------------------|------------------------------------------------|
| Distribution Service chain         | Water Supply (Category1)                 | Indicative statements referring to codes:       |
| Service support function           | Maynilad water supply facility (W1)      | Water supply facility                           |
| Service distribution infrastructure| Maynilad distribution pipes (W2)         | Water distribution pipes                        |
| Service support function           | Maynilad water meters (W3)               | Water meter for individual connection           |
| Service delivery (distribution)    | Individual water supply pipes (W4)       | Connection of Hosepipes from water meter        |
| Consumer (ISFs)                    | Utilisation of service                   | Perception quantity and quality of service      |

| Collection Service chain            | Sanitation (Category 2)                  | Indicative statements referring to codes:       |
| Service delivery (collection)       | Capture waste in toilets (FW1)           | Defecation mode*                                |
| Service collection infrastructure   | Maynilad collection of waste (FW2)       | Waste collection after capture                   |
| Service support function            | Waste transfer (FW3)                     | Waste transfer from the place of collection      |
| Service support function            | Waste treatment (FW4)                    | If the waste sent for treatment                  |
| Consumer (ISFs)                     | Utilisation of service                   | Perception quantity and quality of service      |

| Collection Service chain            | Solid Waste (Garbage)                    | Indicative statements referring to codes:       |
| Service delivery (collection)       | Waste segregation (SW1)                  | People disposing of segregated or mixed waste   |
| Service collection infrastructure   | CENRO Waste disposal facility (SW2)      | Designated place of waste disposal              |
| Service support function            | Waste collection (SW3)                   | Waste collection by CENRO                      |
| Service support function            | Waste treatment (SW4)                    | Waste transfer to waste treatment unit          |
| Consumer (ISFs)                     | Utilisation of service                   | Perception quantity and quality of service      |

*Defecation mode: 1) Open defecation, 2) Toilet with a sewage line 3) Toilet with a pipe released in swamp water.

Table 1
Service chain management framework, applied to categorise status of water and sanitation services.
Cluster 2, by clogging the drainages which further led to an increased level of floodwater for more than two days resulted in the inundation of hosepipes (Dep3) degrading the quality of water. Disrupted dependency here is also considered as a cascading effect, affecting the associated service element in the service chain.

4.3. Cascading effect of disrupted water and sanitation services on informal settlers

After the degradation of water quality from Maynilad, the informal settlement community stopped using water for cooking and cleaning. Maintenance of personal hygiene was also affected by a lack of access to sufficient clean water. Informal settlers were unable to use toilets for 3–4 days until floodwater receded. People opted for open defecation or disposal of faecal waste in floodwater, resulting in highly deplorable conditions, and unhygienic surroundings within the settlement. Unhygienic conditions resulted in health problems such as water-borne diseases and skin diseases. The irregular and unpotable water supply from Maynilad forced the community to purchase drinking water from local vendors. The cost of mineral-water increased by 10% of the regular price due to water scarcity, which affected informal settlers financially.

Prolonged floodwater inundation affected community mobility. It caused the loss of daily wage livelihood, transportation, inability to reach the health centre for medical assistance and other daily chores. Cluster 1, a low lying area, received solid waste from the neighbouring settlements along with floodwater after heavy rainfall, degrading the living condition in the settlement. A considerable amount of solid waste, including food waste, attracted many rodents resulting in the cases of leptospirosis, skin diseases among people who had to swim through the wastewater (Fig. 10). However, Cluster 2 had fewer challenges regarding mobility as the settlements are well connected to the major road of Barangay Catmon and therefore, were able to resume their routine due to easy access to road transportation. Nevertheless, with the knee-high flood water level in both the clusters, people had to swim through floodwater to go out of the settlement. Consumption or prolonged skin contact with contaminated water led to health issues among informal settlers with an increased financial burden. The comparative graph in Fig. 10 further supports the data shared by the FGD.
Fig. 7. Water and sanitation service chain in Cluster 2.

Fig. 8. Cascading effects on water and sanitation service chain in Cluster 1.

Fig. 9. Cascading effects on water and sanitation service chain in Cluster 2.
The community, with increased cases of diseases, socio-economic losses also discussed in literature earlier: disrupted interdependencies [25] also discussed in literature earlier: with physical service infrastructure, and resulted in prolonging the disrupted interdependencies, in addition to dependencies associated with health care services. Thus, service delivery process in informal settlements. Furthermore, the unfavourable spatial location of water and sanitation facilities led to the unorganised disposal of waste in and around the informal settlement and contamination of water hose pipes. These facilities are located either on the periphery of the informal settlement or close to the road network due to lack of space, and to avoid high installation cost of services on landfill and swamp areas. It has increased

4.4. Critical/weak elements of water and sanitation service chain

Service elements of water and sanitation services which are weak and frequently disrupted by the flood water identified as links responsible for triggering cascading effects and worsening the effect of the disaster. Following elements of the service chain framework are the key elements (Figs. 8 and 9):

1. Water supply: Distribution hosepipes (W4)
2. Sanitation: a) Solid waste disposal (SW1) and Waste disposal facility (SW2), b) Faecal waste capture (FW1)

These elements are responsible for delivering the services (distribution and collection) directly to the customers (informal settlers). Disaster-induced disruption of these elements left a long-term impact on the community, with increased cases of diseases, socio-economic losses and disrupted access to water and sanitation services for 2–5 days. As explained earlier (section 3.2), identified four service elements are managed by informal settlers and therefore, lack a control mechanism to ensure the quality of service delivery.

Critical elements of the service chain also assisted in identifying disrupted interdependencies, in addition to dependencies associated with physical service infrastructure, and resulted in prolonging the disaster recovery process. Following are the identified interdependencies [25] also discussed in literature earlier:

**Common Component Interdependency:** The spread of cascading effect across time progressed through different phases of the typhoon, i.e., strong winds followed by heavy rainfall and floodwater inundation. The maximum disruption which triggered the cascading effect, occurred when services were inundated in floodwater for more than two days.

**Spatial Interdependency:** Identified critical elements are not only interdependent for service delivery but also share common space, where water supply pipes are placed in a space with sewage-filled swamp and solid waste landfill, defined as spatial interdependency.

**Functional Interdependency:** There was a delayed response from local authorities to clean drainages and collect solid waste, resulting in clogged water supply pipes. Increased cases of diseases and expensive health care service again led to an organisational dependency of informal settlers on health care services, resulting in more severe consequences.

**Resource Dependency:** Community is dependent on local vendors for drinking water supply in pre and post-disaster conditions defined as resource dependency.

In addition to disrupted interdependencies, factors such as less or no external disaster relief support, inability to afford health services and increased burden of expenses, resulted in increased health issues reported more in Cluster 1 than in Cluster 2. Next section elaborates factors exacerbating the service delivery process in informal settlements.

4.5. Factors worsening cascading effects on informal settlers

The FGDs with the community from informal settlements also indicated some underlying factors which played a crucial role in worsening the consequences of cascading effects. During and after typhoon Glenda, the government response to support informal settlers was delayed, which affected the recovery process of people. Despite having a robust disaster management plan at the barangay level, some informal settlers have been directly or indirectly excluded from the formal mechanism of disaster response relief support. Those people who chose not to evacuate are often neglected and unable to receive relief support on the pretext of not reaching the evacuation centre or Barangay administrative office to collect relief. Also, the health care service available for informal settlers in both barangays was basic; therefore, severe cases emerging after the occurrence of a disaster were referred to private/public hospitals, that were unaffordable for them. There is a provision of the health insurance for the city population, but the government insurance system [34] does not cover informal settlers due to their unrecognised residential status.

“We prefer not to visit the hospital unless it is a serious situation, as we cannot afford expensive medical treatment. Moreover, after typhoon Glenda, the services provided by the hospitals assisted by the government were not sufficient. It became very chaotic to collect medicines and created conflict like situation because of too many patients”. (FGD participant from Cluster 2).

FGD participants also referred to the challenge of land tenure security, which pushed them to occupy space in landfills and swamps with dirty and unhygienic surroundings. There is a close correlation between land tenure status, access to services, and public health. Installation of basic service infrastructure in landfills and swampy land type incurs a considerable cost for service providers. Also, as part of legal requirements, authorised residential status is required to access such services. Therefore, in the case of informal settlers, it is difficult to have access to basic services of water and sanitation, leading to acquiring temporary access through Barangay office or illegal access. Thus, service quality and reliability are compromised, leading to public health challenges.

Moreover, the unfavourable spatial location of water and sanitation facilities led to the unorganised disposal of waste in and around the informal settlement and contamination of water hose pipes. These facilities are located either on the periphery of the informal settlement or close to the road network due to lack of space, and to avoid high installation cost of services on landfill and swamp areas. It has increased
the distance between facilities and houses of informal settlers. It emerged from FGD that to save time and effort of walking; people end up disposing garbage near their houses, resulting in contamination of water supply pipes. The study area is also susceptible to seismic risks (Severe-degree VIII), high risk of liquefaction and storm surge. Illegal electricity connections with unsafe wiring within informal settlements also makes them prone to frequent fire accidents. The combined effect of multiple hazards and poor living conditions in informal settlements, traps informal settlers in a vicious cycle of recurring economic loss. The high frequency of disasters makes them even more vulnerable to future disaster-related losses and associated risks, leading to resilience attrition over time among the informal settlers.

The summary from the above mentioned factors is that the occurrence of cascading effect on water and sanitation services is driven by interdependent and dependent features of the service chain. These underlying factors are intertwined with each other, further exacerbating disrupted water and sanitation service chain. These implications further combine with the negligent behaviour of informal settlers regarding usage of service, attributed to the spatial placement of water and sanitation facilities near informal settlements. Current regulations and practices of local government emphasise the provision of the shelter units and relocation projects [35] than on informal settlement upgrading. Essential water, sanitation and hygiene needs were not targeted adequately to keep up with the requirements of informal settlers. The perpetual degradation of service quality resulted in economic, social and health implications.

5. Discussion

This section presents a critical review of the achieved results, methodological approaches and a reflection on the limitations of this study.

5.1. Implications of the cascading effect on informal settlers

The increased frequency of floods is a consequence of changing normal in the temperature and rainfall, described as ‘new normal’ [36]. This has also gradually changed the perception of ‘normal’ for informal settlers in Catmon. Challenges which come with frequent typhoon/floods and heavy rainfall are considered as a part of routine life [37], and it is no longer a priority to prepare for floods. It could also be seen as gradual resilience attrition of informal settlers and if the time between events reduces then overall resilience will decline, due to lack of timely preparedness to cope with disasters. The changing perception of ‘normal’ among informal settlers is also evident in the slums of Dhaka City. Braun and Ajbheuer, 2018 [38] documented some of the coping capacities of informal settlers, developed to adjust with the changing ‘normal’ environment of the slums. Some of the measures are: saving money, taking a loan, storage of dry food and organising building materials (mainly bricks, sand) before the onset of the flood. However, these measures are ad hoc and often result in debt on households, to survive during floods [38]. Similarly, in some slums in Mumbai, the community used self-formed groups and networks to identify common problems and implement government-assisted interventions [39], which yielded different success results in different groups within a slum area [40].

In Catmon, the community tries to cope with the challenges of disrupted services of water and sanitation with the help of the social network, that they have developed after staying for a longer duration in the same place. However, land tenure security is a significant priority for the informal settlers in Catmon, instead of disaster preparedness (flood/typhoon), which brings water, sanitation and safe hygiene practices further lower on the priority ladder. The analysis highlights that management of faecal and solid waste is inadequate, resulting in unhygienic surroundings, poor water quality and many water related health issues. These services are necessities for their survival but are not considered as a solution to reduce the impact of floods and typhoons. Negligence practices in water, sanitation and hygiene degrade the quality of services and weaken the service chain, resulting in inevitable disruption of the service chain by severe typhoons/floods. Such shortcomings can also be attributed to the lack of firm implementation of regulations for waste management. Also, the City Administration recently had to withdraw an ordinance to ban plastic packaging in 2013 [41], another factor contributing to the generation and accumulation of solid waste. Therefore, the disruption caused in the service chain brings in challenges with different intensity for different households of informal settlers. Families with low-income background suffer from more severe consequences and a long-lasting impact on the coping capacity for future events.

Currently, the local government is implementing the ‘Community Mortgage Programme (CMP)’ to allow informal settlers to buy the land title of the occupied land in Catmon, which also allows the community to retain their social network and livelihood options. However, it is a lengthy procedure of 25 years to complete [42] involving payment of amortisation money in instalments to the landowner. Households with low-income background find it difficult to pay when typhoon or floods frequently hit them. Informal settlement upgrading programmes are not always very effective in terms of providing a better living environment for people. Findings from a study on ‘Kampungs’ (informal settlements) eviction and development project in Jakarta city, the government plans to free the city from informal settlements by 2020 [43]. In the quest to mitigate floods from Jakarta, the government relocated over 25,533 people between 2014 and 2016, from a highly congested and poor environment to a more decent one. However, this initiative still considered ineffective because it resulted in the impoverishment of most of the displaced population, causing disruption of social network and livelihood opportunities [43] further led to degradation of socio-economic levels.

Moreover, implementation of slum development programmes on solid waste, sanitation and hygiene has its own set of challenges while working in an informal settlement. The high density of the transient population in limited space leads to less social cohesion and more challenges to manage people. Disrupted dependencies and interdependencies led to extended recovery periods and spatial spread of cascading effects [2] when families from the informal settlement are not able to recover the level of resource consumption before the next disaster strikes. They find themselves in the vicious cycle of a poverty trap [44] and persistently reduced income and resilience underpinning poverty continuously.

However, the service chain framework applied in this study is a useful tool to extract information at the community level to be used for disaster risk reduction along with the preparedness, response and recovery cycle. The framework can be used to visualise cascading effects to engage the community in understanding their spatial and temporal progression in disrupted critical infrastructure services. In doing so, the community can help in defining their roles in restoring the failed services and defining measures to reduce the likelihood of future cascading effects. Such information can be produced through community mapping exercises. Thus mapping of interdependencies critical infrastructure with the help of the framework would be a measure of preparedness. At the same time, it then can also be used during response as a measure to restore the disrupted links of the infrastructure service chain. The framework can also guide authorities to take decisions on the placement of service infrastructure and to influence user behaviour.

5.2. Critical reflection on research methodology

Assessment of cascading effects on services and people is very much dependent on understanding the complexity of service infrastructure,
the flow of services of service chain elements which are prone to sudden
disruption affecting service delivery to the user [23]. Therefore, the
service chain management framework first breaks down the physical
features of the infrastructure service system into sub-system (distribution
& collection), and then each sub-system into smaller service ele-
ments. This twofold breakdown of the infrastructure systems characterises the susceptibility of critical weak points for disruptions or failure, hence resulting in system failure with a massive effect on its consumers. The framework is useful in evaluating the spread of cascading effects over the temporal progression of the disaster event with its characteristics such as strong wind, rainfall and flooding. This framework is a generic method for studying cascading effects which can be applied in situations where the documented information of the haz-
ardous event is limited.

However, this methodology also has its limitations. It is challenging
to strike a balance between being specific and contextual enough to be
useful while remaining general enough that it could be applied in varied contexts. Service chain management concepts have not been explored much for research in the field of urban disasters and informal settle-
ments. Hence, the service chain framework has been kept small within a
limited geographical extent (Barangay to informal settlements). There is
also a high possibility of occurrence of cascading effect on service chains outside of the geographical context. For example, water supply is from a
dam in the outskirts of Metro Manila and can also be affected by a disa-
er. However, it was not possible to include a more extensive network of the service chain, which would have shifted the emphasis of research on physical infrastructure rather than the affected community.

Though not a limitation, the selection of informal settlements as a
case study only emphasises the cascading effects of the selected area.
However, the problems of informal settlements are not independent;
they are influenced or controlled by the overall functioning of the entire
city. Therefore, to better understand the cascading effects, it would be
relevant to include formal sections/settlements of the city with factors
such as geographical differences (height, slope), population demo-
graphics, housing structures, cultural differences and other associ-
ated aspects of the urban fabric.

6. Conclusion

Cascading effects of natural hazards in a complex network of critical
infrastructure in disaster-prone cities of the global south is an essential
component of scientific research on urban resilience. This research aims
to apply the service chain management approach (an analogy to supply
chain) to assess and understand disaster-induced cascading effects on
water and sanitation services on community residing in informal settle-
ments in Malabon, Philippines. The study has provided insights into
how water and sanitation services are interconnected and tend to fail in
sequence in disaster situations leading to long term effects on informal
settlers. Therefore, the study presents a research method to unravel the
complexity of cascading effects, visualise, and analyse the interdepen-
dent features of disrupted services and its impact on the affected com-
munity, using qualitative data. Service chain management framework is
the principal methodology, which breaks down the flow of infrastruc-
ture services into different sections to assess the disruption caused in
service delivery to its final users. The analysis identified critical weak
elements responsible for triggering cascading effects. The primary rea-
sons other than interdependency of services, contributing to the occur-
rence of cascading effects were the negligent behaviour of informal
settlers, land tenure security and extreme exposure to multi-hazard risk
combined with a low economic background of informal settlers. These
impacts affect informal settlers with extended recovery periods and
persistently reduced income and resilience underpinning poverty
continuously.

Service chain management framework may further guide the local
authorities and other stakeholders to understand the characteristics of
cascading effects varying with time and nature of the impact. Moreover,
as the framework is generic in its applications, it has the potential to
extract relevant information at the community level using the visual-
isation of cascading effects for interdependent/interconnected systems
further to reduce the likelihood of occurrence of cascading effects.
Furthermore, this study provides an opportunity for future research
application of the service chain management framework on critical
infrastructure services in an urban environment prone to disasters. This
research could be furthered through conducting similar research for
different natural hazards in different geographical and socio-economic
context with other critical infrastructure services. The different
context will help to build up a more generic and useable framework to
assess more complex disaster events. Moreover, it will be of high societal
relevance to investigate and understand the perception of the urban
population facing cascading effects from a different infrastructure ser-
vice failure, and what are the local knowledge and adaptation measure
to reduce the impact. Furthermore, future research could also look into
inconsistencies observed in this research and find underlying reasons to
make a service chain framework more robust.

Funding source

This study is part of M.Sc. research at Faculty of Geo-information
Science and Earth Observation, University of Twente, Netherlands.

Note

All the figures and tables in the manuscript are required to be printed
in colour to provide better visualisation of research methodology and
results. All the figures and tables are single column fitting images.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence
the work reported in this paper.

Acknowledgements

The authors wish to thank all the individuals who participated in this
study for their time and collaboration. Specifically, we would like to
thank the staff of Earthquake Megacities Initiative Organisation (Quezon
city) and Human Cities Coalition for their support in data collection in
the study area. We are also grateful to the staff of Malabon City
administration who allowed us the opportunity to interview them and
the community members of Barangay Catmon informal settlements for
their time and patience for FGD sessions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.
org/10.1016/j.ijdrr.2020.101755.

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