

Improving the resilience of water supply towards climate change impacts in Tacloban, Philippines

Rita Gonçalves Simões Marteleira

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**Improving the resilience of water supply towards climate change
impacts in Tacloban, Philippines**

Rita Gonçalves Simões Marteleira

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Professora Doutora Maria José Leitão Barroso Roxo e do
Professor Doutor Pedro Manuel da Hora Santos Coelho

Júri:

Professor Doutor José António Pereira Tenedório (Presidente)
Professor Doutor André Fernandes (Vogal)
Professor Doutor António José Guerreiro de Brito (Vogal)
Professor Doutor António Pedro Nobre Carmona Rodrigues (Vogal)
Professor Doutor Rodrigo de Almada Cardoso Proença de Oliveira (Vogal)

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RESUMO

Na madrugada de 8 de Novembro de 2013, o super tufão Haiyan atingiu o arquipélago das Filipinas, provocando um cenário de catástrofe total. Até à data o maior tufão a atingir um país, a sua excepcional intensidade foi imediatamente relacionada com as alterações globais do clima. Tacloban, a cidade mais severamente atingida, tem sido, desde então, alvo de uma reconstrução que pretende torná-la mais resiliente, visando também a transferência de parte da sua população para norte. No entanto, este novo realojamento ainda não dispõe de um sistema definitivo de abastecimento de água potável.

No contexto da adaptação às alterações climáticas e da redução dos efeitos de desastres determinados por fenómenos hidro-meteorológicos, o termo resiliência tem ganho expressão. Contudo, a sua aplicação frequentemente se foca na robustez de infraestruturas, excluindo a análise da resiliência dos recursos naturais e a componente social. Dada a conhecida interdependência entre os sistemas humanos e naturais, torna-se assim premente a definição de uma visão holística de resiliência. Esta dissertação procurou contribuir para o preenchimento dessa lacuna científica, recorrendo à situação de Tacloban como caso de estudo.

Deste modo, no que respeita à análise da resiliência dos recursos naturais, recorreu-se ao modelo hidrológico QSWAT para quantificar os impactos das alterações climáticas em três linhas de água locais: o rio Binahaan (que acolhe a captação existente), e os rios Pongso e Cabayugan (apontados como potenciais fontes de água para o norte da cidade). Os resultados desta modelação reiteraram a premissa inicial de que o rio Binahaan não dispõe de caudal suficiente, pelo que não constitui uma fonte resiliente. Isto verifica-se particularmente no período de Março a Agosto, quando o número de dias com caudal inferior à taxa de extracção pode atingir os 20.3%. Posto isto, é recomendado o estudo de uma estrutura de retenção de caudais como uma possível solução para combater a dita

sazonalidade. Simultaneamente, foi comprovado que os rios Pongso e Cabayugan podem constituir uma fonte complementar de água, fortalecendo a resiliência geral deste sistema.

Relativamente à componente socioeconómica, através de um questionário domiciliar procurou apurar-se a visão da comunidade acerca da sua resiliência. As respostas obtidas confirmaram a generalizada percepção errónea de resiliência, confundida com a simples prevenção face a desastres. A maioria dos respondentes revelou-se mais ciente de eventos extremos (como os ciclones tropicais e a consequente sobre-elevação das águas) do que relativamente a impactos a longo-prazo, como as inundações ou as secas, que afectarão as disponibilidades hídricas locais, conforme comprovado no desenvolvimento do trabalho de investigação realizado. No entanto, a maioria apontou a melhoria do abastecimento de água como a prioridade para tornar a sua habitação mais resiliente.

De uma maneira geral, considera-se que esta dissertação contribui positivamente para a actual discussão sobre resiliência. Nestes tempos onde as alterações climáticas são uma preocupação global e os fenómenos meteorológicos extremos, como o Haiyan, podem vir a tornar-se mais frequentes, torna-se urgente a integração dos habitantes das zonas mais vulneráveis nas estratégias de adaptação a nível local, contribuindo para o desenvolvimento de comunidades verdadeiramente resilientes.

Palavras-chave: alterações climáticas; desenvolvimento sustentável; gestão de recursos hídricos; modelação hidrológica; resiliência; tufão Haiyan.

ABSTRACT

On November 8th, 2013, super typhoon Haiyan roared ashore in the Philippines, causing catastrophic destruction and thousands of casualties, with its outrageous proportions being often linked to anthropogenic climate change. To the present day, Tacloban City, one of the major cities hit, is being rebuilt to become more resilient, which includes major relocation efforts towards northern storm surge-safer zones. However, this new resettlement still lacks a solid water supply solution.

Whilst the notion of resilience has been increasingly present in the climate change adaptation and disaster risk reduction discussions, most studies focus solely the robustness of infrastructures. Altogether, the resilience of natural resources to disruptors and the social components are not so frequently considered. Nevertheless, the interdependence of human and natural systems makes it imperative that a holistic framework of resilience should be defined. This dissertation aimed to address this scientific gap and Tacloban City was, therefore, chosen as a case study for the referred resilience analysis.

As for the natural resources analysis, the hydrological model QSWAT was used to evaluate the impacts of climate change on three local rivers: Binahaan River (where current catchment is located), and the northern Pongso and Cabayugan Rivers (pointed as potential sources for the supply of Tacloban North). The modeling outcomes have supported the initial premise that Binahaan River did not have enough flow to meet the yearly demand of this city, thus not being a resilient water source. This was particularly true on the period of March to August, when up to 20.3% of days revealed an insufficient flow. For this reason, the feasibility study of a water retaining structure such as a small dam, is highly recommended. Simultaneously, it was demonstrated that the northern rivers can represent an effective complementary source to supply the resettlement areas and enhance overall resilience.

Regarding the socioeconomic component, the community perception of resilience issues was achieved through a household survey. The results have confirmed the generalized misconception about the meaning of resilience, which was simplified to simple preparedness. Furthermore, the responses of the survey have evidenced that Taclobanons seemed to be more aware of the impacts of extreme events enhanced by climate change (such as the tropical cyclones and associated storm surges), than they were conscious of the long-term impacts as floods and, especially, droughts – which are likely to worsen their water supply constraints, as hereby proven by the results of this research. As expected, the residents of water shortage-affected northern resettlement areas seemed to be more concerned about water issues than their downtown neighbors, but, the majority of the respondents, pointed the water supply service as a priority to enhance the resilience of their household.

Overall, one can consider that this dissertation brings a positive contribute to the present discussion on resilience enhancement. In an era when climate change dominates worldwide discussions and extreme phenomena, as Haiyan, are thought to become more frequent, it is urgent to involve the habitants of such hazard-prone areas in the adaptation strategies that will allow them to become truly resilient.

Key-words: climate change; hydrological modeling; resilience; sustainable development; typhoon Haiyan; water resources management.

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Last, but not least, a word of fascination for the ocean waves of Siargao. May their nurturing warm waters and aesthetic perfection help us forget other uproarious days.

DEDICATION

Dedicated to the people of Tacloban.

Hi Tatay Gusting nga paraglabas

Kahuman han dulok,
pagbalik han dagat ha pasipiko,
ginbilin an malangto nga hanang.

Bumulang kan Tonying an iya kamot
natahos dida han nabukid nga siot.
an iya kapanglayan magtugnaw,
nalaylay.

Makagarahom nga dagat
nga nagbuhi kan Tay Gusting,
Nagbuot, naglarang pamawi
han kinabuhi nga ginpaangbit.

Tatay Gusting the fishvendor

*After the storm surge
the sea retreated back to the pacific
leaving behind stench and silt.*

*His still hands caught Tonying's eyes
poking out of a mound of debris
his wrists cold and
lifeless.*

*The mighty sea who gave him life
willed to take back
the life she bestowed.*

Firie Jill T. Ramos¹

¹ Firie Jill T. Ramos, born and raised in Tacloban, writes poems and children's stories in Waray (the dialect spoken in Tacloban). She teaches children with autism, developmental disabilities, and learning delays at The Aram Learning Studio, a school for children with special needs, where she is the co-owner. Firie is founding partner of Amandiwing Books, a publishing outfit for children's stories in Waray. Her work and advocacy is on children with special needs, regional literature, literacy, human rights, and the environment. The text here presented is an excerpt of the original poem, written after Haiyan, which was kindly conceded by the author to be published as part of this dissertation.

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LIST OF ACRONYMS

ADB – Asian Development Bank

BOD – Board of directors

CC – Climate change

CCA – Climate change adaptation

CLUP – Comprehensive Land Use Plan

CPH – Census of Population and Housing (Philippines)

DEM – Digital elevation model

DRR – Disaster risk reduction

DRRM – Disaster risk reduction and management

EEA – European Environmental Agency

ENSO – El-Niño Southern Oscillation

FAO – Food and Agriculture Organization

GCM – Global circulation model

GIS – Geographic information system

HH - Household

HRU – Hydrological response units

INGO – International non-governmental organization

ITC – Intercontinental Convergence Zone

IPCC – International Panel on Climate Change

JTWC – Joint Typhoon Warning Center

LGU – Local Government Unit

LMWD – Leyte Metro Water District

LWUA – Local Water Utilities Association

PAGASA – Philippine Atmospheric, Geophysical and Astronomical Services Administration

PhP – Philippines Piso (national currency of the Republic of the Philippines)

MRII – Mactan Rock Industries, Inc.

NGO – Non-governmental organization

NOAA – National Oceanic and Atmospheric Administration (United States)

NRW – Non-revenue water

RCM – Regional climate model

RGF – Rapid gravitational filtration plant

SWAT – Soil and Water Assessment Tool

SSF – Slow sand filtration plant

WD – Water district

WGEN – Weather generator

WTP – Water treatment plant

UNEP – United Nations Environmental Program

UNDP – United Nations Development Program

USAID – United States Agency for International Development

USDA-ARS – United States Department of Agriculture – Agricultural Research Service

1. INTRODUCTION

Chapter abstract

During the last decade, the term resilience has assumed great relevance in a variety of disciplines, among which disaster risk reduction and climate change adaptation. However, a single definition of the term is yet to be accomplished. Traditionally used in ecology studies to represent the magnitude of a disturbance an ecosystem could support (and the expected time for its recovery), resilience then became to be commonly applied to man-made infrastructures (for example, to define the resistance of a given building towards an earthquake). This latter application of the concept is, according to some authors, focused only on the so called 'hard resilience' and, following a holistic interpretation of the term, the 'soft resilience' components (namely the social aspects and natural environment) should also be considered.

In this context, the use of hydrological models to assess the water resources resilience has increased in popularity. This tool enables to assess the climate change impacts on a certain region, through the direct use of output data from climate models, allowing the anticipation of extremes such as floods or droughts that directly affect the local water availability.

On this dissertation, the hydrological model QSWAT was used to evaluate the impacts of climate change on the water resources surrounding Tacloban, Philippines. It aimed to bring the use of this concept closer to its ecological origin, by including the natural component on the resilience assessment of a community. In addition to the goal of reinforcing the role of hydrological models on these studies, this research had the applied objective of actively contributing to the discussion around the water supply constraints felt in Tacloban after its catastrophic devastation by super typhoon Haiyan.

1.1. Context and motivation

In the summer of 2014 I have applied for a 1.5-month long volunteering internship related to disaster relief. The decision for the Philippines as my destination was rather simple: as an environmental engineer, master in sanitation and water resources management, it was always my ambition to contribute to environmental causes in developing countries. Furthermore, aware that I would engage on this Doctoral Program a few months later, I opted to volunteer in Tacloban, the city in the Philippines mostly affected by Super Typhoon Haiyan on November 8th, 2013 - whose unprecedented, destructive intensity was often related to climate change (CC). Parting from this life changing experience, with this research I expected to build on growing efforts at improving the resilience of Tacloban's water systems towards climate change impacts.

The Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Report* (2013) includes reinforced evidence of a global climate change, based on the work of several independent scientific analyses - from direct observations, to paleoclimate archives, passing through theoretical studies and simulations recurring to climate models. The evidence of human influence on climate has increased since the previous report, and experts consider nowadays to be *extremely likely* that anthropogenic causes are behind the warming observed since the mid-20th century. This influence has been detected in the warming of the atmosphere and the ocean, in the reduction of snow and ice, in the global sea level rise, in the aggravation of some climate extremes and also in changes on the water cycle.

Regarding the impacts on the water cycle, this report claims to be "*likely* that anthropogenic influences have affected the global water cycle since 1960 (...) [contributing] to increases in atmospheric moisture content (*medium confidence*), to global-scale changes in precipitation patterns over land (*medium confidence*), to the intensification of heavy precipitation over land regions (*medium confidence*), and to changes in surface and sub-surface ocean salinity (*very likely*)". Due to the referred variation in the atmospheric moisture, there is also high confidence that the precipitation variability related to the El-Niño Southern Oscillation (ENSO) will likely intensify. Furthermore, there is evidence that these changes in the global water cycle are not to be uniform, with extreme precipitation events over wet tropical

regions (such as the Philippines), becoming more intense and more frequent, as the global mean surface temperature increases (IPCC, 2013).

The study of climate-resilient solutions is therefore one of the research priorities defined by the United Nations Environment Programme (UNEP) on its *Program of Research on Climate Change, Vulnerability, Impacts and Adaptation* (PROVIA). Besides acknowledging the uncertainties that still affect climate change forecasting, the UNEP enhances the importance of building adaptive capacity, resilience and risk management, both on developed and developing countries. Thus, this dissertation was developed in accordance with the following PROVIA's topics: A.1.3. Understanding risks of climate change events, non-linear impacts and tipping points; B.1.2. Water systems; B.1.5. Infrastructure systems and the built environment; and B.3.1. Vulnerable coastal areas and islands (PROVIA, 2013). Moreover, PROVIA has clearly specified the need to assess the vulnerability of large municipal systems in terms of water availability in the future and the determination of damages to the infrastructures incurred during storm-surges is also included on these research guidelines. For these reasons, besides the personal motives referred, opting for Tacloban as a case-study seemed a pertinent and up-to-date choice.

This thesis simultaneously represents the first steps on my long-dreamed career in the development field. It has become a most fulfilling opportunity to overlap my knowledge in water and climate issues with real-time applied research that extrapolated the academic boundaries of its nature.

1.2. State of-the art: Resilience and Water Resources

Resilience – concept evolution and approaches

The concept of resilience has evolved since its original definition by Holling, in 1973, who has coined the term for ecosystems, so as a mean of measuring of the ability of these systems to absorb changes and still persist. In fact, the origin of this word is from Latin, where *resilio*

means to jump back. This initial concept contrasted with the term 'stability', defined as the ability of the system to return to a state of equilibrium after a temporary disturbance. The difference was that a very stable system would not fluctuate greatly but return to normal quickly, whilst a highly resilient system could be quite unstable and undergo significant fluctuations – and achieve normality afterwards. Later, in 1984, also in an ecological framework, Pimm has redefined resilience as the speed at which a system returned to its original state following a perturbation - enhancing the time of recovery as the most important variable, and not the magnitude of the damages (Klein, et al., 2003).

During the last decade, the concept of resilience has conquered some space in a variety of academic disciplines, such as systems engineering, organizational sciences, ecology, psychology, economics, climate change, disaster management, among others (Duijnhoven & Neef, 2014). In the present times, the idea of resilience enhancement has experienced an increase in popularity during climate change discussions, especially those regarding adaptation. Consequently, it has become more and more present on the vocabulary of related organizations, either of worldwide, national, regional or local scope.

Instead of doing an extensive literature review on resilience (which would divert from the objectives of this dissertation), a word cloud was generated for the collection of definitions found on literature and is presented below (Figure 1.1). The consulted references included worldwide scoped entities (such as the UN agencies, or the IPCC), regional agencies (as the EEA and the African Climate, among others) and national or local organizations (as Oxfam, the USAID or the USEPA). A word cloud is a visual representation of text data in which the words are sorted by size, with the ones in the larger font being the most frequent words. It is a useful tool to immediately grasp the main ideas supporting a written piece.



Figure 1.1 – Word cloud created for the definitions of resilience²

From a general perspective, the definitions on the table (refer to Annex I) are similar, although not coincident, and the created word cloud seemed to reflect the major terms supporting the definitions found on literature. One can observe that, amongst the most predominant words, the concepts of *ability/capacity* and *system* stand out: the inherent interconnection of human and natural systems implies that the impacts of natural hazards in one system, or in a given area, will most likely provoke cascading effects in other systems, or other geographies – so regarding resilience within its complex systems context is becoming a more frequent approach. As for the *ability*, nowadays most of the existing measurements of disaster resilience entail the quantification of resilience capacities (or abilities). In fact, the *capacity* of a certain system or community to be resilient is typically regarded to be at the core of the resilience concept, as well as of resilience measurements (Winderl, 2014). Other interesting aspect of this word cloud is the relevance of the terms *absorb*, *adapt*, *functions* and *recover* – defining the main actions in which the study object’s resilience is commonly measured, frequently assessing if it does it in a *timely manner*.

Regarding the subjects that trigger resilience responses, these appear here in the terms *hazard*, *change*, *event* or *disturbance* (being also significantly frequent the word *climate* due to this research being primarily directed towards a climate change related resilience).

² Image created using the free tool available in www.tagcrowd.com, accessed in February 2nd, 2016

Moreover, the duality between attributing resilient properties either to *structures* and/or the *community/social*, other especially frequent terms, will be explained further on this text.

In brief, the resilience of a system can be defined as the ability to reduce both the magnitude and the duration of the deviation from the equilibrium stadium (Proag, 2014). This equilibrium baseline is also commonly referred to as a ‘minimum acceptable level of wellbeing’, considering that the return of the system to a prior unacceptable state does not meet the definition of resilience (FSIN, 2014). Figure 1.2 exemplifies diverse types of resilience, for the same level of damage: one quick (dotted line) and two slow recovery paths (dashed and full lines), one of them where the level of damage oscillates but is ultimately reduced overtime (full line).

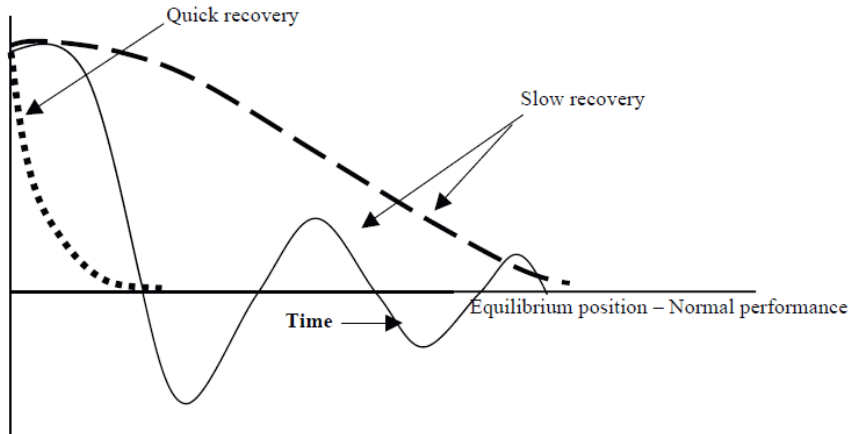


Figure 1.2 - How a system returns to a normal position (Proag, 2014)

Resilience in climate change adaptation and disaster risk reduction

Resilience-enhancing measures play a crucial role in Climate Change Adaptation (CCA) policies. This is evident in SREX, the IPCC’s *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2012). In fact, the IPCC considers that “Disaster risk reduction and climate change adaptation focus on reducing exposure and vulnerability and increasing resilience to the potential impacts of climate extremes” (IPCC, 2012). This report shares the IPCC and UN’s definition of resilience:

“Resilience: The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions.” (IPCC, 2012)

In the context of Disaster Risk Reduction (DRR), sometimes referred as Disaster Risk Reduction and Management (DRRM), climate-related natural hazards (often called climate extremes) have become more pressing. CCA and DRR share a common space of concern, not only because of the increasing weather-related risks, sea level and temperature rise, but also through the increases in societal vulnerabilities (depicted on stresses on water availability, and profitability of agricultural systems). Moreover, these concepts also share a mutual understanding of the components of risk and the processes of building resilience (Turnbull, et al., 2013).

A climate extreme is defined by the IPCC as “the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of the observed values of the variable” (IPCC, 2012) – a definition that does not include any anthropogenic component. In its turn, disasters are defined as “severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery” (IPCC, 2012). The impacts of climate extremes, however, do not depend solely on the dimension of the natural phenomenon, but also on the level of exposure and vulnerability. In parallel with other social indicators, the vulnerability of a community towards a natural hazard is closely related to the occupancy of geographical areas prone to disasters. In fact, with the population rising and consequent urbanization of many Asian cities, the population at risk will be significantly higher in times to come. As for Tacloban, people living in the typhoon

belt areas, with low altitude, high population density and unsafe housing, are extremely vulnerable (Eadie, 2017).

The UN-managed Sendai Framework for Disaster Risk Reduction (2015-2030) succeeded the Hyogo Framework for Action (2005-2015): Building the Resilience of Nations and Communities to Disasters, aiming to assess and review its implementation. Assuming that some progress has been made in terms of loss and damages reduction since Hyogo, the Sendai approach intends to have a more explicit focus on people, their health and livelihood. The term resilience figures on one of the seven global targets proposed - in which is proposed to substantially reduce disaster damage of critical infrastructure and, therefore, increase their resilience – and also as one of the main investment priorities (UNISDR, 2015). Throughout the framework, resilience appears on its social dimension, mainly focusing health and educational aspects, but also water, transportation and communication, among others.

Moreover, risk sharing and transfer mechanisms (operating at local, regional, national or even global scale) can be effective tools to increase the resilience of a community towards climate extremes (IPCC, 2012). Overall, when applied in the DRRM context, resilience often assumes three phases: before the disaster (preparedness), during (ability to respond) and after (recovery). However, as was the case in Tacloban (Chapter 4), resilience is often confused with simple preparedness towards disasters.

The components of resilience

Frequently, in the existing literature on hazards, resilience models mostly focus on the improvement of infrastructures to reduce their probability of failure. From this perspective, critical infrastructure systems (such as water, power or transport utilities) have a determinant role in the communitywide disaster mitigation, thus being high-priority targets for resilience enhancement. The 'R4 Framework of Resilience' (Robustness, Redundancy, Resourcefulness and Rapidity) was structured by Tierney and Bruneau (2007) in the Multidisciplinary Center for Earthquake Engineering Research (MCEER), USA, as a method to

measure the resilience of infrastructures: Robustness, representing the ability of the systems to withstand disaster forces without significant degradation or loss of performance; Redundancy, as the extent to which the system’s components are substitutable, i.e., capable of satisfying the functional requirements after damage occurs; Resourcefulness, as the ability to diagnose and prioritize problems and to initiate solutions (mobilizing material, monetary, technological, informational and human resources) and Rapidity, representing the capacity to restore the system’s functionality in a timely way, thus containing losses and avoiding disruptions.

However, overcoming the infrastructural application of the concept, some authors have distinguished between hard and soft resilience (Figure 1.3): the former linked to the “direct strength of structures or institutions when placed under pressure” (as the R4 Framework abovementioned), by reinforcing them in order to reduce the probability of collapse, and the latter defined as “the ability of systems to absorb and recover from the impact of disruptive events, depending on their flexibility and adaptive capacity of the system as a whole” - rather than just strengthening infrastructures (Proag, 2014).

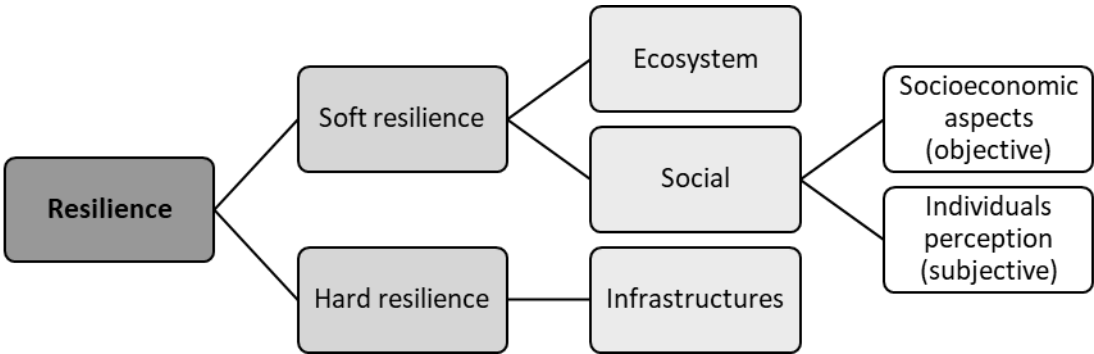


Figure 1.3 - Categories of Resilience

In fact, frequently the models focusing only on hard resilience do not comprehend antecedent social factors that can be observable at the local level and be critical for the

recovery of a system (Cutter, et al., 2008) – the so called social resilience. Eadie et al. (2017) argue that resilience is “not a generic attribute, it is socially situated and culturally determined” and that its measurement is hampered by several factors. Considering a recovering post-Haiyan Tacloban, the author exemplifies that survivors may claim to be more resilient than they actually are, under the fear of being seen as weak, or they may accept goods that they do not really need just not to seem ungrateful, or not to compromise the access to future offerings from specific humanitarian groups. Also, social resilience relates to more “intangible assets, such as trust, faith and familiar and community cohesion” (Eadie, 2017).

Moreover, revisiting the ecological origin of the concept, several studies consider that the condition of natural resources and their dependence by local communities affect the latter vulnerability to climate-related hazards (Eadie, 2017; Folke, 2006). This is true considering the ecosystem services of providing a buffer to disasters such as typhoons and flooding, and the extraction of resources (water, fish, crops, etc.) on which livelihoods are based, especially in developing countries. Maintaining the ecosystem health can, therefore, increase a community’s resilience (Klein, et al., 2003) – so natural resources can also be considered as a branch of soft resilience. Duijnhoven and Neef (2014) go further on this line of thought, claiming that true resilience lies in the interaction of all components and it is essential to define a system’s resilience critical factors. For example, disrupting one aspect, such as an economic crisis, will affect other aspects as the social wellbeing, welfare structures and community-based initiatives. On the other hand, by strengthening one aspect will impact positively the remaining ones – as for example the enhancement of the social cohesion (part of the social resilience) in a given community is known to bring economic gains.

In the context of this dissertation, social aspects, together with the hydrological analysis, were determined as the components of a system’s soft resilience - as opposed to the hard resilience related to the built assets robustness, which was intently not considered.

Measuring Resilience

For Tierney and Bruneau (2007), hard resilience can be “measured by the level of functionality of an infrastructure after a disaster, and by the time it takes for it to return to pre-disaster levels of performance”, as depicted on Figure 1.4 below. For these authors, the resilience triangle drawn represents the loss of functionality the system undertakes from damage and disruption, as well as the pattern of restoration and recovery over time – meaning that resilience enhancement measures must aim at reducing the size of the triangle, either by improving the functionality and performance (vertical axis) or by decreasing the recovery time (horizontal axis).

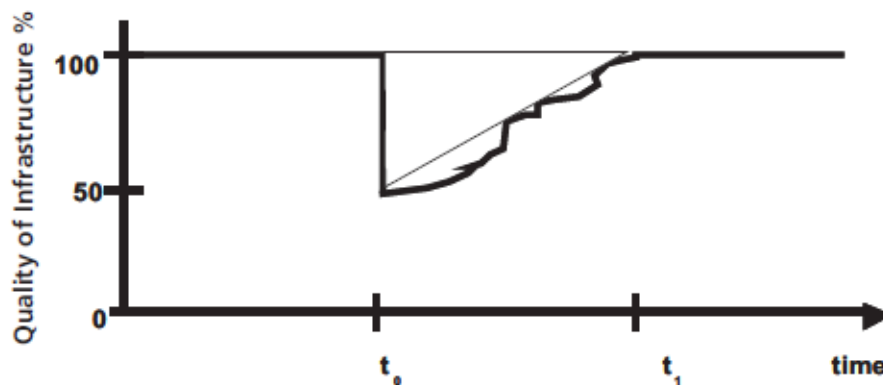


Figure 1.4- The resilience triangle (Tierney & Bruneau, 2007)

An important input to measure inherent resilience – transversal to all its components - is, nevertheless, the temporal scale: a system may seem resilient to extreme weather events (short-term) due to adaptation measures adopted, but it may not be prepared for the impacts of climate change (long-term) (Cutter, et al., 2008). Therefore, resilience is temporal and localized, meaning that what is considered resilient today may not be resilient tomorrow and ‘one size does not fit all’ (Duijnhoven & Neef, 2014).

Nevertheless, the depicted methodologies were often applied in contexts of hard resilience, but for measuring soft resilience different metrics have been proposed. As stated by Eadie

(2017) resilience is a socially situated and culturally determined attribute, which is also related to intangible measures such as trust, faith and social cohesion. Jones and Tanner (2015) added that resilience is heavily shaped by sociocultural and psychological factors such as risk perception, cognitive barriers and personal or cultural values. These authors defend that this 'subjective' resilience measurement can significantly contribute to the construction of a holistic view of resilience (Jones & Tanner, 2015).

Objective social resilience is commonly measured by humanitarian and development workers, recurring to a set of key socio-economic indicators. These include income values and other capitals that support people's livelihoods, which usually require large data sets that may be inexistent in developing countries. On its turn, subjective social resilience can be measured by the level of participation on community activities (which are thought to strengthen cooperation and assistance) (Engle, et al., 2014), personal well-being (as a strong psychosocial strength decreases the change of post-traumatic disorders (Norris, et al., 2008)) self-reliance (Ranjan & Abenayake, 2014), among others.

No holistic framework for measuring disaster resilience has been empirically verified yet, since measuring resilience is too complicated (Winderl, 2014). Often, resilience to a specific event (such as a natural disaster) is equalized to the cost of its recovery (Proag, 2014). Amongst the difficulties of measuring resilience lies the fact that natural hazards are often unpredictable, and the complexity of social responses makes it hard to anticipate them properly and support robust resilience-enhancement strategies. Additionally, it is frequent that disasters achieve such a magnitude that surpasses existing models and regular response plans – with resilience efforts frequently underestimating the disaster consequences and their indirect impacts on other sectors (Duijnhoven & Neef, 2014). This was the case of super typhoon Haiyan devastation in Tacloban, Philippines, the case study chosen for this dissertation presented in detail on Chapter 2.

Water Resources Resilience

As noted, regarding the application of resilience measurements to water supply systems, the possible metrics can be divided into two large groups: the first considering the man-made

part of the system, i.e., the infrastructures or the fluctuations of water demand (hard resilience), and the second focusing on the water sources themselves (soft resilience), which are often achieved by hydrological indicators – the most relevant in the context of this dissertation.

A good example of a resilience analysis was project *Be Secure – Water Security for Resilient Economic Growth and Stability*, developed in the aftermath of super typhoon Haiyan, by the humanitarian group USAID (United States Agency for International Development). As its name suggests, the goals of this four-year project (2012-2017) in the Philippines were to strengthen the capacity of water supply providers to expand coverage and improve their services, to help mobilize the water sector financing, to reinforce the collection/analysis/sharing of water/climate data (and from there reduce the risks from climate-related disasters), whilst improving the Filipino agencies general capacity from ensuring long-term water security. To do so, activities were developed with Local Government Units (LGUs) and water service providers (WSP) in six areas of the Philippines, amongst which Leyte. Having set a target of helping 1.2 million people, by the end of the project USAID had, in fact, helped 1.3 million Filipinos, surpassing its initial expectations (USAID, 2017b). The final report summarized the lessons learned and guidelines to enhance the water system’s hard resilience. The principal CC impacts on the various components of a water supply infrastructure were identified, together with possible adaptation measures to address them: 1) Increased mean annual and/or intensity of precipitation; 2) High winds; 3) Storm surge; 4) Sea level rise; 5) Drought and decreased mean annual precipitation; 6) Increased mean annual temperature, extreme heat and heat waves; and 7) Wild fires. The CC impacts most relevant for this dissertation (numbers 1 and 5) are summarized on Table 1.1 and are hereby considered as water resources soft resilience metrics.

Table 1.1 - Climate Change Impacts on Water Supply Infrastructures (adapted from USAID, 2017a)

Impacts	Increased Mean Annual and/or Intensity of Precipitation	Drought and Decreased Mean Annual Precipitation
River and Water Resources	<ul style="list-style-type: none"> - Increased water turbidity after heavy storm events; - Shifts in river morphology from increased erosive capacity of river during storm events may affect water withdrawal; - Need for dredging to remove sediment, rocks and debris deposited after storm events. 	<ul style="list-style-type: none"> - Decreased availability of surface water resources; - Low river levels affect water intake; - Water systems designed using historical precipitation data are likely to be unsustainable for future projections of reduced precipitation; - Competing demands for water from industrial, agricultural and urban sectors.
Water Impoundments	<ul style="list-style-type: none"> - Additional storage facilities needed to capture water during shorter, higher intensity storms; - Higher turbidity of stored water due to erosion requires more treatment chemicals and time for clarification during treatment; temporary suspension of treatment of stored water may also occur in cases of extreme turbidity; - Decrease in storage capacity of impounding reservoirs due to high sediment deposition 	<ul style="list-style-type: none"> - Increased evaporation decreases availability of surface water; - Need for increased inter-annual storage capacity.
Wells and Spring Sources	<ul style="list-style-type: none"> - Well contamination from flooding; - Physical damage to structures from flooding; Intake pipes on soft soils or steep slopes prone to landslides; - Destruction of spring boxes on steep areas from landslides; - Need for relocation of water intake structures due to shifting riverbed and sediments during storm events; - Higher maintenance costs to keep water intake structures clear of debris deposited after storm events; 	<ul style="list-style-type: none"> - Decreased availability of groundwater resources; - Deeper groundwater tables; - Decreased availability of surface water resources required increased need for additional groundwater sources or deeper wells; - Increased pumping costs to reach deeper groundwater tables.
Storage Tanks	<ul style="list-style-type: none"> - Contamination due to flooding for cisterns; - Physical damage due to landslides. 	<ul style="list-style-type: none"> - Lack of inflow to storage tanks; - Frequently emptied due to higher demand.
Pipelines	<ul style="list-style-type: none"> - Corrosion of metal pipes weaken structures over time - Physical damage to pipes from flooding and landslides - Network contamination from pipes damaged by flooding or landslides 	<ul style="list-style-type: none"> - Decreased supply and intermittent or low pressure; - Increased risk of contamination from wastewater intrusion; - Increased demand for increasingly scarce water resources.

Treatment Facilities	<ul style="list-style-type: none"> - Physical damage to structures from flooding; - Water damage to chemical supplies from flooding; - Lower treatment effectiveness due to higher than normal turbidity or disrupted/shorter treatment operation; - Need for higher treatment plant capacity due to higher precipitation depending on capacity of transmission lines. 	<ul style="list-style-type: none"> - Declining raw water quality due to drought-prone algal blooms or diminished runoff and flows that cause concentration of chemical pollutants; - Increased treatment costs as pollutants become more concentrated.
Auxiliary Services	<ul style="list-style-type: none"> - Loss of power supply; - Loss of telecommunication facilities; - Loss of data. 	(none identified)

Additionally, appropriate adaptation and resilience enhancement measures were identified for the two selected climate impacts (increased precipitation and drought, which affect distinct regions within the country). These measures included the assessment of the ability to switch between water sources, if the current water source was threatened by landslides, changes in river morphology or drought. Moreover, it was advised to continuously monitor changes in the river morphology (which could be achieved via aerial images). Other resilience enhancing measures passed by the increase of the infrastructures' maintenance budget and emergency funds for repair works after an event. The plantation of trees to stabilize landslide-prone areas and help retain rainfall was also recommended.

A pressing concern was related to the fact that current infrastructure design was based on historical data, and climate change could prove these designs to be outdated. Overall, all built assets of a water supply system should be retrofit to be able to withstand stronger climate extremes. This could be materialized through the construction of bund walls around critical system components to prevent flood waters to damage them or raising exposed pipelines above the maximum historical flood levels, for example. If retrofitting was not possible, the construction of new climate-resilient facilities should then be considered (USAID, 2017a).

On a broader perspective, the USEPA's *Adaptation Strategies Guide for Water Utilities* included, as an adaptation measure, the use of hydrological models to project runoff and incorporate model results during water supply planning (USEPA, 2015). In fact, regarding the soft resilience component, in the existing literature there is a multitude of hydrological indicators recommended to assess climate change impacts, i.e., changes in the flow regimen between a reference and future periods. For instance, some possible indicators of CC impacts can be the magnitude, frequency, duration and timing of the flow. The selection of the appropriate indicators depends on the objectives of the study, available data and hydrological characteristics of the basin, among others. In sum, resilience indicators for water systems focus either on water scarcity or quality degradation issues – in the scope of this dissertation, only quantitative water constraints were considered, and water quality degradation was, therefore, deliberately excluded.

A set of acknowledged metrics are the Indicators of Hydrologic Alteration (IHA), proposed by Richter et al. (1996), which comprise 33 hydrological parameters, characterizing variation in flows – including the magnitude of monthly stream flows, magnitude and duration of annual extreme flows, timing of annual extreme flows, frequency and duration of high and low pulses, and rate and frequency of flow changes (Gao, et al., 2012). Moreover, Sellami et al. (2016) have proposed the division of quantitative hydrological indicators into four categories: 1) climate conditions (cumulative monthly precipitation, monthly temperature); 2) water balance (monthly potential evapotranspiration, monthly runoff, monthly soil water content); 3) extreme flow magnitude and frequency (30 years daily discharge, number of low flow days/month, number of high flow days/month); and 4) flow duration and timing of flow (minimum flow duration, maximum flow duration, average annual Julian date of 1-day maximum/1-day minimum and 90-day maximum/90-day minimum).

In the event of the studied flows being used for water supply purposes (as for the case study presented forwardly), it is common the application of water scarcity indicators – which, summarily, compare available flows and water catchment rates. A possible indicator for water scarcity, as defined by Elis (2014), is the % of dependable flow – related to the solo analysis of the hydrological cycle. Examples of those ratios are the indicators: Water Stress

(measured as the ratio of total water availability per total water withdrawals), Water Exploitation Index (the mean annual demand for freshwater, divided by long-term average freshwater resources and the Falkenmark Index (renewable water resources per capita). The vulnerability to water scarcity is, therefore, one of the most commonly applied quantitative indicators, defined as the gap between supply and demand and expressed as a percentage. In its turn, for analyzing the impacts of that scarcity, socioeconomic indicators such as losses of jobs or livelihoods are frequently used. Summarily, the indicators for the sensitivity to water scarcity relate both to the supply and demand of water (Ellis, 2014). Moreover, to determine the sensitivity of a system to water scarcity, caused by a certain event, it is necessary to quantify the stress factor involved. For example, CC can act as a stress factor: in some basins a reduction of 10% rainfall result in a 30% reduction in water availability, while in other basins the same reduction of rainfall can have only a marginal impact on local stream flows. On the other hand, high-demand systems generally implicate higher sensitivities to scarcity, comparing to those where water demand is low. In this regard, projected changes in water demand can serve as an indicator of this sensitivity.

The role of hydrological modeling on climate studies

Whilst CC has recently become a matter of the foremost importance in water studies, the coupling of hydrological and climate studies is a relatively young discipline. Consequently, there is no common practice in terms of how to best apply climate models simulations to CC impact studies, hence the lack of scientific standards (Teutschbein, 2013).

The investigation of the climate and earth systems responses to various radiative forcings has been strongly based on climate models, together with observations and theory (Schmidli, et al., 2007). Being climate one of the most complex geophysical systems to simulate, because of its high number of interacting components and innumerous time and spatial scales to be considered, the understanding of climate dynamics surpasses a direct mathematical solution. Moreover, its global nature makes impracticable the sole use of direct observations and so numerical modeling constitutes the only method to embrace

climate mechanisms and their vulnerability to external forcings (Laprise, 2008). Global Circulation Models (GCM) are coupled numerical models which represent various earth systems, including the atmosphere, oceans, land surface and sea-ice (Fowler, et al., 2007). These models express their physical laws in mathematical terms, by the development of numeric methods that allow the solution of those expressions. These equations are usually applied in the form of a grid such as the latitude-longitude-height grid, used on atmospheric or oceanic models. Afterwards, such phenomena that cannot be represented explicitly due to their high complexity (e.g. biochemical processes in vegetation) are included on the models via their simplified parameterization (Flato, et al., 2013).

However, when more detailed information (and thus higher spatial resolution) is needed in some particular geographical region, Regional Climate Models (RCM) are often used. As pointed out by Rummukainen (2010), these tools have therefore been crucial to the elaboration of climate predictions, which in their terms constitutes a strong argument to convince local policy makers of the risks and impacts of ignoring climate change alerts. It is well accepted that RCM data allows for a more detailed and realistic representation of climate features in islands, including orographic precipitation and other sub-regional variations, usually not captured by the GCM which do not distinguish the climate in islands from the characteristics of the surrounding ocean (Maharaj & New, 2013). In fact, the enhanced resolution of RCM allows for a better description of local dynamics and various forcings – particularly where surface forcing is relevant, such as on mountainous or coastal regions where there is a sharp variation of surface properties (Laprise, 2008). Regarding the downscaling method, two techniques are mainly used: statistical downscaling and dynamical downscaling. While the first one adopts statistical empirical relationships between the regional and global systems, on a dynamic process RCMs are used to simulate small-scale physical processes in concordance with the large-scale information prescribed from a GCM. Driving data from GCMs work as lateral boundary conditions such as temperature, humidity, or circulation, and the quality of these data is determinant for the success of the downscaling exercise (Rummukainen, 2010).

Nevertheless, despite the narrower scale of RCMs, there is still a significant mismatch with the scale at which many hydrological and water resource studies are conducted (Xu, et al.,

2005). In fact, existing literature confirms the difficulty of circulation models in providing detailed regional hydrological scenarios (Chen, et al., 2011; Diaz-Nieto & Wilby, 2005; Hay, et al., 2000). As stated by Teutschbein (2013), even downscaled meteorological variables (such as precipitation and temperature) are biased and thus not suitable to be directly used for hydrological purposes, or should, at least, be handled with caution. Examples of such biases are the occurrence of an excessive number of wet days with low-intensity precipitation, the general over- and underestimation of seasonal precipitation variations, or the inaccurate estimation of extreme temperatures. These errors have their origin in an imperfect model conceptualization, or on the discretization and spatial averaging within the grid cells.

For these reasons, coupled climate and hydrological models are a well-documented method to study the spatial and temporal evolution of water resources at the basin scale. Researchers have studied CC effects in basins runoff worldwide, some including other variables besides runoff, such as soil moisture, water quality or evaporation. For example, studies were conducted to assess how a changing climate increased discharge and attenuated seasonal distribution on the northeastern United States (Berton et al, 2016) and on Mediterranean catchments (Serpa, et al., 2015), to evaluate monthly runoff variations in a catchment in Belgium (Dams, et al., 2015), to determine CC impacts on low-flows on specific northern European rivers (de Wit, et al., 2007), to model the hydrological impact of CC on Canadian basins (Dibike & Coulibaly, 2005; Li, et al., 2016), among others. Although there has been much interest in modeling hydrological impacts of CC worldwide, the truth is that most studies are concerned only with changes on the mean climate and not so many focus on the climate extremes, which may have a greater impact on local hydrological processes (Fowler & Kilsby, 2007).

Some water resources resilience metrics, therefore, because they are related to CC impacts, can be accurately studied through hydrological modeling, which facilitates the benchmarking of various scenarios. An additional sensitivity analysis (a common complement of modeling exercises) allows to better understand the weight of each variable. The main difficulty to do

so, lies in the identification of hydrologically meaningful metrics that replicate all the variables of the flow regime (Sellami, et al., 2016). Additionally, the large numbers of metrics and their interrelation complicates their use, and the obtained results can sometimes even be statistically redundant (Olden & Poff, 2003).

1.3. Moving Beyond: research hypothesis, objectives and innovation

The application of resilience studies has been stepping away from the ecological root of the term, being increasingly present in the humanitarian field and development, and consequently being part of CCA and DRR approaches. An example of the former, within the framework of water resources, can be the water scarcity issues enhanced by a growing demand and altered rainfall patterns. As for the latter, the recurring floods caused by the monsoons on several developing nations is an illustration of this. However, most of these studies focus on the so-called hard resilience, assessing the robustness of man-made infrastructures, or only on the socioeconomic branch of soft resilience. Although intensively studied, the soft resilience of natural resources to disruptors, such as CC long term impacts or extreme weather events is somewhat not frequently included on those typical resilience studies. Nevertheless, the interdependence of human and natural systems makes it imperative that a holistic framework of resilience, considering the three pillars (environmental, social and built infrastructures), should be developed.

This dissertation therefore aims to address this scientific gap by integrating the two less commonly crossed branches of soft resilience: the resilience of natural resources to CC impacts and the social resilience (considering both the objective socioeconomic typical indicators and the subjective social resilience measurements). It hopes to add up to the present discussions about the meaning of resilience, aiming to contribute to the definition of a holistic application of the term. Moreover, it aims to bring back resilience closer to its ecological origins, by including the evaluation of the water sources behavior on the resilience assessment of a community which depends on them (or that may be severely affected by them).

Given its applied research nature, as it addresses a real-life case study and not only a theoretical hypothesis, this dissertation has the specific goal of contributing to the resolution of the water constraints felt in Tacloban. Despite being acknowledged even before the typhoon, the supply constraints assumed great importance after Haiyan due to the relocation of a significant part of the city's residents (approximately 90,000 habitants, circa 40% of the total population). For some of the concerned parties (such as the water district and the city's LGU), in fact, this reconstruction could be faced as an opportunity to address land planning and resources distribution issues, such as the water supply network.

As it recurs to the application of hydrological modeling to a real-life case study, this work has the parallel purpose of reaffirming the role of this tool in the context of CC impact studies and DRR policies. The novelty field of combining hydrological models with GIS tools enhances these possibilities, with great contributions to risk mapping and DRRM in general. Additionally, the downscaling of rainfall changes, from GCMs to RCMs and posteriorly via hydrological models, to the watershed level, is a growing popular field which can enlighten water resources management in future times.

In a world with a changing climate, it is pertinent that water supply projects conducted in developing nations consider the growing demand constraints and CC impacts to the water resources availability (for example, to avoid the in vain construction of water intake structures on waterways that will eventually dry). On a more humanitarian perspective, the use of hydrological models to foresee the devastation caused by future disasters, can help to draw DRR plans that go beyond early warning systems and current prevention measures – allowing for the flourishing of truly resilient communities.

1.4. Research methodology and dissertation structure

The present dissertation is divided into five chapters that help to better structure the tasks undertaken. Primarily, Introduction (Chapter 1) includes a literature review on the meaning, evolution and metrics of resilience, together with its applications within the water resources sciences. On this chapter is given the context and motivation behind this endeavor to

contribute to the overall knowledge and to address specific local constraints (both its goals and innovative characteristics are listed as well).

On Chapter 2, is presented the chosen case study, the City of Tacloban located in Leyte, Philippines. This involves the summary of the physical and sociodemographic characteristics of the analyzed territory, as well as the changes brought by super typhoon Haiyan (namely on the territorial planning and the water resources scarcity aggravation).

Thereafter, the two resilience analyzes undertaken are separated into Chapters 3 and 4. Despite being complementary in the sense that they help to construct a more holistic view of resilience, these two analyzes relied on independent methodologies and thus were hereby decoupled.

On Chapter 3, Water Resources Resilience, the reliability of local waterways for supply purposes (both present and under climatic changes impacts) were examined. The main methodology behind this task was the use of the hydrological model SWAT, coupled with a GIS system that helped visualizing the results. This analysis has taken into consideration the relocation of a large share of Tacloban's population towards northern territories, so far unoccupied.

In its turn, on Chapter 4 was described the community resilience analysis that was based on locally conducted surveys. The covered topics included the characterization of respondents and their natural hazards, climate change and resilience perception (focusing also the impacts of typhoon Haiyan on their households). Additionally, the community's understanding of the water supply constraints they were experiencing was a highlight from these results.

Finally, the conclusions on Chapter 5 summarize the overall findings of this dissertation, acknowledge the limitations of this work and outline potential future developments.

The overall methodology consisted on a combination of desk reviews (including the state-of-the-art review, the hydrological modeling exercise and the survey data analysis) and field trips to Tacloban. Considering that a real-life situation was addressed (instead of a solely theoretical analysis), these field trips assumed the utmost importance hence allowing an immersive experience of the territory. These trips were essential to collect the data necessary for the two resilience analyzes, simultaneously allowing the capture of photographs and the interview of key intervening actors, such as the LGU, the LMWD board and Taclobanons in general. Three field trips to Tacloban were conducted in the course of this dissertation (March 2016, October 2016 and January 2018).

The choice for these methodologies, along with the expected dissertation timeline, brought some limitations to its findings. For example, the inability to speak the local language (despite most Filipinos, including the interviewed LGU and LMWD staff members, speaking very good English), has limited the community perception analysis to the data collected on the household survey. Also, resource limitations (of being an individual researcher and being hosted by an institution that did not had them available) have made impossible the collection of real flow measurements on Binahaan, Pongso and Cabayugan Rivers. Therefore, the calibration of the hydrological model outputs was performed recurring to a neighboring river's measurements, which, despite not being the ideal procedure, was considered a feasible solution that did not affect the reliability of the findings presented.

2. CASE-STUDY PRESENTATION: TACLOBAN, PHILIPPINES

Chapter Abstract

On November 8th, 2013, super typhoon Haiyan roared ashore in Leyte, Philippines, causing catastrophic destruction and over six thousand casualties. Being one of the major cities affected, Tacloban soon became the focus of the world media attention and relief operations.

Tacloban City was, therefore, the case-study chosen for this dissertation, given the water scarcity constraints it was facing in the aftermath of Haiyan. Due to the outrageous dimension of this catastrophe, the city became a hub for various research, relief and recovery projects, in which resilience was a dominant concept. Under the slogan of 'Build Back Better', this city underwent major relocation efforts towards the unoccupied northern territories (which would accommodate over 40% of the population in 2018), on supposedly storm-surge safer areas.

However, as of January 2018, the relocated families still lacked a proper water supply. In fact, they relied on water trucks to provide them with potable water that seldom was sufficient to meet their real demand. For that reason (together with livelihood related issues), many families were felling back to the city and rebuilding their houses on hazard prone areas.

The local water district, LMWD, had presented their intention of extending the current network to Tacloban North. Nevertheless, the existence of water shortage complaints (reported even before the typhoon), together with network losses and the feared impacts of CC on Binahaan River, where LMWD catchment was located, led the local government to consider another option. Supported by the INGO USAID, in 2015 a study was conducted to assess the viability of the exploitation of two rivers in northern Leyte (Pongso and Cabayugan Rivers) to supply potable water to the new resettlement areas. By the closing time of this dissertation, the administrative disputes between the local government of Tacloban and the provincial government of Leyte for the management of LMWD were holding back the decision for a definitive water supply solution. In this context, the resilience analysis of the two proposed solutions has become the main focus of this research.

2.1. Brief History of Tacloban

The first settler of Tacloban, thought to have occupied the hill where presently the City Hall is located, named it 'Kankabatok' after his own name Kabatok. This was until 1770, when the Augustinian Mission arrived (before the Franciscans, in 1813) and renamed it 'Tarakluban' after the 'Taklub', the fishing gear made of bamboo used by local inhabitants to catch crabs, shrimps and fish - later, this name evolved to its present designation, Tacloban. Tacloban was first proclaimed a municipality as early as in 1770, becoming the capital of Leyte in 1830 because of its harbor privileged location for trading purposes. Tacloban has since then became the premier city of the Eastern Visayas, with significant economic and strategic importance, reflected on its central position in terms of commerce, trade and industry, education and technology – leading to its classification as a highly urbanized city in 2008 (City Government of Tacloban, 2018).

Tacloban was likewise a point of historical interest during the World War II. On May of 1942, the Japanese forces fortified the city starting a two-year occupation, using its port as the main entrance for the Japanese Imperial Naval Forces. This time was considered the darkest period of Tacloban's history due to the torture of its civilians by the Japanese. This was until General Douglas MacArthur landed on Leyte beaches (near Palo), in October 20th, 1944, and liberated Taclobanons from the Japanese forces. Later, he fulfilled his famous promise 'I shall return', spoken after he was forced to flee back to Australia, leaving thousands of American and Filipino soldiers lacking food and supplies. These landings signaled the eventual victory of the Filipino and American forces, making Tacloban the temporary capital of the Philippines until the complete liberation of the country (City Government of Tacloban, 2018).

2.2. Administrative division

The Philippines are divided into 17 regions with the purpose of organizing the country's 80 provinces, for administrative convenience (Figure 2.1). The largest islands, Luzon (that hosts the capital Manila) and Mindanao, together with the central region of the Visayas islands, represent the three primary regions of the archipelago (CIA, 2015) (Gultiano, et al., 2003). The Visayas are therefore an extensive group of islands that lie between Luzon and

Mindanao, although belonging structurally to neither. This region consists of several large islands and several hundred smaller islets in the Visayan, Camotes and Samar seas. It is commonly divided in three sub-regions: Western Visayas (with the major islands Negros and Panay), Central Visayas (Bohol and Cebu) and Eastern Visayas (Samar and Leyte).

In Leyte Island, the Northern Leyte province occupies over three-quarters of the island spreading over 6.31 million km² and is home to over 1.97 million people according to the 2015 Census, with a density of 270 inhabitants per square kilometer (POPCEN, 2015). This province comprises 40 municipalities and three cities (the two independent cities of Tacloban and Ormoc and the component city of Baybay), with Tacloban being its administrative capital and the capital of Region VIII (Figure 2.2).

Tacloban City municipality occupies circa 201.72 km² (including the islets within its boundary jurisdiction). Administratively, the municipality is divided in 138 *barangays* (Figure 2.3Figure 2.1), each having its own council – the *barangay* is the smallest administrative division in the country and is the native term for village. Modern *barangays* are managed by elected officials, headed by the *Barangay* Captain, which is aided by the *Barangay* Council. This council is considered to be a Local Government Unit (LGU), similar to the provincial and the municipal governments, with *barangay* elections typically being strongly contested, with great participation of the community. Finally, some larger *barangays* can be divided into smaller areas, called *purok*.

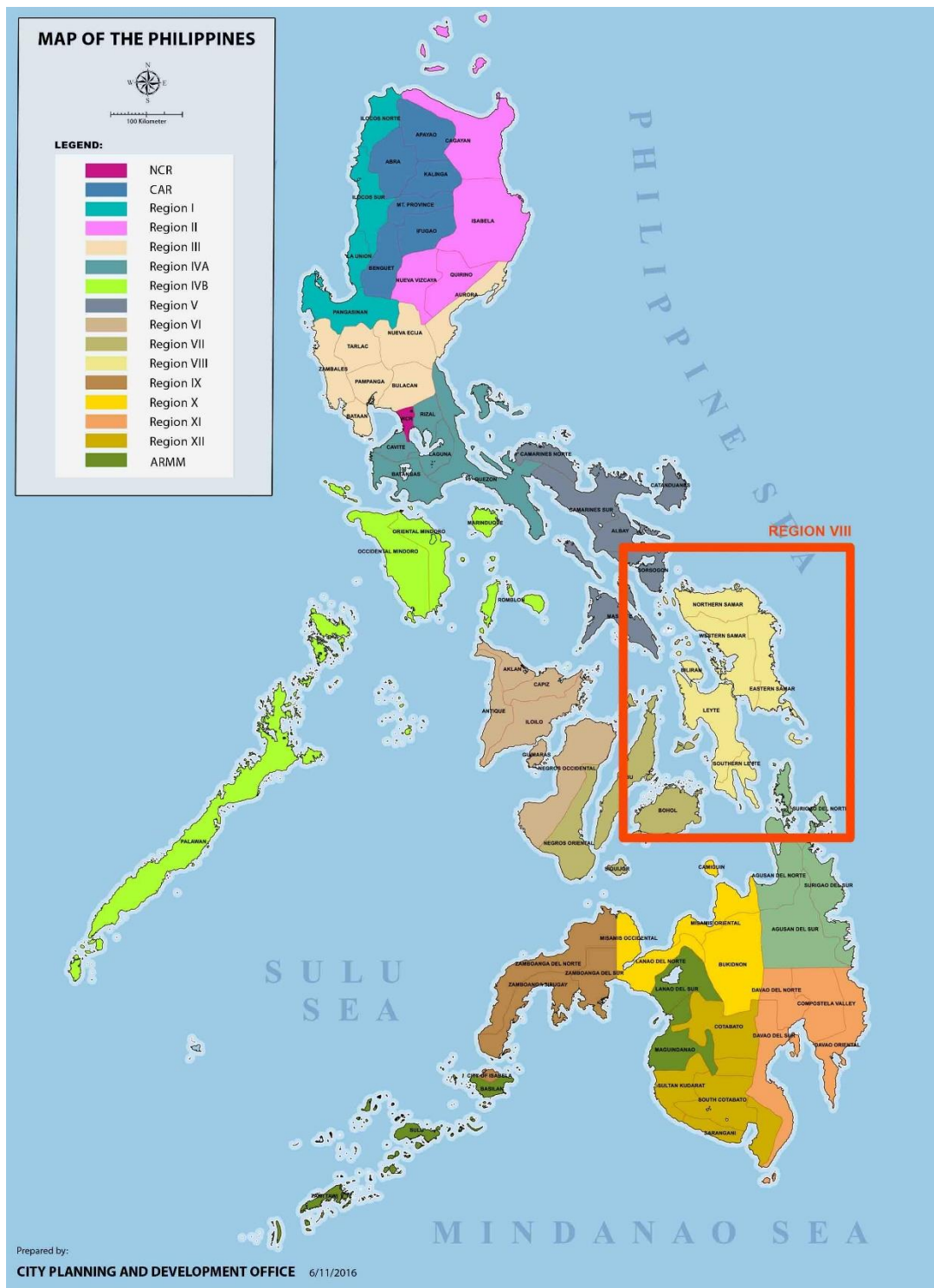


Figure 2.1 – Administrative regions of the Philippines and location of Region VIII (City Government of Tacloban, 2018)

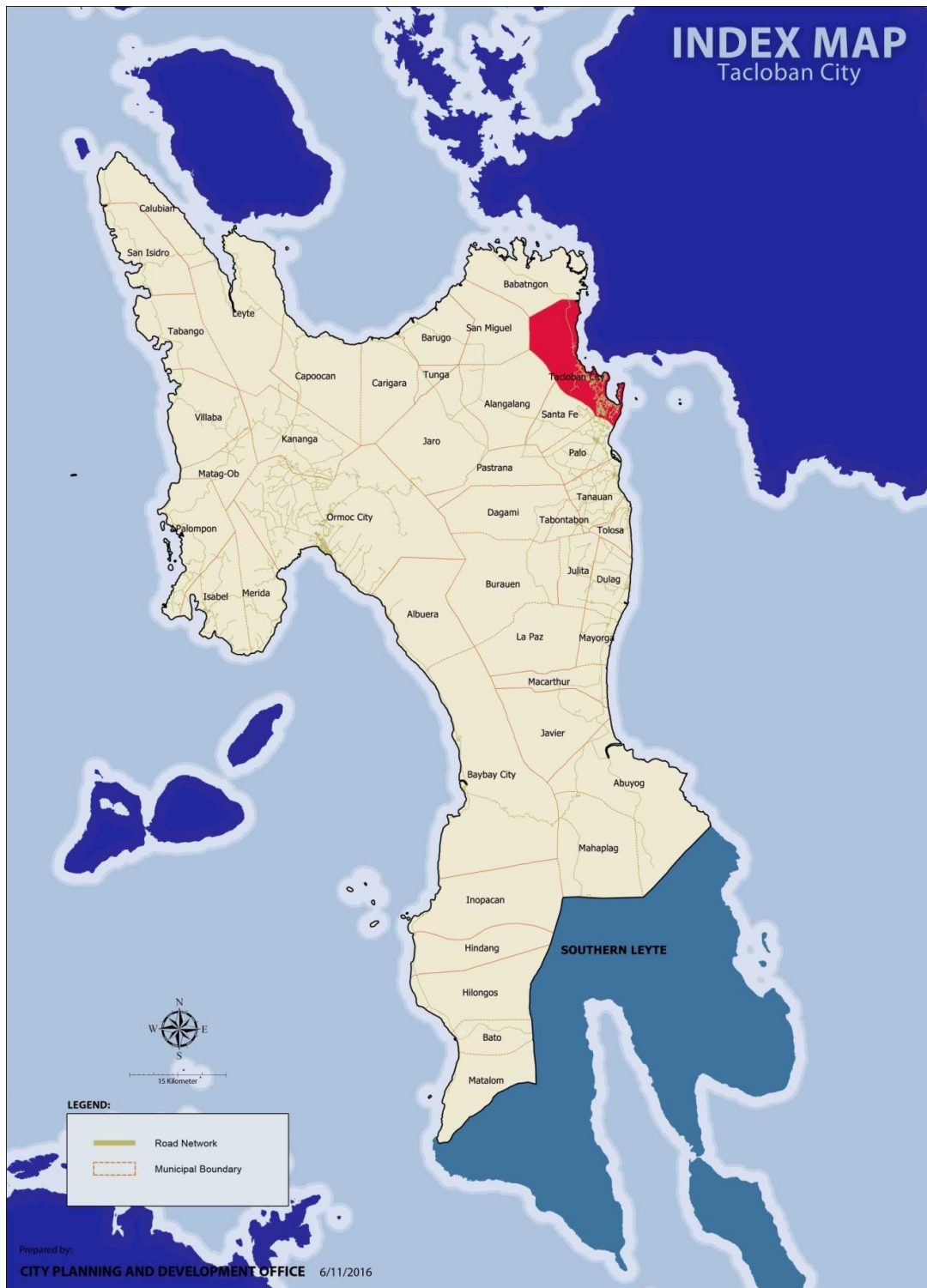


Figure 2.2 - Location of Tacloban municipality in Northern Leyte (City Government of Tacloban, 2018)

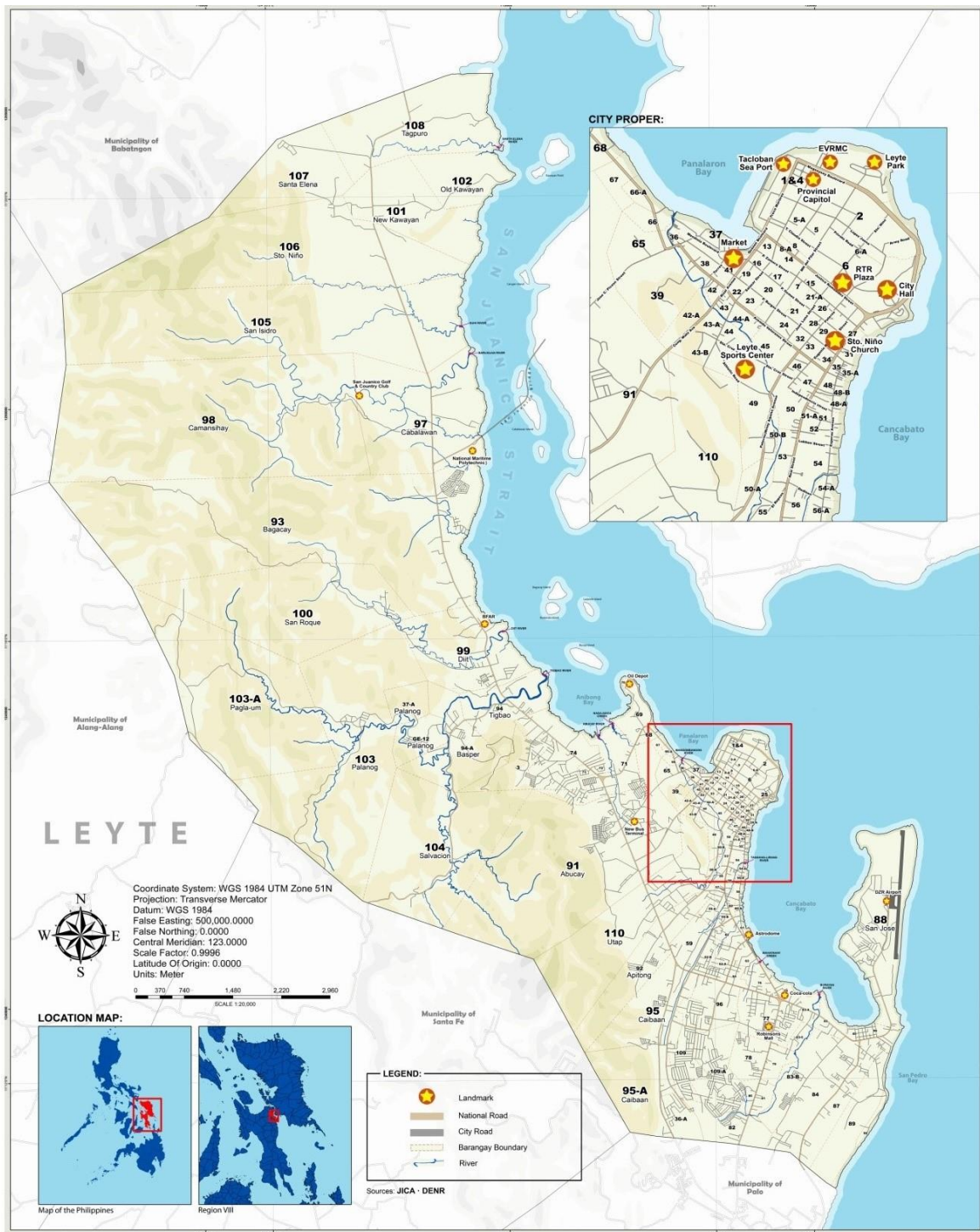


Figure 2.3 - Tacloban Barangay Map³ (City Government of Tacloban, 2018)

³ After typhoon Haiyan, during the forced revision of the city CLUP, the LGU has redefined some of the barangays boundaries. This is the reason why the map presented on this page, corresponding to the updated version, does not correspond exactly to the barangay division used in the GIS maps ahead. Future studies should consider this updated map for the barangay division reference.

2.3. Spatial and Natural Characterization

Geography and topography

The Republic of the Philippines is hosted on an archipelago of 7 107 islands and islets in Southeast Asia, with a total area of 300 000 km² that stretches for over 1 850 km. Being an extremely fragmented territory, the Philippines have one of the longest shorelines in the world, adding up to 235 973 km (HDN, 2013). This island group is surrounded by four tropical seas: the Philippine Sea to the east, the South China to the west and north, the Sulu Sea to the southwest and the Celebes Sea to the south (DLIFLC, 2011). Only 1 000 islands are populated and less than one half of those are larger than 2.5 km². In fact, the 11 largest islands make up 94% of the country's landmass. As stated by Wernstedt and Spencer (1967), this "physiographic diversity supplies one of the important basic ingredients in the development of significant regionalism within the Philippine Islands".

Despite its relatively small area, the Philippines have a considerable variety of landscapes. Most of the islands of the Philippines include a mountainous core to their island topography and, although uplands occur in almost 65% of its area, there are also extensive lowlands, particularly on the larger islands. Volcanic, sedimentary and metamorphic rock materials have contributed to the islands development on its different stages – in addition, rock weathering and land dissection are very rapid given the local climate. The central longitudinal section of the Philippines, extending from Luzon southward to Leyte and Mindanao constitutes a tectonic province, being an area of considerable seismic and volcanic activity. In combination, these two processes have created a varied topographic landscape characterized by sharp contrasts (Figure 2.4). Hundreds of volcanoes dot the Philippines, but only 22 are active nowadays (Wernstedt & Spencer, 1967). The Filipino islands mountainous interiors and narrow coasts evidence their volcanic origin and larger islands contain an array of hills, plateaus and plains, which, in a varying combination, make up the landforms of the country (HDN, 2013). Being part of the Eastern Visayas region (Region VIII), Leyte is a very irregularly shaped island, with deep embayments along its coast – this dissertation chosen case study, the city of Tacloban, is located on the northeastern coast of Leyte island.

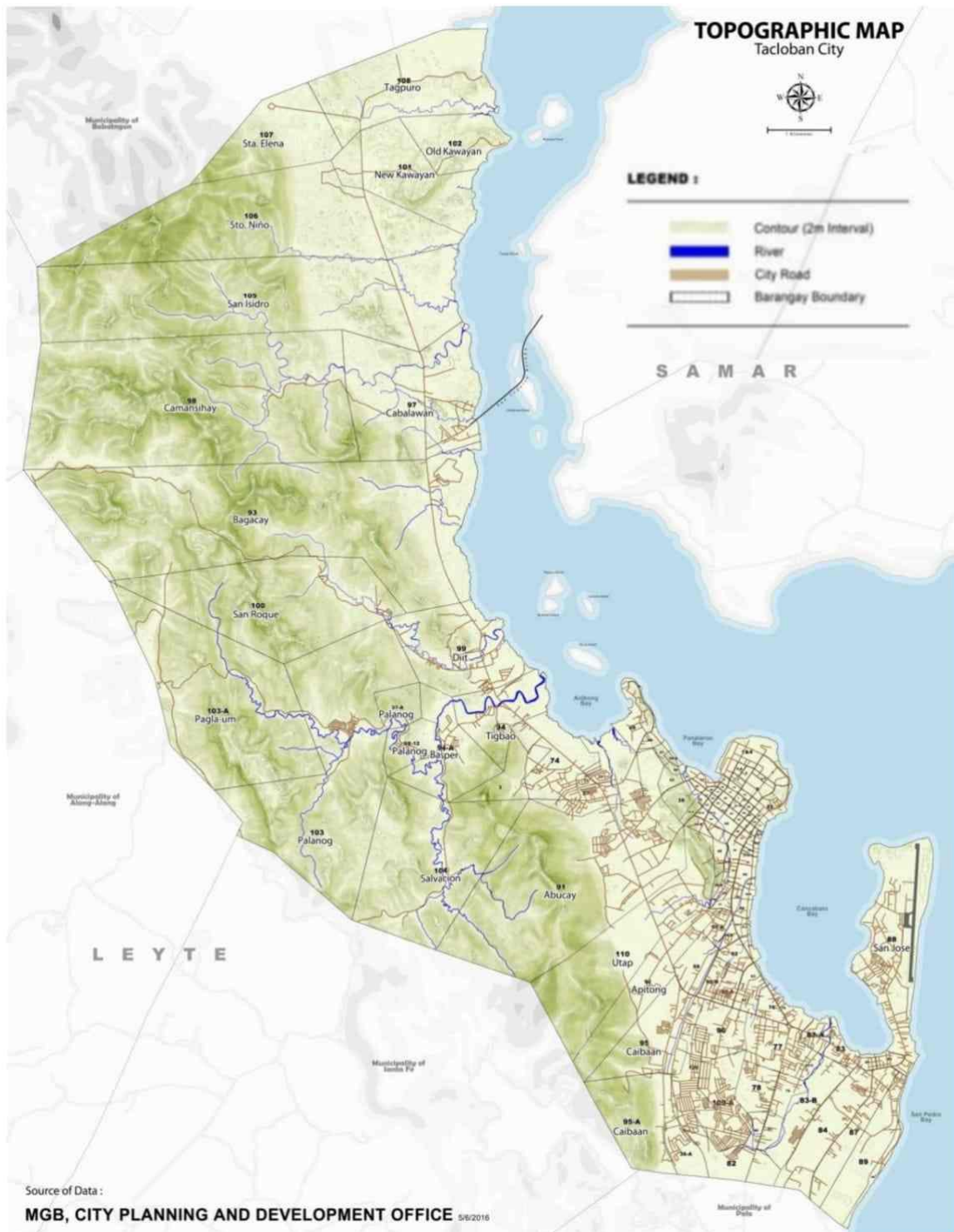


Figure 2.4 - Topographic map (City Government of Tacloban, 2018)

This island basic physiographic features are formed by three mountain ranges, aligned approximately in parallel and separated by lowlands. The northeastern highlands (Mount Naga-Naga, including Bagahupi Peak, Bubunao and Garang), which border the San Juanico Strait near to the city of Tacloban, reach above 450 meters. Together with this Naga-Naga range (on the western vicinity of the city), Sta Elena range (on the northern part) isolates Tacloban from the neighboring municipalities of Palo, Sta. Fe, Alang-Alang, San Miguel and Babatngon (USAID, 2015). Tacloban City proper has a mean elevation of only 3.05 meters above the sea level (City Government of Tacloban, 2018).

Soils and geology

Leyte is inferred to be a product of magmatic and tectonic actions, generated by the under-thrusted Philippine Sea Plate. The Leyte Valley (rich in alluvium matter) stretching from the northeastern and central highlands of the island (including Mount Cancajanag, Alto Peak and Mount Pina) represents a continuation of the large basin below the Samar Sea and Leyte Gulf (Wernstedt & Spencer, 1967). Two minor faults have been identified, located to the western and northern parts of the city, which are thought to be inactive, although no actual studies to date were found regarding the nature of these geological structures (USAID, 2015).

Tacloban vicinity has four distinctive rock formation units: the Quaternary Alluvium; the Turbidite; the San Ricardo Formation and the Tacloban Ophiolite – the latter represented by the long stretch of small mountains west of Tacloban. On its turn, the Quaternary Alluvium is composed by recent soil deposits and sands, which can be loose or compacted, found mostly along coastal plains and surrounding the existing water bodies. This whole area is a deposit of mineral resources, both metallic (mostly copper and iron) and non-metallic (red-burning clay). In fact, the typical soils in Tacloban are clay-textured (which comes as a relevant fact to understand the water retention capability of the local soils (see Figure 2.5). Tacloban clay series, found in the mountains around the city, are moderately deep, fine clayey soils. The Naga-Naga series are poorly drained, formed by recent alluvial soils found on the level areas just above the swamps. In its turn, the Caibaan series, found on the medium plain before the

more sloped areas, are characteristically very deep and poorly drained fine clayey soils. The Pawing Clay, a brown to dark-brown very friable sandy loam, has a substratum below consisting of stratified layers of silt loam, sandy loam, loamy sand and sand. Finally, the Sta. Elena series are made of deep and poorly drained soils, which can be found on the region's piedmont landscape, and commonly has high concentrations of decomposed organic matter (City Government of Tacloban, 2018; USAID, 2015).

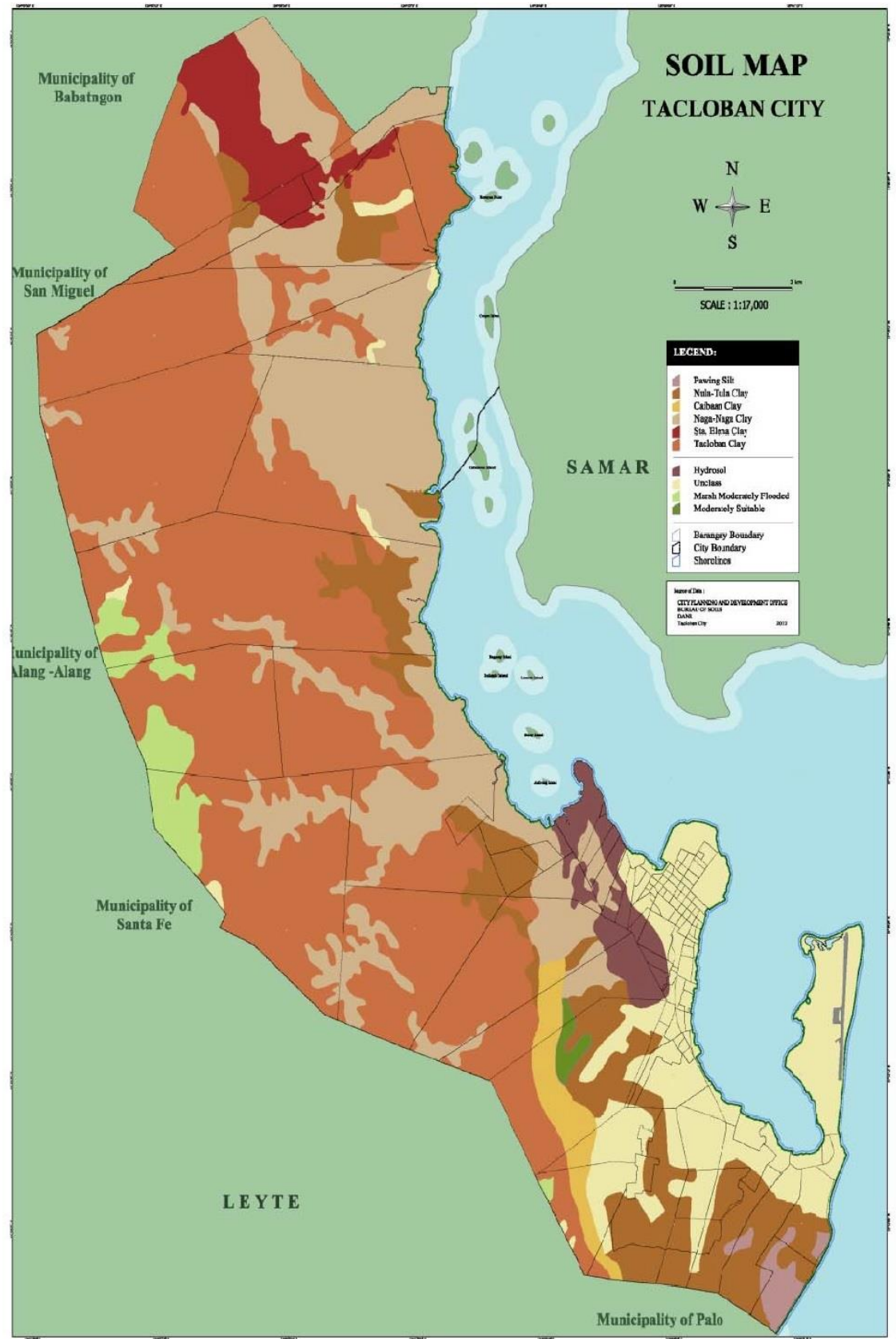


Figure 2.5 - Soil map of Tacloban municipality (USAID, 2015)

Land use and territory

At 110° 14'36" North and about 125° East (circa 580 km southeast of Manila), Tacloban's city territorial jurisdiction spreads from the mountainous ridge to the marine reefs.

After typhoon Haiyan devastation, Tacloban City's Comprehensive Land Use Plan (CLUP) for 2013-2022, which had been up for approval before the catastrophe, was considered inadequate to the real development needs and recovery processes of the city (Santos, et al., 2016). Therefore, a new CLUP for the time period of 2017-2025 was developed, taking into account Climate Change Adaptation practices and Disaster Risk Reduction and Management. This plan was endorsed by the Regional Land Use Committee on April 20th, 2017 and is often mentioned as the reference of the sectoral developments of the city and as "the essential guide for resiliency practices, recovery and redevelopment attuned to climate change and environmental protection and conservation". In fact, the concept of resilience assumes great importance throughout this document, hence the vision established for the city in 2017-2025 is written as "a globally competitive, resilient, green city" (City Government of Tacloban, 2018).

The 2017-2025 CLUP is, therefore, "a climate and disaster risk resilient plan utilizing as reference (...) the Climate Change Act of 2009 (RA9729) and the Philippine Disaster Risk Reduction Management Act of 2010 (RA10121) as a tool to a hazard-free land use plan" (City Government of Tacloban, 2018). As pointed out by Santos et al. (2016), the lessons learned from Haiyan regarding CCA and DRRM should be reflected on CLUPs nationwide, and not only on Haiyan-affected areas, so as to improve climate change resilience at a local level. According to the City Planning Office personal interviewed on January 2018, the latter was expected to be finally approved on May of the same year and implemented afterwards.

As observed on Figure 2.6, this new CLUP proposes the decrease of residential areas, downtown, and an increase of socialized housing on Tacloban North resettlement areas (because of super typhoon Haiyan aftermath, as explained forwardly). Therefore, the new Land Use Plan highlights the urbanization of over 3 000 hectares of higher ground terrain, supposedly safe from coastal flooding – a measure to prevent the loss of lives and the

destruction of the city in the eventuality of a new typhoon. In terms of economic activities, agriculture, commerce and tourism are privileged over light industry, which is almost completely excluded from the municipality. However, a concerning factor of this new land use classification, as evidenced on Table 2.1 and Figure 2.6, is also the continuity in forest protection and production areas, which can play a determinant role as buffer areas when facing extreme weather events.

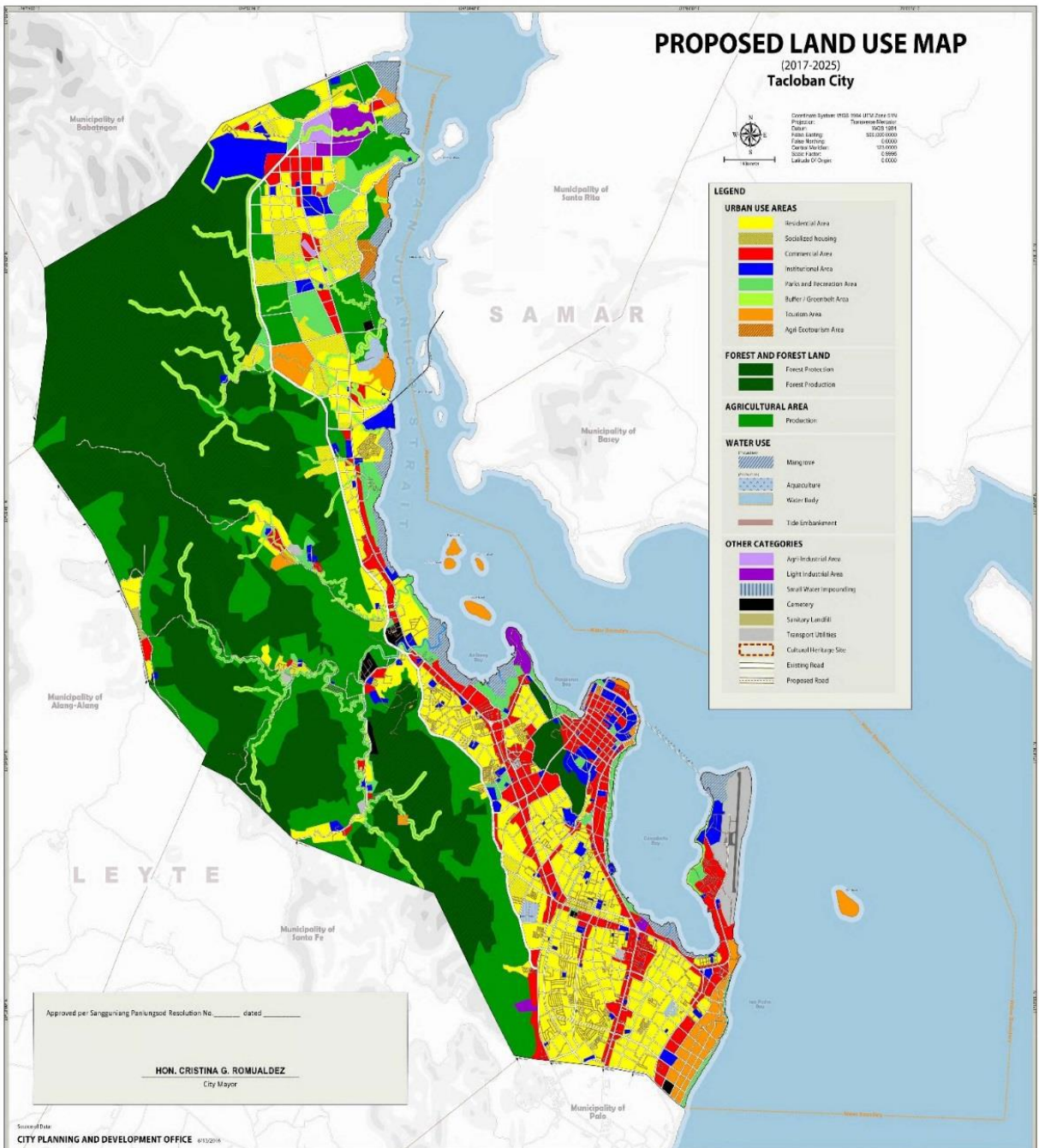


Figure 2.6 - Tacloban municipality proposed land use map (2017-2025) (City Government of Tacloban, 2016)

Table 2.1 - Land classification matrix of Tacloban City (City Government of Tacloban, 2018)

Land Use	Existing Land Use (ha)	Proposed Land Use 2017-2025 (ha)	Status (ha)
Urban Use Areas			
Residential Area	2 405.50	1 400.00	-1 005.50
Socialized Housing Area		253.52	+253.52
Commercial	505.30	779.40	+274.10
Institutional	138.98	324.86	+185.88
Special Institution	22.51	22.51	-
Parks	38.98	337.90	+298.92
Tourism Area	72.18	212.82	+140.64
Buffer Area	373.41	409.35	+35.94
Forest and Forest Land			
Protection Forest	1 993.43	1 993.43	-
Production Forest	1 910.11	1 910.11	-
Industrial Tree Plantation		81.99	+81.99
Agricultural Area			
Agricultural	1 881.03	1 598.92	-282.11
Water Use			
Rivers	67.03	67.03	-
Mangroves	190.54	190.54	-
Aquaculture	17.63	17.63	-
Water Impounding		15.04	+15.04
Cancabato Marine Protection	562.76	181.17	-381.59
Dio Fish Sanctuary	50.00	50.00	-
San Juanico Mariculture Area	1 023.85	1 023.85	-
San Pedro Bay	8 023.51	8 023.51	-
Other Categories			
Agri-Industrial	179.37	27.72	-151.65
Light-Industrial	74.90	74.92	-
Cemeteries	20.00	29.67	+9.67
Sanitary Landfill	4.00	5.00	+1.00
Utilities	102.08	125.07	+22.99
Roads	514.85	980.50	+465.65
Greenbelt Infrastructure Zone	-	26.27	+26.27
Tide Embankment	-	3.82	+3.82
Proposed Bridge	-	5.46	+5.46
TOTAL	20 172.00	20 172.00	-

Climate

The Philippines have a tropical maritime climate, characterized by continuous heat and high humidity, due to its proximity to the equator (DLIFLC, 2011). However, there is a multitude of significant variations, as the high temperatures, typical of tropical lowlands, are not encountered in the islands highlands. This variability is derived from the latitude, the variations in sunshine received (consequent of cloud cover rates), continental effects (especially in the North) and exposure to northeast and southwest monsoonal air masses (Gultiano, et al., 2003). Moreover, the distribution of the precipitation is also very heterogeneous, both in quantity and seasonality – and these variations are sufficient to justify the regional variety existent in the islands sensible climate, natural vegetation and possible crops to be cultivated (Wernstedt & Spencer, 1967).

Thus, four different regional climates can be distinguished in the archipelago, according to the Corona classification. The Corona classification of climate is based on the monthly rainfall received during the year: a region is considered to have Type I climate if there is a distinct wet season (from June to November) and a dry season (December to May); Type II climate is assumed when there is no dry period during the year, with a more pronounced wet season from November to February; on Type III a short dry season exists, usually from February to April; and finally, a region with Type IV climate has its rainfall almost evenly distributed during the whole year (PAGASA, 2011). Table 2.2 schematizes this classification climate types.

Table 2.2 - Corona Climate Classification

Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
I	Dry season					Wet season						Dry
II	Wetter season		Wet season								Wetter season	
III	Wet	Dry season			Wet season							
IV	(No seasons, evenly distributed rainfall)											

As one can observe from Figure 2.7, these four categories distribution within the Filipino archipelago is approximately vertical, with Type I climate being found mostly on the eastern coast of eastern islands (Luzon and Palawan mostly) and Type II on the western boundary of the archipelago. Regarding Types III and IV, these are found in the central region of the archipelago on northern and southern islands, respectively.

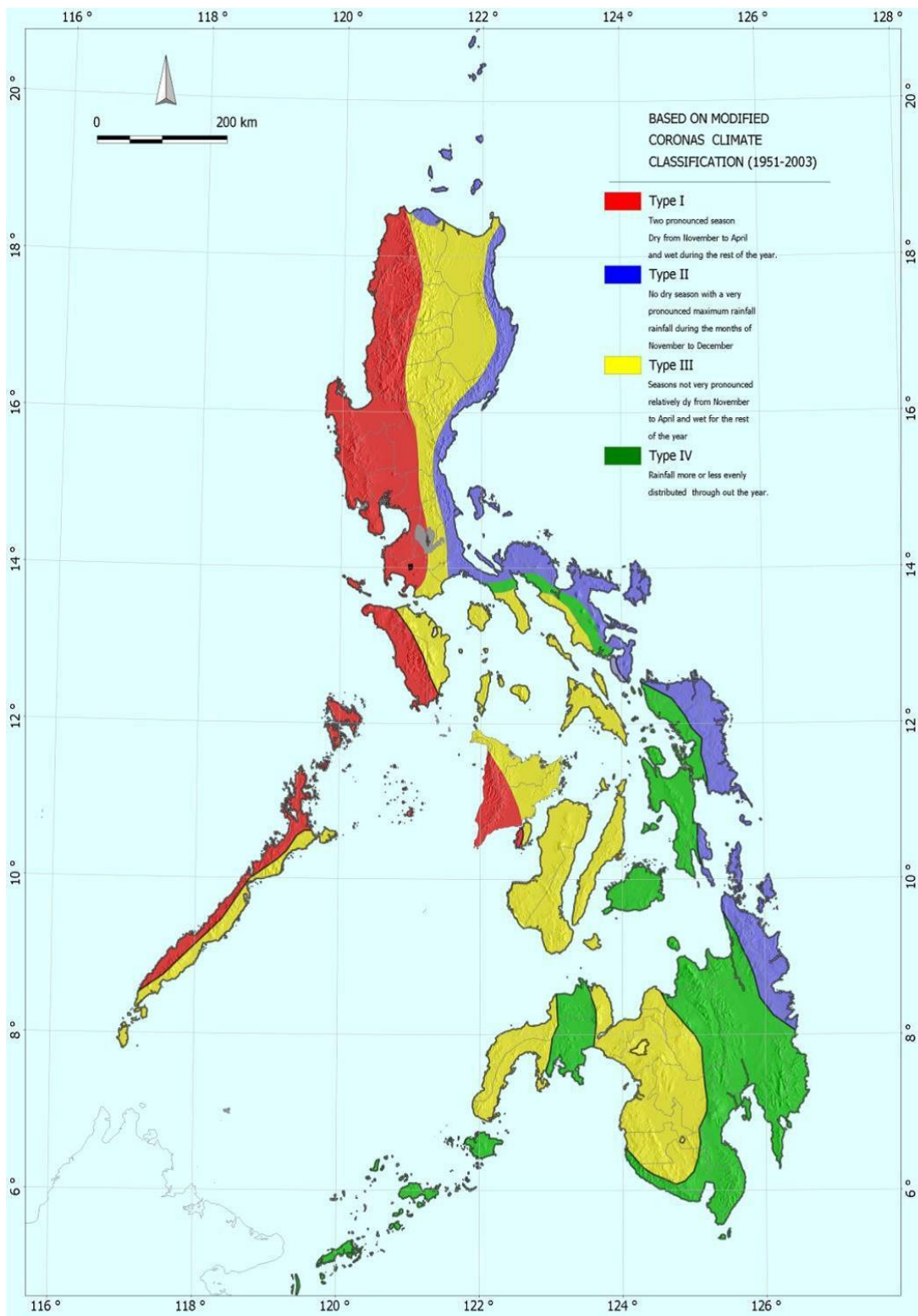


Figure 2.7 - Climate map of the Philippines (PAGASA, 2011)

Temperatures in the Philippines rarely rise above 37°C and are often lower in mountainous regions. Latitude plays, therefore, a negligible effect in the variation of annual temperatures, whilst, on the other hand, the size of individual islands and the collective effect of their combined insular area affect temperature variations more than latitude – for example, temperatures in central Luzon and Mindanao are up to two degrees higher than on the coast of these islands, evidencing a slight continental modification. Moreover, slightly warmer temperatures are found on the islands of Sibuyan Sea, on the central part of the archipelago, as these are surrounded by other islands (Wernstedt & Spencer, 1967).

In Tacloban, the mean annual temperatures round 27.2°C and do not rise above 31.5°C nor decrease below 22°C. Figure 2.8 shows the annual variation of the maximum and minimum temperatures for Tacloban City, based on the latest Climatological Normals, published by PAGASA.

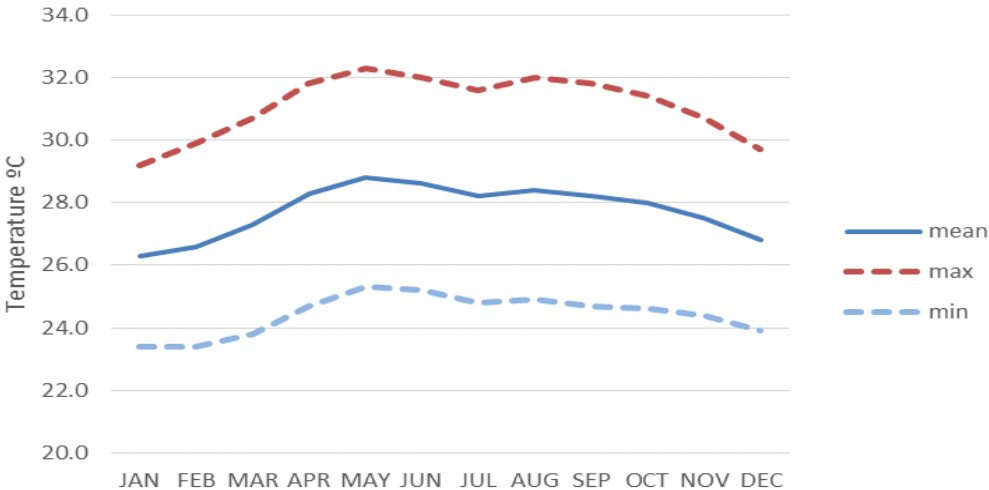


Figure 2.8 – Climatological Normals (1981-2010) mean temperatures for Tacloban City (PAGASA, 2016)

Rainfall is the single most important climatic element in the tropical regions, as it can be highly variable in distribution, intensity and duration. The seasonality of rainfall in the Philippines ranges from stations receiving summer maximums, to those experiencing winter maximums and those with no difference between seasons (Wernstedt & Spencer, 1967). Annual rainfall adds up to 5 000 mm in the mountainous east coast of the country and between 2 000 mm to 5 000 mm in most localities. Exceptionally, in some inland valleys and

sheltered areas, annual rainfall is only of 1 000 mm (Gultiano, et al., 2003). This variety in precipitation results from different reasons: orographic factors, local and frontal convections or even frontal rains associated with the Intertropical Front, easterly waves or tropical cyclones – with the most predominant causes being the Intertropical Front or the passage of tropical storms. The Intertropical Front, or Intercontinental Convergence Zone (ITC), is the zone of convergence of air masses from the northern and southern hemispheres, from which results heavy rainfall (particularly when and where the front stagnates). In January, the ITC is situated south of the equator near Java, Indonesia, south of the Philippines, so north and northeast air flows across the Philippines are set in motion, bringing North Pacific and Northeast Monsoon air masses into the area. On its turn, in July, the ITC is established north of the archipelago, causing the southern air masses to flow across it (Indian Ocean and South Pacific air masses) (Wernstedt & Spencer, 1967). The precipitation in the archipelago is also severely vulnerable to the El Niño and La Niña events, with the most severe droughts being registered during the latter (Gultiano, et al., 2003).

In Tacloban, rainfall is unevenly distributed within the year. According to what has been previously described, the climate in Tacloban can resemble a Type II climate - although some authors classify it as a Type IV - with no dry season and a period of more intense rainfall from November to February and the maximum rainfall being often reached on the month of December (according to the Climatological Normals for 1981-2010 consulted) (Figure 2.9).

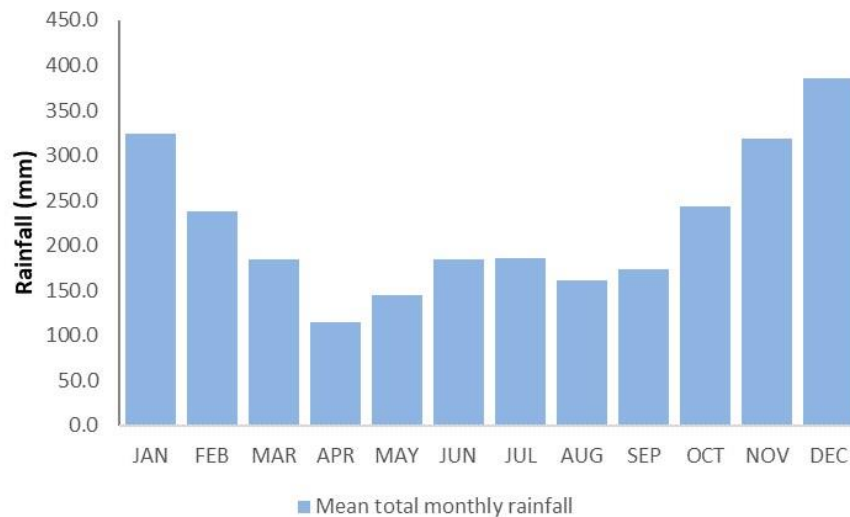


Figure 2.9 – Climatological normal (1981-2010) mean rainfall for Tacloban City (PAGASA, 2016)

Concerning **extreme weather events**, the archipelago of the Philippines coincides with the typhoon belt, with the most severe storms crossing the archipelago from July to October (Gultiano, et al., 2003) and circa 20 typhoons occurring per year, with five to six of which being potentially destructive. In the central islands, however, typhoons are more frequent from October to December, striking Samar and Leyte with the greatest frequency and severity (Wernstedt & Spencer, 1967) – whilst Mindanao is generally free from risk (Gultiano, et al., 2003). In fact, within the Visayas, the eastern sub-region is the least populated and least developed one because it is front-line on the typhoon routes, functioning as a weather buffer for the western and central islands - partially explaining their more developed economies (DLIFLC, 2011).

Tacloban resides on the 100 years return period of the Saffir Simpson Category 4, and in the 250 years return period of a Category 5 typhoon. Thus, statistically speaking, a storm as big as Haiyan is expected on the next 250 years (although the calculated speeds for Eastern Leyte seem to suggest a return period of 200 years only) (GIZ, 2014), not excluding the fact that climate change may significantly shorten these return periods. As a matter of fact, as pointed out by the LGU members on the interviews held in the city hall in March 2016, before Haiyan they expected a big typhoon every 18 years, but now they cannot rely on those numbers. An evidence of this was the passage of typhoon Ruby (called *Hagupit* by the

Filipinos) in December 2014, which, although less destructive than Haiyan, was also a Category 5 typhoon.

Climate change

The Republic of the Philippines is one of the most vulnerable territories to climate change impacts, given its geographic location in the Tropical Pacific, archipelagic formation and population distribution. Recently, this country was ranked highest in the world in terms of vulnerability to cyclone occurrence, and third in terms of people exposed to seasonal events (Climate Change Commission, 2012).

This nation has already experienced noticeable adverse effects in recent years, with the observed changes in its climate in most recent times having never been seen in the past 140 years. Climate trends evaluated for the 1951-2009 period (using as reference data from 1971-2000) revealed an increase in the annual mean temperature by 0.65°C, with an increase of 0.36°C and 0.1°C in terms of maximum and minimum temperatures, respectively. The trends of rainfall (extreme rainfall intensity and frequency) are not so clear, with very little spatial coherence, varying between islands and regions (i.e., in some increasing, whilst decreasing in others). Furthermore, for the referred period there has been observed a slightly superior number of tropical cyclones, although there is still no solid evidence of an increase in their frequency (PAGASA, 2011). In fact, the IPCC claims to have low confidence in the attribution of anthropogenic climate change to changes in tropical cyclone activity (IPCC, 2012). However, recent existing literature seems to corroborate the idea that, although there will be less tropical cyclones worldwide, they will likely be more intense and with higher levels of rainfall, due to the effects of global warming (Santos, 2018).

Official climate projections in the Philippines were obtained by PAGASA, parting from UK's Met Office Hadley Center for Climate Prediction and Research's RCM named PRECIS - *Providing Regional Climates for Impact Studies*. This RCM aimed at facilitating impact, vulnerability and adaptation assessments in developing countries where capacities to develop such studies are often limited. Three emission scenarios were considered, namely

the A2 (high-range emission scenario), the A1B (medium-range emission scenario) and B2 (low-range emission scenario). The high-range scenario corresponds to the 'business as usual' emissions, considering a continuously growing population and a regionally-oriented economic development (although with heterogeneous per capita growth and technological updates). In its turn, the med-range emission scenario, despite assuming also a very rapid economic growth, considers a peak in the world population growth in the mid-century and a decline afterwards. Additionally, it assumes a rapid dissemination of new and more efficient technologies, with energy generation balanced across all sources. Finally, the low-range emissions scenario contrasts with the aforementioned scenarios by assuming a world with local solutions to economic, social and environmental sustainability, with a continuously increasing population (although at a lower rate than for the previous scenarios), intermediate levels of economic development, and a less rapid technological shift (but oriented by environmental protection and social equity principles) (PAGASA, 2011).

The downscaling of global projections to the Philippines was performed using a grid resolution of 25 per 25 km, thus allowing more detailed regional information of the projected parameters. The boundary data used was extracted from the ECHAM4 (the 4th generation coupled ocean-atmosphere general GCM, which uses a comprehensive parameterization package developed at the Max Planck Institute for Meteorology in Hamburg, Germany) and HAdCM3Q0 models. Two periods were considered: 2006-2035 and 2036-2065, abbreviated to 2020 and 2050 for practical reasons, following their mean years. Overall, for future climate scenarios (thus for 2020 and 2050), considering the atmospheric resilience of greenhouse gases already emitted, PAGASA states that all areas of the country will get even warmer, with more severe temperature increases in the already warmer months. Annual mean temperatures are expected to rise by 0.9°C to 1.1°C in 2020 and by 1.8°C to 2.2°C in 2050. Regarding the seasonal rainfall changes, projections point out that dry seasons are expected to become drier and wet seasons wetter, and thus there is the likelihood of occurrence of both floods and droughts. However, spatial variability still plays a relevant role in future projections, and different regions will suffer different impacts.

Concerning the Visayas, large increases in rainfall are expected (of 2% to 22%), especially during the southwest monsoon season (in June, July and August). Heavy rainfall events

(exceeding 300 mm) in 2020 and 2050 will continue to become more frequent. In 2020, rainfall in Leyte is expected to increase in all seasons except in March to April months, where a decrease of 8.9% is expected. This situation may worsen to less 18.9% rainfall in 2050. For this same period, temperature increases are expected to be the highest (+1.2% in 2020 and +2.3% in 2050), which may worsen the situations of water scarcity for its various uses in Leyte – and most probably affecting the quantity and the quality of the water supply service in Tacloban City. Overall, on an annual basis, regional projections for Provinces in Region 8 (which include the island of Leyte and its close neighbor Samar) show a temperature increase in 2020 which is also aggravated in the long-term scenario (PAGASA, 2011). These projections are summarized in Table 2.3.

Table 2.3 - Seasonal temperature increases (°C) and rainfall variation (%) in 2020 and 2050 under medium-range emission scenario for Leyte, Region 8 (adapted) (PAGASA, 2011)

Scenario/ Trimester	Temperature Projections			Rainfall Projections		
	Baseline (°C)	2020 (°C)	2050 (°C)	Baseline (mm)	2020 (%)	2050 (%)
DJF	24.6	+0.9	+1.8	689.5	+3.0	+9.4
MAM	27.8	+1.2	+2.3	342	-8.9	-18.9
JJA	28	+1.1	+2.2	568.7	+9.5	+19.6
SON	27.7	+1.0	+1.9	725.5	+7.4	+19.5

In 2009, the National Government gave the first steps to fight CC by implementing the Millennium Development Goals Fund (MDGF) through a joint program called *Strengthening the Philippines' Institutional Capacity to Adapt to Climate Change*. This three-year program was funded by the Government of Spain and some agencies within the United Nations (UNDP, UNEP, FAO, UN Habitat and others). Within this period, the objective was to have “climate risk reduction mainstreamed into key national and selected local development plans and processes, (...) [enhancing] national and local capability to develop, manage and administer projects addressing climate change risks and coping with mechanisms improved through pilot adaptation projects” (PAGASA, 2011). The Philippines Government Republic Act nr 9727, from July 27th, 2009, (otherwise known as the *Climate Change Act*), has then established the organizational structure of the Climate Change Commission (CCC). This

entity, responsible for addressing climate change issues on the country, has translated the national CC framework strategy to create the *National Climate Change Action Plan: 2011-2028* (NCCAP). The NCCAP prioritizes “food security, water sufficiency, ecosystem and environmental stability, human security, climate-smart industries and services, sustainable energy and capacity development as the strategic direction for 2011 to 2018” (Climate Change Commission, 2012). Particularly, the water sufficiency chapter (The Action Plan, Chapter II, pp.11), defined as a national strategic priority, includes “assessing the resilience of major water resources and infrastructures” – an interesting choice of words considering the objectives of this dissertation, as it applies the term resilience to the water resources themselves and not solely to the water supply system infrastructures. These objectives were to be achieved through vulnerability and risk analysis and the formulation of a roadmap for climate-proofing critical infrastructures. Under the same strategic topic, it is enhanced the importance of conducting a water supply-demand analysis for various hydrologic conditions and scenarios (again, a topic to which the hydrological modeling developed in this dissertation makes a significant contribution), as well as the review and adaptation of existing and new systems, by 2016 - hence, providing an adequate framework for this dissertation.

Water resources

Given its geography and location, the Philippines have abundant freshwater resources obtained from rainfall, groundwater and surface water - there is a total of 421 rivers, over 60 lakes and 100 000 ha of freshwater swamps in the archipelago (Wernstedt & Spencer, 1967). In the whole country, the total dependable surface supply from rivers, lakes and reservoirs is estimated at 125.8 billion m³, whilst the groundwater potential is solely of 20.2 billion m³. At least theoretically, the Philippines should have no problems of water scarcity, but due to the geographical and seasonal variations of rainfall, water scarcity is felt in some regions of the country. Moreover, some regions are affected also by water quality issues due to untreated domestic and industrial effluents, agricultural and urban run-offs and saltwater intrusion on coastal aquifers (Climate Change Commission, 2012).

In Leyte, no major river basins of national importance are usually considered. However, Leyte is an island with considerable availability of water, in the form of rivers, lakes and aquifers. Lake Danao, located in the municipality of Ormoc, covers an area of 148 ha. The

area has poor aquifer yielding characteristics (ADB, 2010), with no literature found regarding groundwater resources in Tacloban vicinity. In downtown Tacloban City there are four main drainage basins, located at *barangays* Abucay, Mangonbangon, Tanghas-Lirang and Burayan. These waterways flow towards the northern alluvial plains of the city. In the northern part of the municipality, other rivers drain the hilly mountains to the northwest, to San Juanico Strait and Anibong Bay – such as the streams found in *barangays* Camansihay, Bagacay, Cabalawan, Sto Niño, San Roque and Tigbao (USAID, 2015). The city’s major rivers are the Abucay, Mangonbangon and Burayan, which are classified as urban drainage channels and are severely polluted (Figure 2.10) – which was expected hence Tacloban City lacks a sewage collection and treatment system. Thus, no possible water sources are present within the Tacloban city boundaries due to these waterways reduced flow and poor water quality.



Figure 2.10 - Heavily polluted drainage channel in Tacloban City (Personal archive, March 2016)

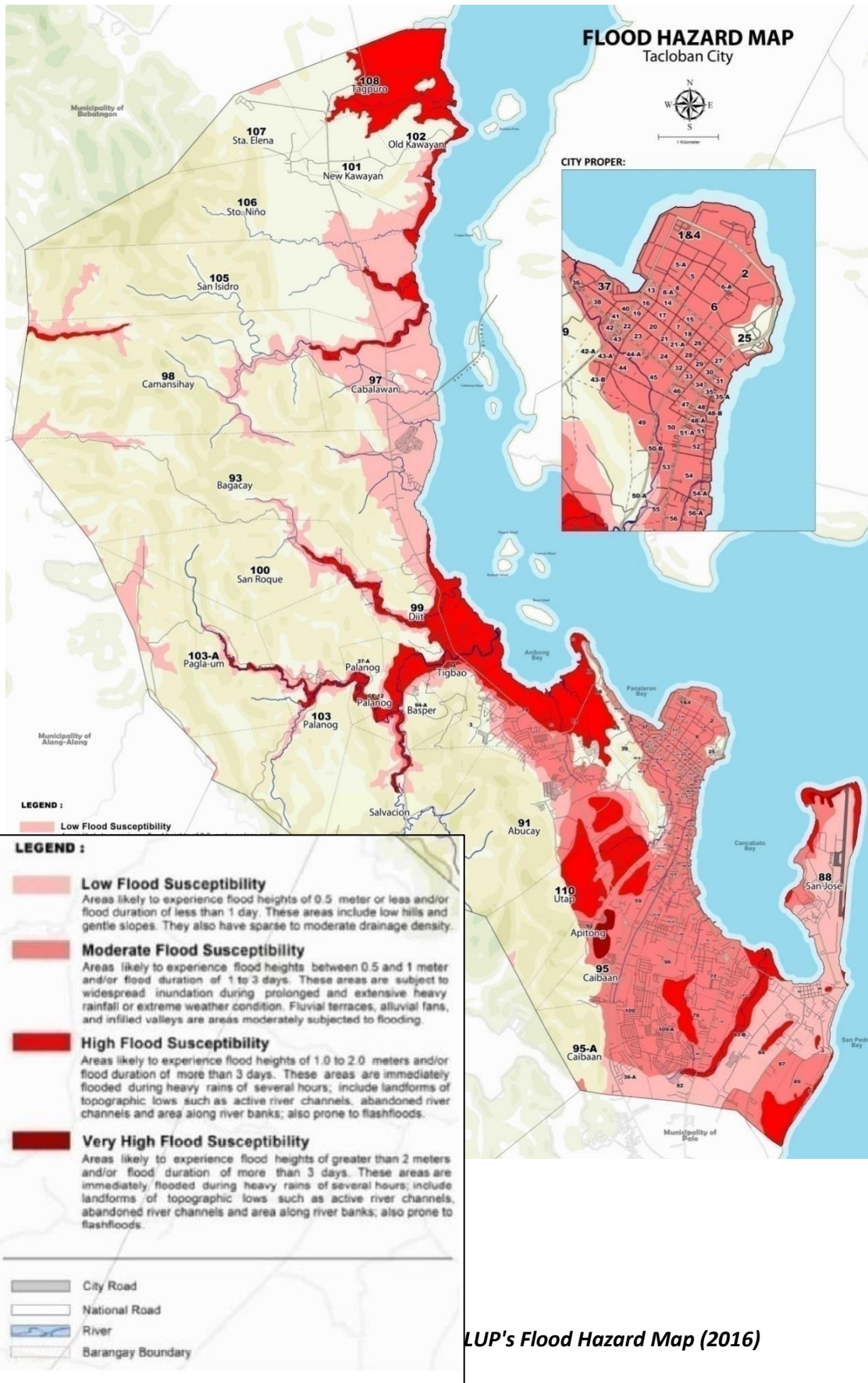
Risk and disaster risk reduction

In the social impact assessment performed after super typhoon Haiyan, it was stressed that the Philippines is the only country in the world where the number of lives lost due to natural disasters has increased in recent years (NDRRMC, 2014a). Within the country, Tacloban is one of the most vulnerable cities and it is believed that the calamity provoked by Haiyan may have contributed significantly for these statistics. In Tacloban, therefore, the revised

CLUP seeks to include CCA and DRR principles, so as to “reduce the exposure and vulnerability of population, people, infrastructure, economic activities and the environment to natural hazards” (City Government of Tacloban, 2018). This document considers as potential hazards to affect the city: landslides (earthquake and rainfall induced), flooding, ground shaking, storm surge, soil liquefaction and tsunamis. Moreover, while *barangays* differ in risks to hazards, all 138 *barangays* of the City present some sort of vulnerability to typhoons. Overall, northern *barangays* are more vulnerable to rain induced landslides, while flooding is more likely to affect the city proper and low-lying *barangays*. Likewise, hazards risk maps were developed and the zoning ordinance of the CLUP is coherent with them, so as to avoid residential areas on the risky locations.

Figure 2.11 and Figure 2.12 depict the CLUP’s risk maps for flooding and storm surge hazards, respectively. On the latter, is evident the prominent risk of storm surge in the Anibong bay area where Haiyan’s surge has caused most casualties. It was, among other reasons explained forwardly, based on these risk maps that the relocation areas for Haiyan’s victims were chosen on high lying northern territories.

However, a full assurance that the residential areas are risk free is a utopic goal to achieve. This was proven by the big flooding that occurred in northern Tacloban in December 2017. The affected families were residents of the permanent shelters, in Nula-Tula area and their houses were flooded by the rise of local small waterways level (once again, due to the inefficient/inexistent storm water drainage system all over Tacloban). Regarding the rise of the sea level in San Juanico Strait, in 2017 was initiated the construction of a tide embankment that would spread from Palo towards the southern limit of the city of Tacloban (although it would not protect the city proper). Despite being conceived as a solution against future devastating storm surges such as Haiyan’s, members of Tacloban City LGU, interviewed in January 2018, feared that this solution would in fact create a false sense of security amongst coastal residents that would still rebuild their houses in the coastline.



LUP's Flood Hazard Map (2016)

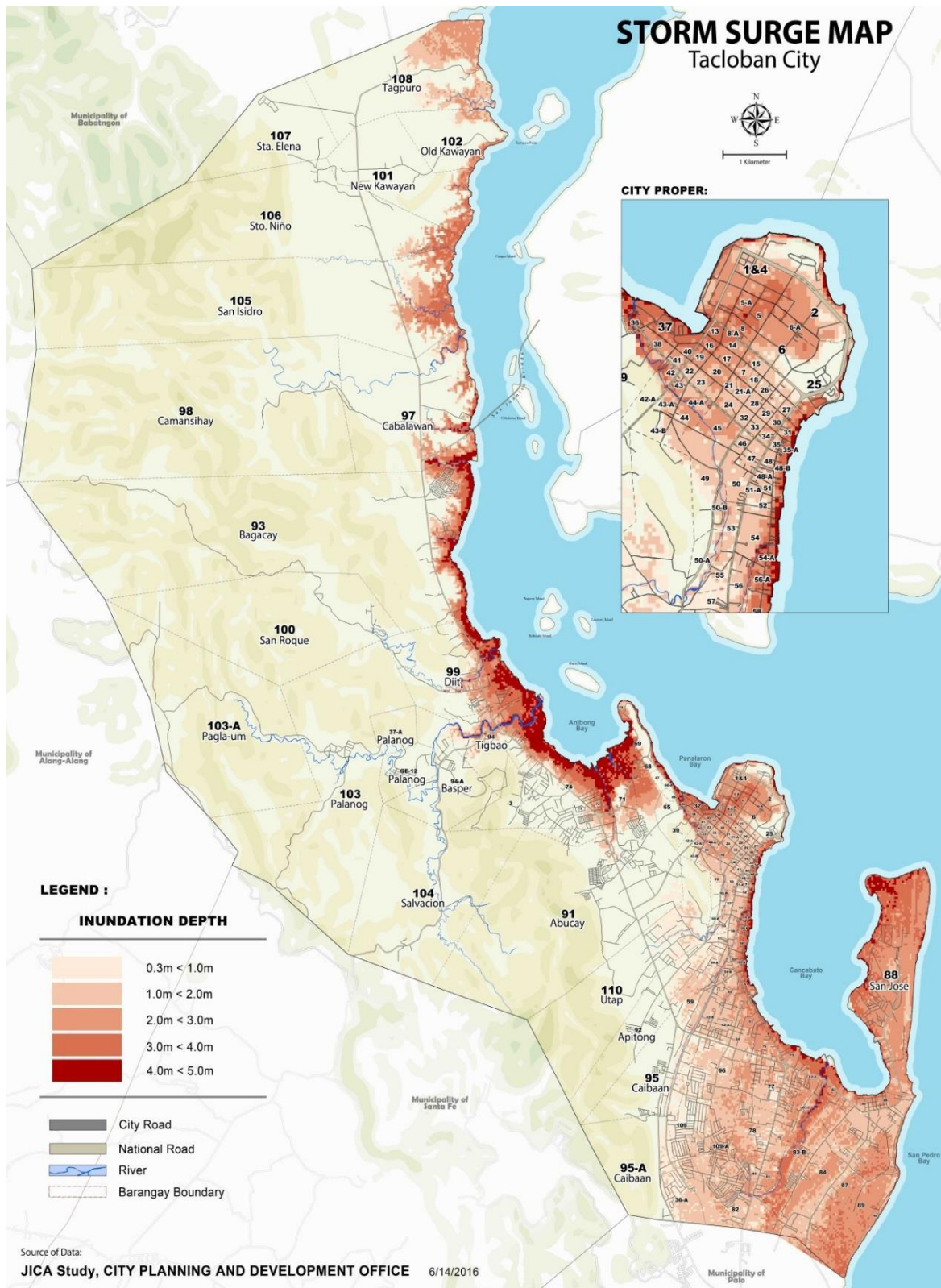


Figure 2.12 - Tacloban City's CLUP Storm Surge Hazard Map (2016)

2.4. Socio-demographic characterization

Demographics

Based on the 2015 Census of Population and Housing (CPH), as of August 2015, Tacloban City registered a total population of 242 089 residents - which represented 12.3% of the total population of Leyte (of 1 966 768 total residents), 5.45% of the residents of Region VIII (440 150 residents) and only 0.24% of the national total (100 981 437 residents).

From the previous census (2010), the city's population has increased of 20 915 persons, corresponding to an increase rate of 1.73%. If the population of Tacloban continues to increase at this rate, it is expected to double in 2055 (PSA, 2017a). However, this rate was lower than the one registered for the 2000-2015 period, of 2.01% indicating that the city's demographic growth has slightly decreased over the last decade. Despite of this, Tacloban is markedly one of the fastest growing cities in the country, which posted a national Population Growth Rate (PGR) of 1.84% for 2000-2015 (PSA, 2013; POPCEN, 2015). The country's average annual population growth rate is expected to decrease to 1.64% in 2015-2020, to 1.46% in 2020-2025 and to 1.27% in 2025-2030, according to most recent projections (PSA, 2017b). Table 2.4 shows the Tacloban's total population evolution since 1970.

Table 2.4 - Tacloban's Total Population 1970-2010 (POPCEN, 2015)

Decennial Census	Total Population (thousand people)
1970	76.5
1980	102.5
1990	136.9
2000	178.6
2010	221.2
2015	242.1

It should be noted that these numbers correspond only to the resident population of Tacloban City, as the 56th largest city of the country and the only categorized highly urbanized city in Region VIII. Nevertheless, considering its economic and strategic

importance for the region (i.e. the number of services and jobs), the daytime population can reach 1 million people, according to the LGU members interviewed in March 2016. In 2015, Tacloban had a population density of 1 200 habitants per square kilometer, which was significantly lower than the density of Manila, the country capital and one of the most densely populated cities in the world, with over 71 thousand people per square kilometer. Amongst the city’s 138 *barangays*, as of 2010, *Barangay* 91 was the most populated one, making up to 3.87% of the city’s population (with 9 361 residents), followed by *Barangays* 74 and 109-A (with 8 518 and 8 206 residents, respectively). The fastest growing *barangays* in Tacloban were *Brgy.* 106 (St. Niño), with a PGR of 35%, followed by *Brgy.* 101 (New Kawayan) and *Brgy.* 108 (Tagpuro), with PGRs of 24.5% and 12.7%, respectively. These *barangays* correspond to the northern Tacloban relocation areas, where Haiyan affected families have been given new permanent housing (PSA, 2017a; POPCEN, 2015).

Following the trend of most Asian developing countries, Tacloban has a very young population (Figure 2.13), with the median age being of only 22.6 years old (for 2015). However, this is already higher than the value for 2000, which was of 20.7 years, although lower than 2010’s of 22.7 years. This decrease in the number of young Taclobanons was also evident in the evolution of the dimension of the average household, which decreased from 5.1 persons, in 2000, to 4.8 persons in 2010 (a number that was sustained in 2015) (PSA, 2017a; POPCEN, 2015).

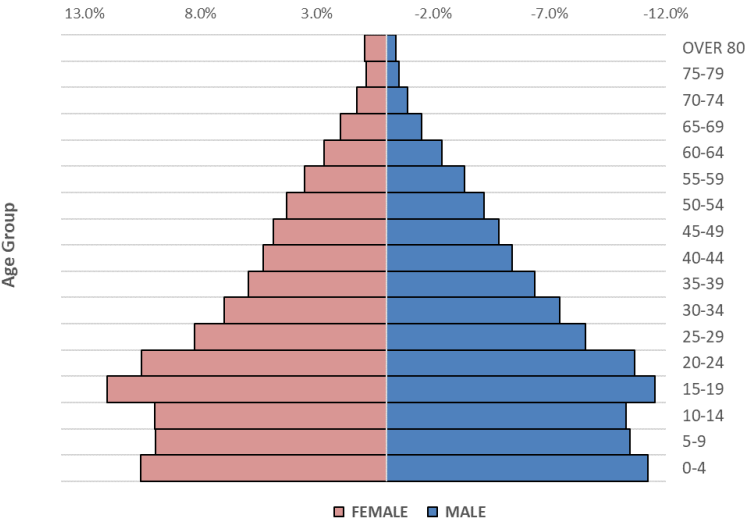


Figure 2.13- Population pyramid of Tacloban, 2015 (POPCEN, 2015)

Regarding Taclobanons education, accordingly to the age distribution presented 20.3% are still attending elementary school, 15% are in high school and 13% are college undergraduates. Overall, 18.2% of citizens are academic degree holders, of which 57% are females and 3.2% of those had a *Post Baccaulaureate* degree (POPCEN, 2015)⁴.

Livelihood

Still, in August 2015 over 31% of the residents were under the age of 15, representing the young dependents group that, together with the old dependents of over 65 years old (circa 4%), totalized a dependency ratio of 60 dependents per 100 workers. Leyte's main economic activities include agriculture (rice, coconut and sugarcane as the main crops), fishing, industrial, energy⁵ and mining. Regarding Taclobanon's livelihood (see Figure 2.14), the major occupation groups included services and sales workers (21.4% of over 15 years old gainful workers), elementary occupations⁶ (21.2%) and managers (11.6%) (POPCEN, 2015). It is relevant to enhance the importance of self-employment (19.4% of the working population on the 2010 Census), which includes the *sari-sari* shops presented on Figure 2.15.

Despite being a coastal city, it is curious the small percentage of fisherman in Tacloban (Figure 2.16), as of forestry workers and farmers, of only 3.6%, which is extremely low comparing to the regional value of the whole Leyte Island, of circa 20% - a consequence of Tacloban being the main city on this mostly rural territory.

⁴ Although it would be advisable, it was not possible to access to national education data for comparison purposes.

⁵ The island has the largest geothermal plant in Asia and the excess of produced electricity is supplied to the natural grid, to be consumed in Luzon and Mindanao.

⁶ Elementary occupations include unskilled workers, such as street vendors, construction site workers, domestic helpers, cleaners or farm helpers, among others.

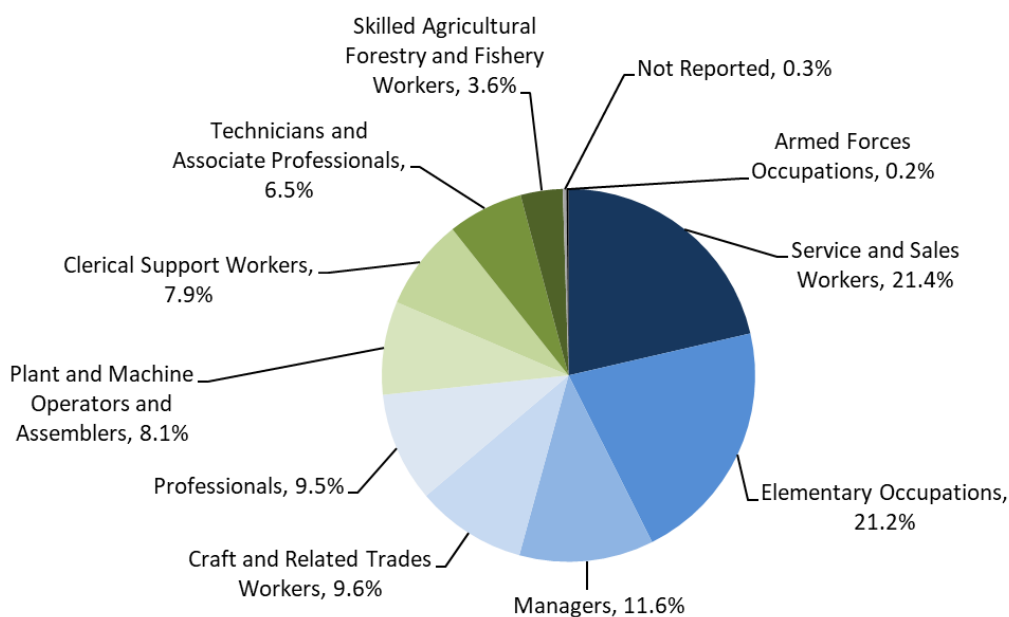


Figure 2.14 - Taclobanons major occupation groups (over 15 years old gainful workers) (POPCEN, 2015)

Regarding the gender distribution among the working population, there is a ratio of 61.6% males to 38.4% females. Over 90% of farmers, forestry workers and fisherman, trade and related workers, armed forces and plant/machine operators are males. Similarly, elementary occupations are held by a majority of 72.1% of males. On the other hand, occupations as managers, clerks and professionals, employ a majority of women (POPCEN, 2015).

Most recent data from the 2015 FIES (Family Income and Expenditure Survey), a nationwide survey of households undertaken by the National Statistics Office, evidenced that Region VIII families income are lower than national average: 2.76% of this region's inhabitants earn under 40 000 Philippine Peso (PhP) per year (against 1.56% national average); 7.29% earn 40 000-59 999 PhP/year (3.97% national average); 25.11% belong to the income class of 60 000-99 999 PhP/year (14.38% national average); 46.76% have annual earnings between 100 000-249 999 PhP/year (45.39% for the country) and only 18.07% earn more than 250 000 annually (comparing to the natural average of 34.70%) (FIES, 2015).



Figure 2.15 - Livelihood: Sari-sari Store (Personal archive: August 2014)



Figure 2.16 - Livelihood: fishing boat (Personal archive: October 2016)

2.5. Super Typhoon Haiyan

On the morning of November 8th, 2013, Super Typhoon Haiyan (Figure 2.17) roared ashore in the Visayas region, causing catastrophic destruction and thousands of casualties, particularly within the Leyte and Samar islands. Being one of the major cities hit, Tacloban soon became the focus of world media attention and relief operations.

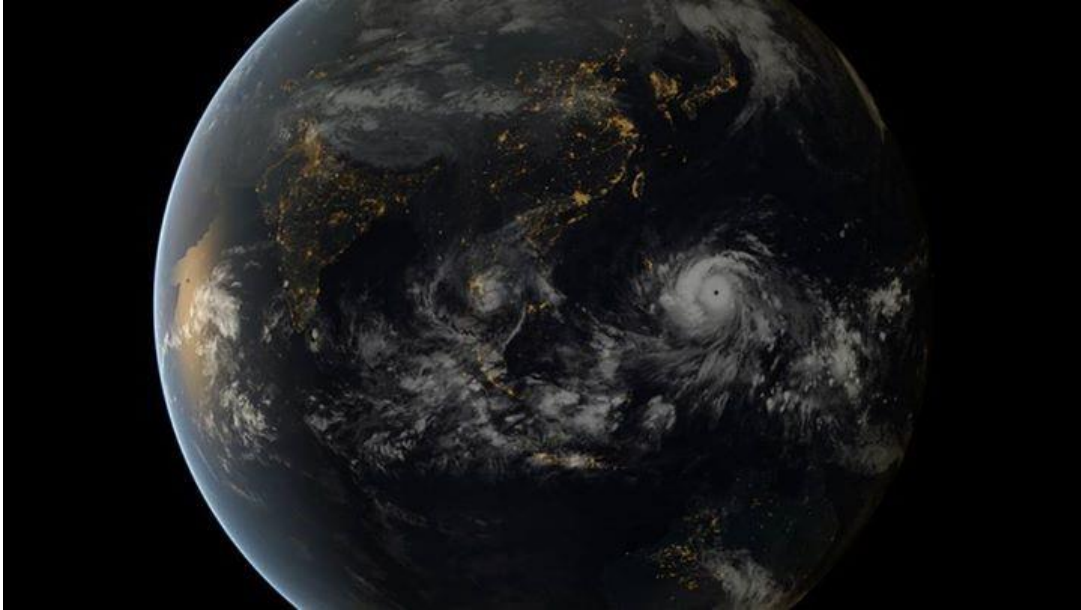


Figure 2.17 - Satellite picture of the approximation of Typhoon Haiyan to the Philippines, where is visible its outrageous dimension (EUMETSAT, 2013)

Genesis and intensity

Haiyan was initially detected on November 2nd as a tropical perturbation south of Pohnpei (one of the Micronesia Islands), related with the low atmospheric pressures typical of the monsoon season. This perturbation has strengthened over the next 24 hours, moving West towards the Chuuk atoll (also on the Micronesia Islands) (Figure 2.18). The first cyclone alert was emitted by the Joint Typhoon Warning Center (JTWC), a cooperation between the US Navy and Armed Forces, on November 3rd (JTWC, 2013).

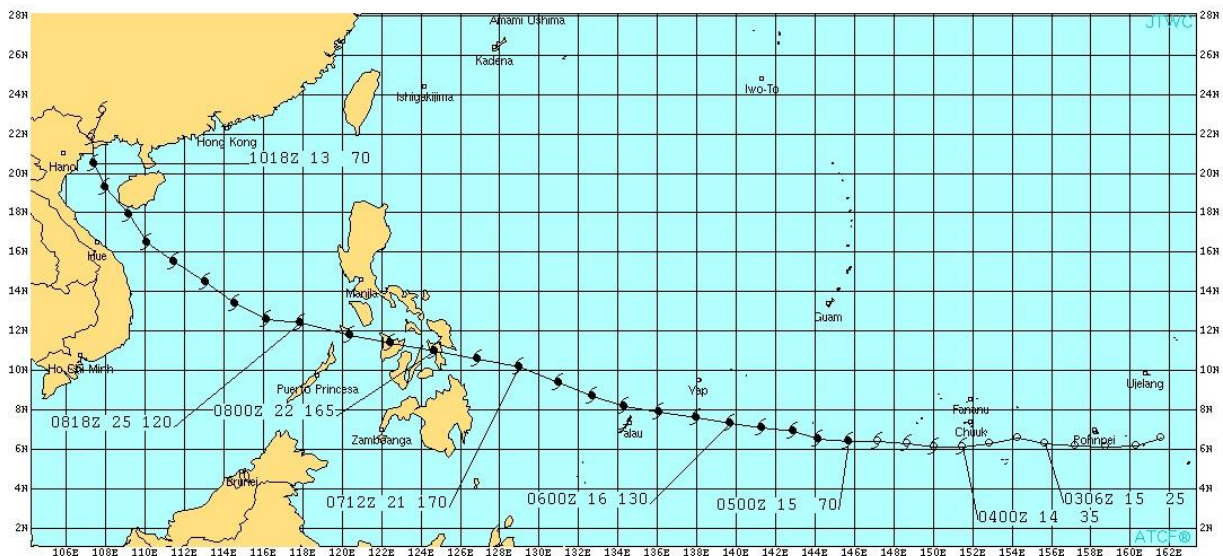


Figure 2.18 - Typhoon Haiyan Track (JTWC, 2013)

On the following 48 hours Haiyan kept intensifying at a rate above average, receiving the classification of a tropical storm (with winds of over 65 km/h) on November 4th and being reclassified as a typhoon (winds over of 130 km/h) the following day. Typhoon Haiyan's winds have then rapidly increased in less than 24 hours, and on November 6th wind gusts of 240 km/h were recorded. While approaching the coastal areas shallower waters, Haiyan has yet strengthened, with winds of circa 250 km/h being recorded over Kyangel Island (Micronesia). Here, the environmental conditions were again favorable to its intensification, with special emphasis to the local sea water elevated temperatures (of circa 29°C) along the typhoon track (JTWC, 2013). Although the JTWC models have anticipated this process of intensification, they did not foresee the rapidity at which it has occurred, according to the later direct observations of the catastrophe.

Haiyan, designated by the Filipino authorities as Yolanda, made its first landfall on the Philippines on November 8th close to Guian, on the eastern extreme of Samar, before traversing the municipality of Tolosa, Leyte. At the moment of its landfall, the maximum wind strength was estimated to be of 378 km/h (City Government of Tacloban, 2014), which would make this storm the strongest to date to ever make a landfall. Haiyan was classified as

a Category 5 Super Typhoon, the highest of the Saffir-Simpson scale⁷, travelling with a translational speed of 15 to 23 knots (around 40 km/h) – as a matter of fact, this impressive translational velocity during its track may have contributed to the formation of the storm surge that has devastated Tacloban.

Instead of a gradual increase of the sea level and expected flooding, tsunami-like waves of more than 6 m high were formed during the early hours of November 8th. Waves like these, with its genesis in atmospheric events, are often designated as *meteo-tsunamis* and are thought to be induced by severe perturbations on moving air masses, such as pressure discontinuities, passage of fronts or, as in this case, tropical cyclones. The surge came rapidly, in some locations with nearly the same force and rapidity of a destructive tsunami. The wind direction north of the typhoon eye was on-shore, while on its south was off-shore. This helps to explain the appearance of a high storm surge in the area of Tacloban, while the southern areas experienced a relatively smaller one (GIZ, 2014). Moreover, the configuration of the local coastline (namely the San Juanico Strait) made Tacloban even more vulnerable, as it funneled the storm surge between Leyte and Samar and towards the city (City Government of Tacloban, 2014; Lander, et al., 2014).

This was a phenomenon that many people did not fully understand and the precise threat that the surge represented was not communicated by the authorities effectively (OXFAM, 2013; GIZ, 2014). This helps to understand why the surge caused so many casualties, as people have reportedly underestimated the necessity to evacuate the coastal areas. It should be noted, however, that the tide was low the time the surge hit – some hours later, the water level and, therefore, the storm surge, could have been considerably higher (GIZ, 2014).

The typhoon has crossed the Philippines rapidly and emerged on China South Sea, with an intensity of still approximately 220 km/h. On November 9th, it has curved North towards the Gulf of Tonkin (Vietnam) where it weakened, making a landfall on Vietnam on the following

⁷ The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 classification of tropical cyclones, with 5 being the most destructive. It provides examples of the types of damage and impacts in the US associated with winds of a given intensity (NOAA, 2018).

day with lower wind gusts of 130 km/h. Posteriorly, Haiyan hit the South of China where has finally dissipated due to the existing continental friction effect (JTWC, 2013).

Haiyan - the aftermath

The National State of Calamity was issued on November 11th, by the country's president at the time, Benigno S. Aquino III (NEDA, 2013b). Nine of the country's 17 administrative regions have been affected by this disaster, covering 12 122 *barangays* in 44 provinces, 591 municipalities and 57 cities. More than 2.6 million families (12.2 million individuals) were affected by the storm, the majority in the Visayas. Moreover, about 4.4 million people have been displaced, and over 400 000 housed in more than 1 500 evacuation centers. As of April 3rd, 2014, 6 293 individuals were reported dead (more than 80% in Tacloban, Palo and Tanauan municipalities), 28 689 injured and 1 061 people were still missing (NDRRMC, 2014a).

These typhoon-affected areas, in the prior year of 2012, had accounted for 17.4% of the country's GDP, contributing with 26.8% of the national agricultural yield, 16% of the industry's and 15.8% of services. However, the affected provinces were some of the poorest in the country - with data showing that the average household income was only 75% of the national average. Moreover, these peoples' main sources of livelihood (agriculture, fisheries and tourism) were gravely affected by the storm, which has severely aggravated their situation and their capacity of recovering from it (NEDA, 2013b).

The scenario in Tacloban City after the passage of Haiyan was one of total catastrophe (Figure 2.19). In Tacloban City alone, of the 30 513 totally damaged houses in the city, 90% were located along the coastline. The number of partially damaged houses ascended to more than 23 thousand and, from these, circa 10 thousand belonged to the urban poor and/or the so called 'informal settler families' (which main sources of livelihood, their small businesses, have also been destroyed by the typhoon) (City Government of Tacloban, 2014).



Figure 2.19 - Tacloban's scenario after Haiyan⁸

The National Government response was guided by three strategic documents: RAY – Recovery Assistance on Yolanda, PDNA – Post-Disaster Needs Assessment and CRRP – Yolanda Comprehensive Rehabilitation and Recovery Plan. The CRRP was based on the policy guidance coming from RAY, and it provided projects, programs and activities to meet the needs identified in the PDNA. Moreover, the CRRP was complemented by the rehabilitation plans prepared at the city level (for Tacloban the TRRP – Tacloban Rehabilitation and Recovery Plan). These plans intended to help managing the recovery of the affected region, as well as to adequately allocate national and foreign aid funds.

The total impact of the typhoon ascended to PhP 132.4 billion Filipino Pesos (PhP) (circa 2.62 billion USD), 32% in losses and 68% in damages, with the total recovery costs being estimated as PhP 104.6 billion (2.07 billion USD) (NDRRMC, 2014a). These represented 0.9% of the country's GDP in 2013 and were expected to reduce economic growth by 0.3% in 2013 and 2014 (NEDA, 2013b). Moreover, over PhP 360.8 billion (about 7.12 billion USD) would be

⁸ Image retrieved from the online source: The Australian, November 15th, 2013 (<https://www.theaustralian.com.au/news/world/tacloban-looters-mum-and-her-sick-kids/news-story/004eb44376c407062ce56dbc26bbbd9d?sv=be262559c57b4aa432dbb1f3cddb21c1>)

needed to bring the economy back to its level of performance prior to the typhoon. On the same report, it was coined the 'Build Back Better' slogan, representative of the vision of seeing this recovery process as an opportunity to build more resilient communities.

Haiyan's impact on social facilities and services was also major, with over 6 000 people living in tents, schools and evacuation centers for many months after the disaster. All the city's seven hospitals and health centers were badly damaged and the same was accounted for 90% of local schools. Airports, seaports and several roads and bridges were declared unusable and communication land-lines took several months to be fully restored. The total recovery costs for this city alone were estimated as PhP 12.9 billion, as its damages ascended to PhP 6.9 billion and its losses to PhP 5.3 billion (City Government of Tacloban, 2014).

Tacloban's TRRP included, in addition, the intention of preparing a Disaster Risk Reduction and Management Plan (TCDRRMP), which would embrace an early warning and evacuation strategy, the contingency plans and the emergency response procedures. Moreover, it foresaw the creation of new residential, commercial and institutional areas, circa 6 km north from the original city which were commonly denominated Tacloban North, as described below.

Tacloban City North Development

Immediately after the catastrophe, in November 2013, the national government instructed municipalities to implement a 40-meter 'no build zone' in coastal areas, to prevent the reconstruction in storm surge dangerous areas. This legislation was forcedly adapted from existing laws for water resources management, which were not specific for the communities' safety (OXFAM, 2014c). Moreover, this zoning was claimed to be impractical, as it excluded all infrastructures from that area, including fishing and touristic facilities (Santos, et al., 2016). Soon the 'no build zone' criteria were abandoned, and families started to rebuild their houses on the same locations as they were before the typhoon.

Thereon, the major effort of Tacloban's recovery process became the relocation of people towards north. This relocation project had a projected population of approximately 90 000 people by the end of 2018, meaning that circa 40% of the city's original residents would be moved north. Whilst the permanent houses were being constructed (by the National Housing Authority (NHA) and several INGOs), the families left homeless by Haiyan were accommodated already in the northern territories in temporary shelters (see Figure 2.20 and Figure 2.21). The Tacloban City North Development site, formerly allocated for industrial development, was then reclassified to accommodate the EVRG (Eastern Visayas Regional Growth Center), including the resettlement of the displaced population during Haiyan. An investment of PhP 4.8 billion for housing was carried out and an additional investment of PhP 5 billion was estimated for the remaining facilities. However, as of June 2016, a gap of PhP 4.85 billion were yet to be committed. The majority of this investment was to be carried out by National Government Agencies, private sector and NGO's investment, with Tacloban City LGU covering over 17% of it with its own budget (City Government of Tacloban, 2016).

According to the LGU's master plan for Tacloban North (which can be consulted on the report 'Tacloban North Integrated Development Plan', from June 2016), this 'city within the city' would accommodate not only new residential spaces, but also parks and ecotourism facilities, a new University of the Philippines campus, an agroindustry and light manufacturing zone, a new city center institutional area and the new Eastern Visayas Regional Medical Center (EVRMC), the largest medical center of the region.



Figure 2.20- Tacloban North temporary shelters panoramic view (detail of the LMWD truck at the distance) (Personal archive, October 2016)



Figure 2.21 - Tacloban North temporary shelters (Personal archive, March 2016)

However, those relocation measures never were well accepted by Taclobanons. On focus groups conducted by the INGO Oxfam, in 2014, citizens emphasized other options rather than relocation to improve their security, such as the construction of more robust evacuation centers. The fisherman present on those discussions expressed their worries about the lack of livelihood options on the northern territories: when asked about what would be most important in these relocation sites, 49% answered the livelihood opportunities (28% of which expressed the desire of maintaining their current livelihoods, whilst 21% only wanted to make a living); 31.8% highlighted the safety from future disasters; and 12.8% pointed as most important the assurance of basic needs, such as water and electricity (OXFAM, 2014c). However, a significant aspect to consider regarding the difficulty of creating livelihood solutions up north, was the fact that no space was left on the new residential buildings for businesses (the family owned Sari-Sari stores), despite the local tendency of Taclobanons to combine shops with their homes (Boase, 2014). Together with the referred lack of livelihood, the absence of water (explained on the following section with more detail) remained the true obstacle to the site development, which would also be slowed by sanitation and community cohesion issues (Boase, 2014).

The initial schedules for relocation, aiming for 96% of the families being relocated by the end of 2017, had then to be replaced by the plan to move only 48% of the families at that point (and only 16% by the end of 2016) maintaining a slow transfer of families throughout 2017 – to allow for water supply, schools, roads, sewage and livelihood projects to be urgently developed. Priority for relocation was given to the original residents of the coastal areas, followed by the ones next to rivers and on landslide prone zones. Unfortunately, this did not happen within the desired timeliness and the lack of livelihood choices on the northern territories (considering the cost of traveling to the old city every day was unbearable for most relocated families), led people to flee back to the city and rebuild their houses in the storm surge prone areas. This situation was foreseen by OML researchers, who studied the relocation process closely (Santos, et al., 2016). The dissatisfaction of relocated families was corroborated on the fieldtrips by contacting with the communities and is present in several LGU and INGO's reports.

As of October 2016, in an interview held in Tacloban, members of the city's LGU estimated that the number of informal settlers in the city rounded 28 000 people. These families have built (or, in the majority of cases, rebuilt) their houses on the coastal areas of downtown Tacloban, in order to stay closer to their jobs, their children's school and other facilities. Many of these families, who had even been given new houses in Tacloban North, have opted to abandon them for these reasons. This was the case of the coastal *barangay* Anibong, which was totally leveled by the storm surge, but which was soon totally occupied, not only by its original residents but allegedly also by poor families from eastern Samar, who moved in hoping they would get new houses as well.

The problems existing in Tacloban North resettlement areas seemed to stem directly from a lack of vision and coordination of efforts. Moreover, the resettlement territories were, for the most part, already owned by the city government and the NHA. This excluded the need for the expropriation of the lands that would most certainly delay the recovery process, but in its turn resulted in the new areas being somewhat fragmented (Boase, 2014). As corroborated in 'Learning from Tacloban' - a report resulting from a 3-days workshop who gathered, in 2014, local and national government experts, NGOs, INGOs and the private sector to reflect on the recovery process - a key lesson to retain was the importance of not compromising long-term permanent development by rushing decisions during the relief process. As stated by LMWD (September 2017) as well, referring to the water supply situation specifically, this lack of coordination came from the Filipino central government, who overlooked these facilities when planning the NHA relocation areas, by not setting a budget aside for their development. Moreover, LWUA (the Local Water Utilities Association, based in Manila) was only invited to take part of the process in 2015, when the NHA permanent houses were already being completed and people were in the process of moving from the temporary shelters.

The response to these problems by the city's LGU was contained in the referred masterplan for Tacloban North itself, where it was acknowledged that, whilst the socialized housing

relocation sites were, in June 2016, in an advanced state of completion despite proceeding with relative isolation, the supporting infrastructures, utilities and services were being kept behind by the lack of coordination between stakeholders. Hence, this plan aimed to guide the immediate and long-term development of Tacloban North on years to come, focusing on enabling those infrastructures around which the community can thrive (City Government of Tacloban, 2016) – with the severe water supply constraints on the resettlement areas amongst the most critical aspects to be addressed.

2.6. Water Supply Constraints

Water uses and demand

The area surrounding Tacloban has by no means a natural water deficit, concerning raw water availability as both surface and groundwater. Tacloban municipality, specifically, has several waterways, although they do not provide enough flow to justify their commercial exploitation – besides being mainly used as wastewater drainage channels.

Considering that only 25% of the city's households were connected to LMWD, which “due to political disputes does not intend to increase their service area within the City of Tacloban”, households and other establishments in the city were forced to source their water from deep and shallow wells. According to USAID, an estimated number of 2 759 wells existed in the city, the majority of which are privately owned shallow wells and only 54 are registered (USAID, 2015). Regarding the piezometric conditions, the static water level of wells distributed throughout the study area ranged from 0.90 to 4.57 meters below the surface. This shallow aquifer was, however, reportedly easily affected by seasonal changes. Both shallow wells and dug wells existed in the area: wells drilled to 25-90 m showed a yield of less than 2 L/s, and wells drilled close to the coastline produced mostly saline water. The ones drilled farther away from the coastline, which penetrated the sedimentary and metamorphic rocks, have showed also very poor yield.

Moreover, high iron and manganese concentrations were reported on the groundwater extracted from dug wells, shallow wells and deep wells, drilled to about 40 meters. The shallow alluvial aquifer laying under Tacloban is, therefore, not an advisable groundwater

source due to its limited thickness, which makes it highly susceptible to pollution and contamination, as well as marine water intrusion (ADB, 2010). Furthermore, Tolentino et al. (2016) have evaluated the impacts of typhoon Haiyan on the aquifer recharge in Tacloban and stated that there might be a decrease in the recharge rates due to the loss of vegetation (Tolentino, et al., 2016).

Figure 2.22 below, summarizes the information gathered on the 2010 National Census regarding water sources and uses in Tacloban.

Comparison of water sources for drinking, cooking and laundry/bathing

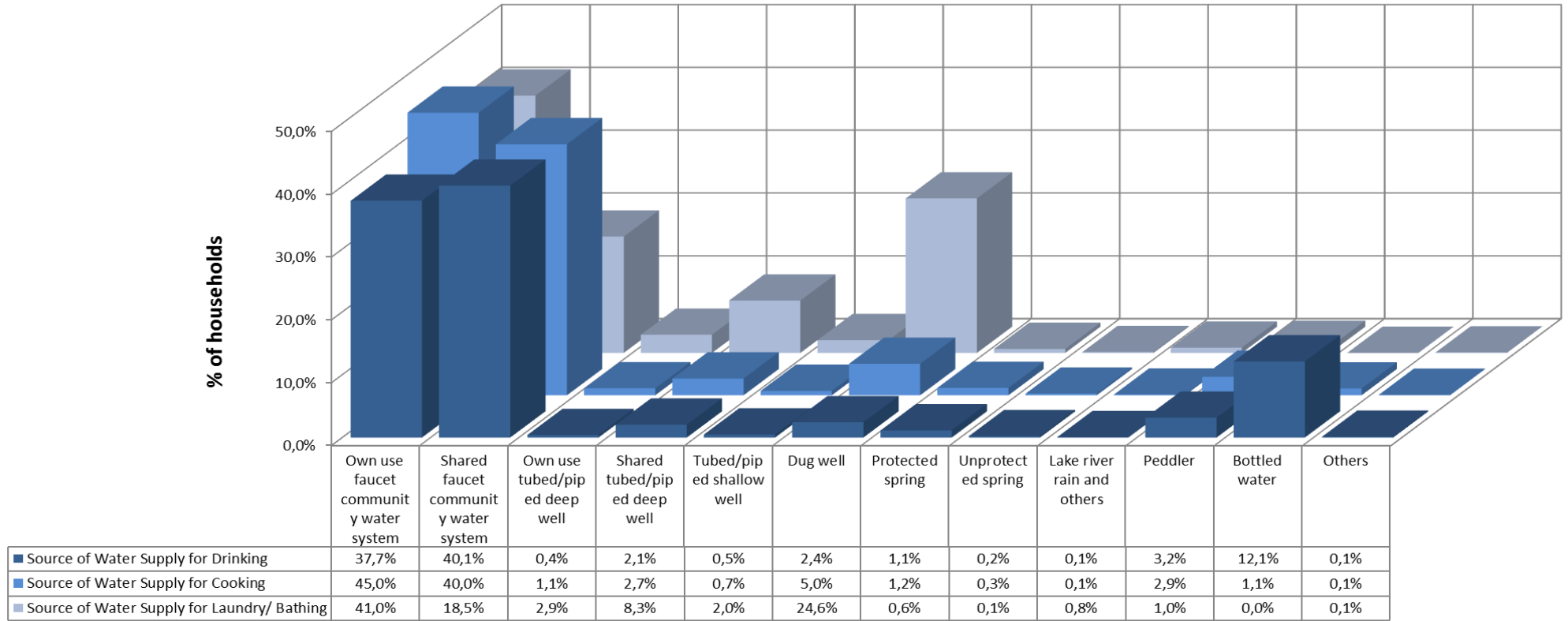


Figure 2.22 - Comparison of water sources per use on Tacloban's households (POPCEN, 2010)

As can be observed on Figure 2.22, as of 2010 only 37.7% of the households in Tacloban city were served by their own use faucet for drinking purposes, with a large percentage (40.1%) still depending on shared faucets. However, this adds up to only 77.8% of the households benefiting from centralized water services, with 12.1% still depending on bottled water and many still recurring to own or shared wells. Meanwhile, bottled water is seldom used for cooking, with piped water being the main source for this use, but still with 5% of the households recurring to dug wells. Lastly, concerning bathing and laundry uses, 41.0% rely on own faucets, 18.5% on shared ones and an astonishing 24.6% recur to dug wells.

From this analysis, it is relevant to point out that more households served by their own water faucet use its water for cooking (in which the water is assumedly boiled), followed by bathing and cleaning purposes and fewer (37.7%) for drinking. This may indicate that population in Tacloban has some concerns regarding the quality of the supplied water, as it seems that even households with piped water tend to rely on bottled water (much costlier) when it comes to drinking it.

These water uses have seemed to evolve, according to the most recent census, of 2015⁹ (Table 2.5). According to this data, the percentage of households (HH) with access to their own faucet has increased to 50%, and the use of shared faucets decreased to 17.3% - which seems to indicate that new faucets could have been installed throughout the city. However, the non-controlled water sources such as the owned deep wells and the protected springs, have experienced an increase in their demand. This could, perhaps, be a consequence of the residents moved for Tacloban North where the supply network was still underdeveloped, making them turn to those sources to satisfy the needs of the family. Curiously, however, the consume of bottled water has decreased significantly during these 5 years, which may be a reflection of the increase of other options, or even of the post-Haiyan decrease in purchase capacity of the families.

⁹ Note: Due to the fact that the 2015 Census excluded the laundry and bathing uses, considering only drinking and cooking purposes, the graphical comparison on Figure 2.22 was based on the more complete 2010 data.

Table 2.5 - Source of water supply for drinking: 2010 and 2015 comparison

	2010	2015
Own use faucet community water system	37.7%	50.0%
Shared faucet community water system	40.1%	17.3%
Own use tubed/piped deep well	0.4%	21.5%
Shared tubed/piped deep well	2.1%	0.7%
Tubed/piped shallow well	0.5%	2.6%
Dug well	2.4%	0.4%
Protected spring	1.1%	2.4%
Unprotected spring	0.2%	0.3%
Lake river rain and others	0.1%	0.3%
Peddler	3.2%	0.1%
Bottled water	12.1%	1.6%
Others	0.1%	0%

Leyte Metro Water District (LMWD)

Early records of water supply services in Leyte date back to the 1930's. From 1939 to 1974 there were two distinct utilities serving this region's four municipalities: Dagami, Tanauan, Tolosa and Tacloban - at the time not such an urbanized city as in the present day. Both utilities, Leyte Metropolitan Waterworks Supply System (LMWSS) and Tolosa Water Supply System (TWSS) were merged in 1975 to form the Leyte Metropolitan Water District (LMWD), which remains the water utility serving Tacloban and its surrounding provinces (ADB, 2010). At present, this utility is serving one city and seven municipalities, namely: Tacloban City, Dagami, Palo, Pastrana, Sta. Fe, Tabontabon, Tanauan and Tolosa.

About 99% of the water supplied by this water district (WD) comes from surface water sources, located to the west of the service area, and 1% comes from localized groundwater sources (one to the south and one to the north of the service area). The main surface water source is Binahaan River, located on the neighboring municipality of Jaro, but which spring is in Lake Ormoc. LMWD has a program for Binahaan's watershed of 33 ha protection, patrolling it to prevent land

uses that may affect the water quality and/or availability and promoting its reforestation. The watershed occupies part of Ormoc municipality, where its spring is located, Dagami, Jaro, Tabontabon, Tanauan, Palo and Pastrana, whilst Tacloban city is located in a different, coastal watershed. This river was tapped in 1975, following reports that Tiagbao River (the original source) water quality was becoming more deteriorated and due to the sand pumping on various deep wells (ADB, 2010; USAID, 2015). The National Water Resources Board (NWRB) has then granted LMWD a permit for the withdrawal of 1 000 L/s (86.400 m³/day) for the intake near Binahaan's existing filtration plant (ADB, 2010). This plant is a slow sand filtration (SSF) plant located 97.50 m with an average capacity of 400 m³/h, depending upon the influent water quality. Hence there is no disinfection stage, its effluent flows through Water Treatment Plant 1 (WTP1), a Rapid Gravity Filtration (RGF) Plant built in 1993 with Japanese investment, which is overdosed with chlorine to assure an adequate level after mixing the filtered water flow with water from Binahaan catchment.

This infrastructure treats the superficial runoff of a 222 218 km² watershed. On this WTP1, elevated 105.80 m, with a maximum capacity of 1 000 m³/h (24 000 m³/day), water follows the following treatment scheme: the coagulation/flocculation stage is achieved in a step waterfall and an extended mixing tank; from there, it passes through two sediment tanks to the sand filters; chlorination is carried out between the rapid gravity filter and the storage reservoirs. It is stated that, although most of the times WTP1's effluent respects the national quality standards (despite automated monitoring being inexistent (ADB, 2010)), at times of high turbidity the chemical dosing pumps were not capable of providing the necessary volume of disinfectant, forcing a plant slow down to conform with quality requirements. Figure 2.23 depicts the location of these infrastructures¹⁰.

¹⁰ As of March 2016, LMWD did not have its network on a computerized mapping or GIS system. Therefore, Figure 2.23 schematizes a draft of LMWD's facilities and network, developed in QGIS using the available referred sources of information.

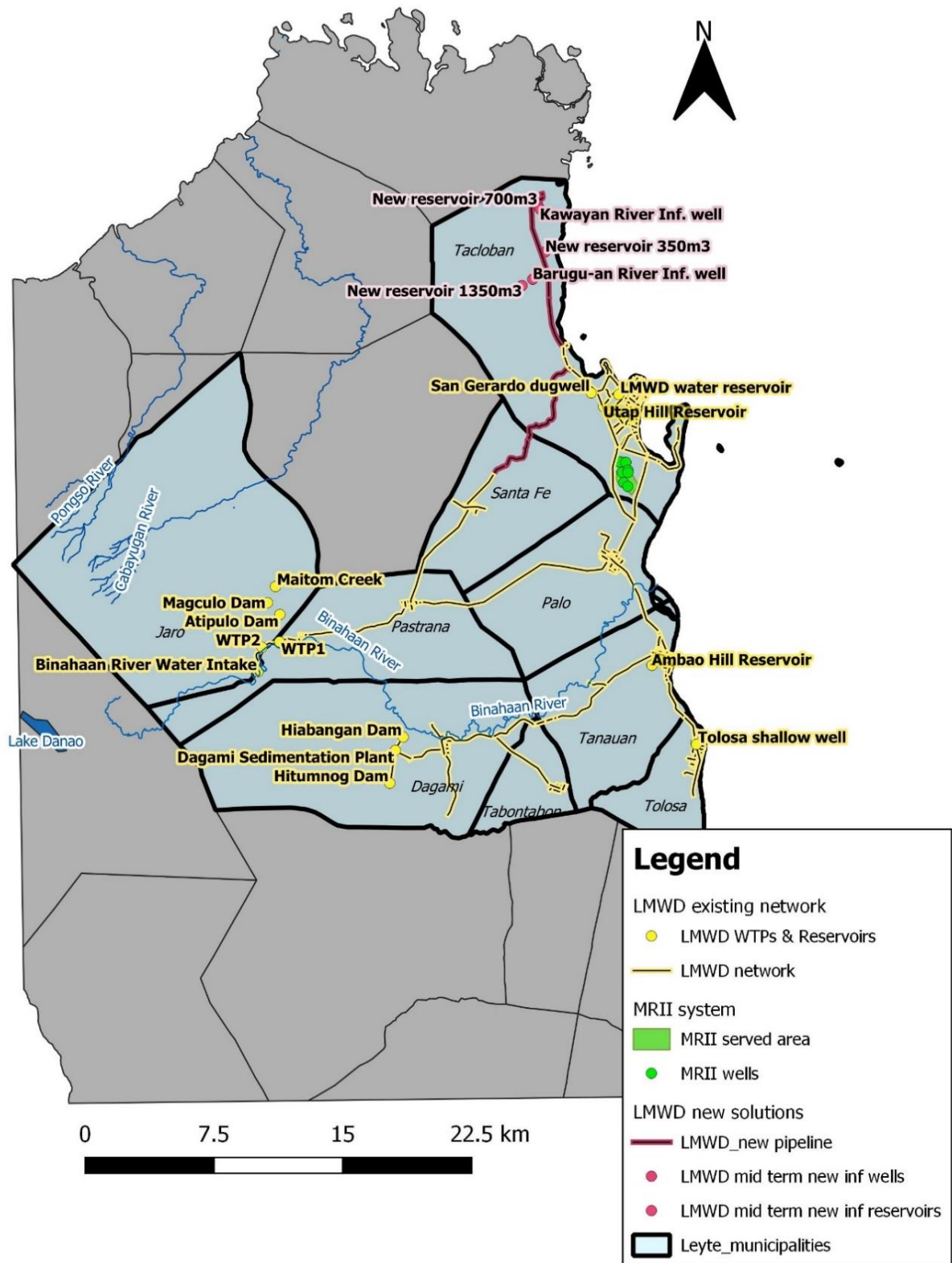


Figure 2.23 - Water supply system scheme for Tacloban City (existing and possible future developments)

From 1980, only some minor rehabilitation works have been undertaken. As a result, before the end of 1989, water concessionaires in the more elevated areas and at the ends of the distribution lines started to complain about water interruptions and supply inadequacy – particularly during the period of interruption of Tingib facilities functioning due to the high turbidity of Binahaan River, resulting from heavy rains and flooding. These constituted the first evidences that the system was approaching its limitations and that the existing treatment plant needed to be upgraded and/or that the construction of a new treatment plant was urgent (USAID, 2015; ADB, 2010). In 2013, LMWD build a second WTP, copying the exact design of the Japanese-built one (which had proved to be typhoon-resilient and operated satisfactorily). This second treatment plant, built near the first one in Brgy. Hibunawon, Jaro (except for the sludge lagoon which is located in Brgy. Tingib, Pastrana), is also a Rapid Gravity Filtration plant, with a capacity of producing 30 000 m³/day. The new raw water intake was located also on Binahaan River, upstream from the first catchment (ADB, 2010). While WTP1 and the Dagami plant supply the municipalities of Pastrana, Sta. Fe, Palo, Tanauan, Tolosa and Tacloban City, WTP2 was planned to supply only Tacloban City, where more than 63% of LMWD's concessionaries were based (LMWD, 2015).

On a parallel supply line, Dagami Sedimentation Plant operates since 1964, treating water harvested from the Hiabangan and Hitumnog Rivers, the first water sources to be tapped on this system. The Dagami plant is located at 152 m and has a daily production of 6 000 m³ of potable water. Despite being equipped with a flocculation facility, the good quality of the raw water all year round exempts the need for chemical dosing for sedimentation. Posteriorly to its filtration, water is disinfected via a pressurized chlorinator. There is a meter on this plant outlet, which in 2010 was still read manually every hour (ADB, 2010). Table 2.6 summarizes LMWD treatment plants and their respective productive capacities, which add up to a total daily production of circa 65 000 m³/day.

Table 2.6 - LMWD production data (LMWD, 2016; ADB, 2010; USAID, 2015)

Water Source	Location	Discharge (l/s)	Treatment Plant Name (year)	Treatment type	Capacity m ³ /day
Atipulo/Magculo/Maitom creeks	Jaro, Leyte	33 (7%)	Old Tingib WTP (year?)	Slow Sand Filtration (SSF)	≈3 000*
Binahaan River	(Brgy Tingib) Pastrana, Leyte	349 (77%)	WTP1, Tingib RGF (1993)	Rapid Gravity Filtration (RGF)	30 523
			WTP2, RGF (2013)	Rapid Gravity Filtration (RGF)	28 448
Hiabangan and Hutmnog Rivers	Dagami, Leyte	73 (26%)	Dagami Plant (1964)	Sedimentation basin	6 117
TOTAL					65 088

* the SSF water passes through WTP1, so it does not add up to the total daily production

As for groundwater sources, LMWD uses only one shallow well (Tolosa well, in Brgy. Imelda, Tolosa) with an insignificant discharge of 2.5 L/s (216 m³/day) and one dug well (San Gerardo well, in Brgy. Nulatula, Tacloban City) with a small capacity of 2 L/s (172.8 m³/day) – but which supplies only the San Gerardo Subdivision. There are three distribution reservoirs: the Utap Hill Reservoir, the Ambao Hill Reservoir and the Tolosa Reservoir. The first two (8 300 and 2 300 m³ of capacity, respectively) were concrete ground reservoirs that operated on a floating-in-the-line scheme, but both are no longer being used as water does not reach the inlet due to pressure insufficiency. In its turn, the elevated concrete reservoir in Tolosa (95 m³) stores water extracted from the Tolosa well, operating on a fill-and-draw scheme (ADB, 2010).

The treated water of Binahaan River and Atipulo/Magculo/Maitom creeks is conveyed by gravity through a single transmission line and a portion of the water is distributed to the towns of Pastrana and Sta. Fe. In its turn, the treated water of Hiabangan River and Hitumnog creek is also conveyed by gravity through a separated transmission line and part of this water is consumed in the municipalities of Dagami, Tabontabon, Tanauan and Tolosa. This way, the two transmission lines connect only at Palo, and the remaining water is presumed to flow towards Tacloban City. In the northern part of the city, at the LMWD motor

site are installed pumps that lift the water by circa 50 m to feed two subdivisions in the hilly areas of northwest Tacloban (USAID, 2015).

Concerning the existing number of connections, as of 2016 LMWD has published the following data, referent to the year of 2015 (Table 2.7).

Table 2.7 - Summary of active water service connections (LMWD, 2016)

Municipality	Number of connections
Tacloban City	19 656
Palo	6 461
Tanauan	2 405
Tolosa	333
Tabon-Tabon	226
Dagami	1 120
Pastrana	529
Sta. Fe	216
TOTAL	30 944

As seen on Figure 2.23, this water district does not serve the totality of Tacloban City municipality, hence a total of 18 *barangays* on the northern part are not yet supplied, with the existing network (as of end of 2016) ending by the slaughterhouse on Brgy. Diit (Brgy.99). These areas supposedly relied on water tanks and/or people bought water jugs from LMWD. ADB's report of 2010 (prior to Haiyan) claims that the existing connections correspond only to 17% of the population within the franchise area, which is significantly low to a utility of this dimension. However, on the same report is stated that nearly three quarters of the non-connected families showed interest in being connected to an improved LMWD network (ADB, 2010). A similar survey conducted by USAID in 2015, where a total of 845 households in all the service area (280 of which in Tacloban City) were interviewed, showed that over 87% of those not connected to any WD were willing to pay and to connect to a sustainable water service (USAID, 2015).

In 2012 Mactan Rock was hired by the city of Tacloban to help alleviate the water supply problems in the city, by tapping seven local wells in the northern area.

Nowadays, Mactan Rock Industries, Inc. (MRII) serves approximately 50% to 60% of the V&G subdivision (a group of barangays), where those wells are located, producing an average of 272 m³/day (USAID, 2015).

The water supply service provided by LMWD to Tacloban is not, however, one without problems. For over a decade (i.e., long before Haiyan), Taclobanons have been experiencing a decrease in the water pressure, related to the increase of the number of connections without an accompanying expansion of the network: despite the other municipalities presenting no complaints, the pressure in Tacloban has decreased significantly, varying from 5 to 1 meters across a 24-hour period. This lack of pressure affects the service quality and also the revenues for the water utility, as additional connections do not bring about an increase in sales. As a medium-term solution to increase water pressure in Tacloban City, LMWD had plans to install an in-line pressure booster on the 500 mm transmission line between Palo and Tacloban. This would deliver a pressure of 25 m in the city of Tacloban (provided that a minimum pressure of 14 m was maintained in the transmission line in Palo), which was expected to cause leakage issues that would have to be addressed after (ADB, 2010; USAID, 2015).

Along with the pressure constraints, non-revenue water indexes in LMWD's system were as high as 55% of the production - consequence of an aging network and illegal connections (40%), not from poor households but rather businesses and farmers who could assumedly pay for the consumed water. On an interview held in March 2016, LMWD defended that most leaks were not on the transmission lines but rather on the distribution network, especially in Tacloban City, considering that some pipes dated from the 1930's and needed urgent replacement. Nevertheless, the analysis of production and billing data seemed to point towards a leak in the Tingib-Palo transmission line. The strategy utilized to address the NRW issues, would pass by the replacement process of old meters, as only legitimate customers would be reconnected. Before Haiyan, LMWD had a team responsible for checking illegal connections, visiting 10 to 15 sites per day

(ADB, 2010) – but no information was found to confirm if these visits persist nowadays. Diminishing the 65 000 m³ of daily production by the 55% of NRW and by the fact that only 70% of the produced water going to residential consumptions (the remaining 20.66% goes to commercial/industrial, 8.73% to governmental uses and 0.44% for bulk sale) (USAID, 2015), the per capita consumption for LMWD customers was estimated as 132.51 L/hab.day.

LMWD administrative disputes

LMWD has the nature of a government-owned and controlled operation, with a juridical core separated and distinct from its members, directors, officers and employees. For over a decade, the company has been managed by a board of directors (BOD) appointed by the provincial government of Leyte. This was defined following the Presidential Decree 198, which mandated that only an LGU that had 75% of water consumers of a water district would have the authority to manage it. If the number of connections were lower than that, the BOD would be appointed by the provincial government.

However, the provincial-supported BOD mandates have extensively been marked by a significant lack of transparency. During the interviews held in Tacloban on March 8th, 2016, with the Disaster Risk Reduction and Management Office (DRRMO) from the local government, it was learned that, in fact, in some areas of the city, LMWD did not have a single meter per customer, but rather one meter per subdivision (which serves approximately more than 200 households). This was the main reason that several interviewed parties (among LGU offices, NGOs, INGOs and community in general) have pointed out for the non-expansion of the water network towards north. Hence, if the real number of connections were to be evaluated (which would be facilitated by the creation of thousands of new connections up north), LMWD's management would shift to the city. These 'institutional problems' within the water district and the local government date

from before Haiyan and have raised obstacles to the WD operation before (ADB, 2010).

Other illegalities undertaken by the provincial board included allegedly using dummy contractors for the construction of the office building, the purchase of vehicles and the exemption of fees to buildings owned by board members. The water district employees were simultaneously not pleased with the ruling board, hence they refused to implement the Collective Negotiation Agreement, entered into by the management and workers in 2006 that would grant them various of their entitled benefits. The BOD malpractices were tentatively exposed in 2000 and 2004 by two laborer-union leaders (pioneers of LMWDEA, the Leyte Metro Water District Employees Association), which were consequently brutally assassinated. From thereon, LMWD workers had been living in fear and the exploitation situations perpetuated.

In the course of this dissertation, however, a major plot twist has occurred, with Tacloban's Mayor Cristina Romualdez filing a petition to the Supreme Court. The Supreme Court had then declared PD198 as unconstitutional, ruling that a highly urbanized city that does not vote for provincial officials needs only 51% of the total number of water consumers to gain the authority to manage the water district. Hence, in 2014, LMWD had, in a written and published report, stated that 67.5% of its customers were Tacloban City residents, the city government had now the legal right to manage the WD. In May of 2017, Romualdez wrote to the Filipino President Rodrigo Duterte, seeking his intervention that included giving the city the right to appoint a new BOD, which she did in December 11th of the same year. In January 17th of 2018, the new board (formed by a majority of former Tacloban's LGU officials) took over LMWD with the support of the General Manager (GM) and the majority of employees. Ever since, the resolution of the Tacloban North resettlement area water shortage has been on the hands of this new BOD, which

claimed that they would start by addressing the very high volumes of NRW, which would increase the service provided.

Haiyan impacts on the water sector

According to LWUA's reports, the damage to the typhoon affected Water Districts was relatively minor. The mostly destroyed infrastructures were the superficial equipment and some water sources, reservoirs and transmission pipelines, with the major subterranean assets (i.e. distribution networks) being relatively untouched (NEDA, 2013b).

As reported in RAY, however, after super typhoon Haiyan the total damage for the water sector was estimated as almost PhP 3 000 million (PhP 429 million public and PHP 2 569 million private) – considering the operating losses of water utilities and smaller operators, both during the recovery and reconstruction periods, and also for the increased cost of water for households until pre-disaster supply levels were restored. Therefore, the needs estimated for the affected region's water sector recovery were of PhP 5 747 million (PhP 1 850 million for recovery and PhP 3 897 million for reconstruction) - these funds would be channeled by LWUA to the utilities (NEDA, 2013a). Accordingly, on PDNA is stated that the Region VIII water sector was 'greatly affected', with the provinces of Samar, Eastern Samar and Tacloban City presenting the most damages: Tacloban City's assets alone incurred for over PhP 30 million of damages (0.6 million USD), PhP 141 million (2.79 million USD) in losses and recovery needs of almost PhP 170 million (3.37 million USD) (NDRRMC, 2014a).

In Leyte, Haiyan was thought to be the cause of possible changes in some local river flow patterns, with the consequent flooding of low-lying coastal areas. Several watersheds in the affected areas experienced also some increased sedimentation due to soil erosion and sporadic landslides (NDRRMC, 2014a).

According to the German INGO, GIZ, Haiyan brought 100-150 mm of rain for the central-southern part of Leyte, and less than 100 mm for the northern part of the island. These amounts are considerably small for a typhoon the size of Haiyan and typically are not sufficient to cause major floods. However, in the morning of the 8th of November, in the town of Dagami, there was a flood of more than 1 meter high. Nevertheless, as there was no registered flooding upstream, in Tingib, Pastrana, it was assumed that the water came from the affluent Guinaronga (southwest of Dagami), and not from the Binahaan River itself (GIZ, 2014).

Reportedly, in Dagami waterplant, which before the typhoon required only a disinfection of the raw water, there was a need to correct its turbidity after Haiyan. Binahaan River has also increased its turbidity: on a day without rain, turbidity has increased from 1-5 NTU before Haiyan to 4-6 NTU after Haiyan; but on the event of a typhoon and/or heavy rains it has reached up to 35 000 NTU (in 2 to 3 hours) due to the loss of forest area uphill. More alarmingly, the river which is Tacloban's main water source seemed to change its course after the typhoon, which sounded the alarm in LMWD offices. Supported by INGOs, the utility rapidly proceeded to construct a river embankment protection structure (Abarquez, 2016).

Moreover, as the affected areas rely on local surface and groundwater sources for domestic supply, some concerns were raised due to water quality insecurity. This was explained by the fact that these water bodies could have been contaminated from the debris, decomposing dead bodies and damaged storage facilities of oil and chemicals, which could have leaked chemical substances to groundwaters. However, no information was found regarding groundwater quality (NEDA, 2013b; NDRRMC, 2014a), except for the reports of interviewed persons from LGU claiming that, a week after Haiyan, all the wells were salted because of the marine intrusion caused by the massive storm surge.

In an interview held in March 2016, LMWD's General Manager stated that the water utility infrastructures were not significantly affected by the typhoon Haiyan, considering that the transmission lines are buried and that the treatment plants are located uphill, far from the surge flooded areas. Only a 10-inches (25 cm) supply line was exposed due to the uprooting of nearby trees but this situation was rapidly resolved. The most critical damage to LMWD's network was on the distribution lines: after Haiyan, people were allowed to utilize cut connections as an emergency source of water and, as a result of these illegal connections that continued even 6 to 8 months after the typhoon, non-revenue water (NRW) was as high as 60% in Tacloban City. This caused the pressure to be uneven in some points of the distribution network (evolving from 40% before the storm), and the exposure of the open pipes raised contamination concerns as well. Moreover, due to the pressure decreases, residents with two stories houses have installed private pumps, which has worsened the overall situation.

However, the main office, located in the first row of buildings on the coastal drive next to Tacloban's harbor was badly hit by the storm surge. In result, several vehicles parked outside were destroyed, along with the servers causing the loss of many archives of the network and customer data which were not yet computerized. The main reported difficulty after the typhoon was to get fuel for the WTP generators to work, that was aggravated by the fact that the road to the WTP was cut as a result of falling trees. For this, the USA Navy donated 10 000 liters of fuel, but LMWD still lacked the container to receive it. Since the water plants were not damaged, 60% of the water supply was immediately restored after the initial clearing/desilting, but the production by LMWD was limited to 80% because of these fuel requirement concerns and fears of water wastages (Abarquez, 2016).

Allegedly, a few days after the typhoon, 200 000 people had access to clean and safe water (OXFAM, 2014b). As of November 18th, 2013, Oxfam's WASH team has reported that 'the water crisis in Tacloban was over, with (assured quality) water flowing at a good pressure' (OXFAM, 2016). By the end of November of 2013, the

water services in the city have hence been totally restored to the pre-typhoon levels, despite covering only 35% of the city's requirements (City Government of Tacloban, 2014).

LMWD had, in recent times, started taking the necessary measures to prevent damages from a new typhoon. The final reports of LMWD for the USAID's 'Be Secure' project summarize the utility's vulnerability and risk assessment analyses results: considering the PAGASA-projected increase of rainfall during monsoon periods, the inundation and siltation of Binahaan intake facilities is expected, affecting the operation of WTP 1 and 2, as is the total damage of the Dagami facilities under the same scenario; similarly, the decrease rainfall during the dry season may cause low flows during the summer; moreover, the forecasted temperature increases may provoke a higher demand by consumers and facilitate algal blooms, while the expected sea level rise of 0.23 m may increase the exposure of coastal facilities to storm surges. Finally, future storms strong winds (of over 200 km/h) can be responsible for power outages and damages to infrastructures and electrical/mechanical equipment – hence, the retrofitting of the generator building advised, together with the embankment of surface water intake structures (Homer, 2016). Amongst the lessons learned from the Haiyan's experience, LMWD highlights now the importance of: stocking up on fuel (for at least 15 days of operation) and chemicals (up to 3 to 4 months of consumption); a portable water filtration system; a resilient communication system; cleaning tools and first aid kits; an alternative raw water line; set aside calamity funds; and back-up databases as well as to secure the electronic servers and other vital equipment (Abarquez, 2016).

The water scarcity in Tacloban North

The lack of water supply in Tacloban North was known even before Haiyan, but afterwards it gained critical importance, considering the relocation efforts made by

the NHA and INGO's. Thus, the TRRP emphasized the need for a 'comprehensive water resource master plan (...) to be a primary responsibility of the local government', including 'not only the improvement of existing water supply, development of a new/sustainable water source, improvement and upgrading of water distribution system and the management of consequent wastewater' (City Government of Tacloban, 2014). Tacloban's city masterplan for Tacloban North development summarizes several solutions for these water supply constraints, which are mentioned also in the city's TRRP, and that have been discussed with the various stakeholders on the 2016 and 2018 fieldtrips. A total investment on the water supply is estimated by the LGU to ascend to PhP 743.1 million (with an investment of PhP 729 million expected from LWUA¹¹), divided in short-term, medium-term and long-term solutions:

- 1) **Short term solution – Provision of bulk water using tankers:** As a short-term solution, the city's LGU has deployed a combination of water bought from a private company (who's water catchment is somewhere in Tigbao) sent by trucks, three times a week, to refill small reservoirs located in the resettlement areas, so as to supply the relocated families. In parallel, LMWD also provided potable water: two large underground tanks were planned, one next to San Juanico Bridge to serve the proposed commercial/agro-trading facilities, and another for the new resettlement sites. The distribution was then provided by water trucks – but, contrarily to the water supplied by the LGU, this supply was not free of charge. Overall, this solution was never sufficient: the LGU-contracted and the LMWD trucks altogether did not provide enough water for the communities at north, but the water utility claimed to lack the means to acquire new trucks. Even worse, the trucks used by the LGU were not real water transport vehicles but adapted trucks with tankers. For this reason,

¹¹ As of March 9th, 2018, a PhP 565 Million from LWUA was still on a bidding uncertainty (after the bidding process failed twice, and the fund being available since 2014).

they broke easily and water loss was significant. This solution provided only circa 100 liters per family per day (20 L/person.day, or 1 jug of water, considering the average household of 5 people). This was way below the minimum required: following LMWD's calculations, for the 10.217 families living in Tacloban North at the time (early 2016), 1.026 m³/day would be required, but the private contractor who managed the trucks distribution could only provide 380 m³/day. Nonetheless, these relocated communities did not seem to trust the quality of this water: by mistake, once one truck had written 'untreated water' instead of 'treated' and from thereon people started doubting the quality of the water provided. According to the interviews conducted in March 2016 with the LGU, there have been some situations of infant diarrhea as well, but their relation to the supplied water was never proved. In response, families were buying water jugs for drinking and cooking purposes, using the supplied water only for cleaning and laundry. As of January 2018, according to LMWD, communities relocated to Tacloban North still relied on this supposed-to-be short lived solution. This was because the distribution pipeline was still too far from the northern relocation areas. The supply trucks and community tanks present on the relocation areas are shown on Figures 2.24 to 2.29.



Figure 2.24 - Tacloban North permanent shelters, water supply truck (GMA Kapuso Village) (Personal archive, January 2018)



Figure 2.25 - Water jugs, Tacloban North relocation sites (Personal archive, March 2016)



Figure 2.26 - LMWD water distribution truck (Personal archive, March 2016)



Figure 2.27- Tacloban North temporary shelter water tank (Personal archive, March 2016)



Figure 2.28 - Tacloban North permanent housing water tank (Personal archive, October 2016)



Figure 2.29 - Tacloban North permanent housing water jugs (Personal archive, October 2016)

- 2) **Medium term – Deep Well Installation and Small Water Impounding Basins (SWIM):** In the meanwhile, LMWD proposed the development of a medium-term water supply system to be operational in early 2017, so as to avoid further delays on the relocation of the families. This was a mixed solution composed by infiltration wells at the Kawayan and the Barugu-an rivers, 20-ton water tankers, large reservoirs and the construction of permanent piping (connecting Tigbao to Tagboro, already thinking of the long-term solution ahead) (City Government of Tacloban, 2016). It was predicted the digging of three infiltration wells at Brgy. New Cabalawan, as Brgy. Bagacay and near the slaughterhouse; these wells should not exceed the capacity of 4 L/s, with depths from 80 to 100 meters. Complementary to the wells, it was expected the construction of three small basins to collect rainwater in the following small waterways: Bahagupi, Cabalawan and Tigbao. The collected water could be used for domestic purposes but could as well be tapped for the irrigation of farms and the existing 18-hole Golf Course in Bahagupi watershed (City Government of Tacloban, 2014). Slightly better than the short-term solution, this solution could supply 600 m³/day (not yet the 1.026 m³ demanded daily) acting only as a palliative, but it was expected to cost over PhP 159 million. (City Government of Tacloban, 2016). As of September 2017, LWUA had reportedly bided out this mid-term solution, while simultaneously investing on the distribution lines and the transmission line from downtown to the north that would serve the long-term solution described next. In October 2016, LGU pointed the mid-term solution to be unlikely to be developed, as the LMWD's proposal of expanding their current network using the old reservoir in *Barangay* 39 (part of the long-term solution) had its funding already approved.

- 3) **Long term – Harnessing surface water from Jaro:** A long-term solution has been prepared by LMWD, with the support of LWUA. Due to the large investment associated (PhP 527 million), this long-term solution came last in the TRRP measures. Its development was scheduled to start by the 1st semester of 2017 and, with an implementation window of 18 months, was expected to be capable of delivering water by mid-2018 (City Government of Tacloban, 2016). As of September 2017, LMWD stated that they had finished the surveys and topographic studies and were about to initiate the hydraulic studies and to prepare the documents for funding, bidding and constructing the new network. Therefore, this solution would still take two to three years to be fully implemented (i.e. no sooner than 2020). Technically, the solution most often presented comprised the embankment of a tributary of Binahaan River even more upstream (140 m), in the town of Jaro, with nearby dug wells to increase the water intake. Thus, this new solution does not comprehend a new WTP but only the implementation of infiltration galleries to maximize the operation of WTP1. The water should flow to the city through the middle range, in Sta. Fe, (80 meters above sea level) through a new 38 km transmission line – assuming that this difference of 60 meters is sufficient to provide the hydraulic thrust, exempting pumping needs (City Government of Tacloban, 2014).

In sum, as of January 2018, LMWD still supported the idea that Binahaan River was a good quality source of water, with enough flow to support a new intake infrastructure. The water district was granted a permit to extract 1 000 L/s and was only using 720 L/s for the two existing WTP so there was still room for expansion. Additionally, the old BOD stressed that the rivers and wells in Tacloban North, because of the local geology, did not provide enough water to meet the resettlement community demands (especially in the summer, March to May), and therefore Binahaan was still the best available solution. The new BOD, when consulted in early 2018, seemed more open to the possibility of exploring the

northern rivers as complementary water sources. In fact, the city's LGU had always supported that the capacity of the LMWD long-term proposal, as it stands, would not be sufficient to provide the water required for the Tacloban North residents, if the NRW percentages were not addressed (City Government of Tacloban, 2016). This LGU concern was shared with USAID, as stated in their report, presented hereafter. Moreover, the city-appointed BOD had discovered that the old management team kept some valves on the distribution lines half closed. This would assumingly provoke pressure problems and thus discourage the requests for new connections. The new administration believed (as of January 2018), that the complete opening of those valves would be sufficient to improve the network problems, felt in some parts of the city. Additionally, they supported the idea that addressing the NRW volumes was the key to increase the available volume of water. In spite of those being their immediate actions, they saw the exploitations of the northern rivers to place new catchments as a long-term necessity.

Northern Rivers Catchments Proposal

Even before the devastation provoked by super typhoon Haiyan, the water scarcity issues were well known by the local entities, so as the insufficiency of Binahaan River for supply purposes. A possible solution (for the long term) that had been discussed before, was to harvest water from two northern rivers of Leyte: Pongso River and Cabayugan River. In fact, interviewed members of the LGU (as of January 2018) claimed that the city already held the permits to explore these northern sources.

This idea was corroborated by USAID in the context of the project Be Secure, in which six provinces were chosen to be helped, among which Leyte and Tacloban City within. In March 2015, this INGO published the report "Tacloban City North Bulk Water Supply Project – Rapid Feasibility study", a study to "assess the technical and economic feasibility of developing an independent water supply and

piped water distribution system that will meet the water demand projections for the City of Tacloban Northern Area” – which main goals were to “implement a climate-resilient water supply system” and “increase the capacity of the water supply provider to develop and maintain sustainable water supply programs”. Moreover, this rapid feasibility study would assist the LGU in establishing a Public-Private-Partnership (PPP) to supply water to the northern portion of the city (USAID, 2015). For this reason, and because a lot of information for this dissertation was obtained from Be Secure’s reports, from here on the northern Leyte rivers exploration solution shall be denominated as ‘USAID solution’.

The water supplied by LMWD from Binahaan River was herein declared not to be enough to serve the current and estimated future demands, especially considering the high NRW rates that affected the existing transmission and distribution lines after Haiyan. USAID teams have then studied the viability of two new water sources, also in Jaro (approximately 30 km west of Tacloban), to supply Tacloban North: the Pongso and Cabayugan Rivers.

The two watersheds are characterized forwardly:

- **Pongso River** watershed (Figure 2.30) is adjacent to and north of Cabayugan watershed. Its headwater is located in Mount Mamban and it runs in northwestern direction. Two tributaries merge with Pongso close to the proposed extraction point: Silaua River, 11 km long, which traverses along the watershed’s south boundary and Tunga River, 9 km long that traverses along the north boundary. From the extraction point (180 m), the river then flows in the northeast direction, passing through the town of Tunga and continuing to join Himinglos River before its discharge to Carigara Bay. Pongso’s watershed elevation varies from 1 100 m on the south to 1 000 m on the north. It has a triangular shape at the proposed extraction point, totaling 9 km in length and an area of 31 km². As seen on

Figure 2.30, this waterway has direct uses by the local communities, which could raise a concern about the raw water contamination.



Figure 2.30 - Pongso River (USAID, 2015)

- **Cabayugan River** (Figure 2.31), in its turn, has bounded multi peaks (from east to west): Alto Peak (1 100 m), Mount Janagdan (1 120 m), and other 1 075, 968, 1 215 and 1 185 m unnamed peaks. Three tributaries run within the watershed: a south leg river with 8 km, a central river with a length of 10 km and a north leg river with only 6 km long. The elevation of the USAID's proposed extraction point is 150 m. From there, this river flows NE towards Jaro and joins Mainit River into a wide wetland. During extreme rainfalls, however, the floodwaters are impounded over the wetland and may eventually discharge northward to Yapan-Pongso-Himonglos River and finally to Carigara Bay. This egg-shaped watershed has a major length of about 7 km in NE direction, totaling 34 km².



Figure 2.31 - Cabayugan river bank (USAID, 2015)

In the assessment of Pongso and Cabayugan Rivers as surface water sources (Figure 2.32), USAID estimated that the flow capacity of those waterways, was of 43 000 - 70 000 m³/day and 47 000 - 76 000 m³/day, respectively. However, the National Water Resources Board (NWRB) has issued water right permits of only 25 000 m³/day for each of these two rivers. Thus, the Pongso and Cabayugan combined extraction rate for the USAID proposed solution would be of circa 50.000 m³/day (equivalent to 0.58 m³/s).

This was considered sufficient to serve Tacloban North water needs, as the demand projections for 2040 were estimated to be of 46 100 m³/day (considering the nine most densely populated *barangays* in Tacloban North only, as the remaining sparsely populated areas connection could not be immediately viable in the development of the system.)

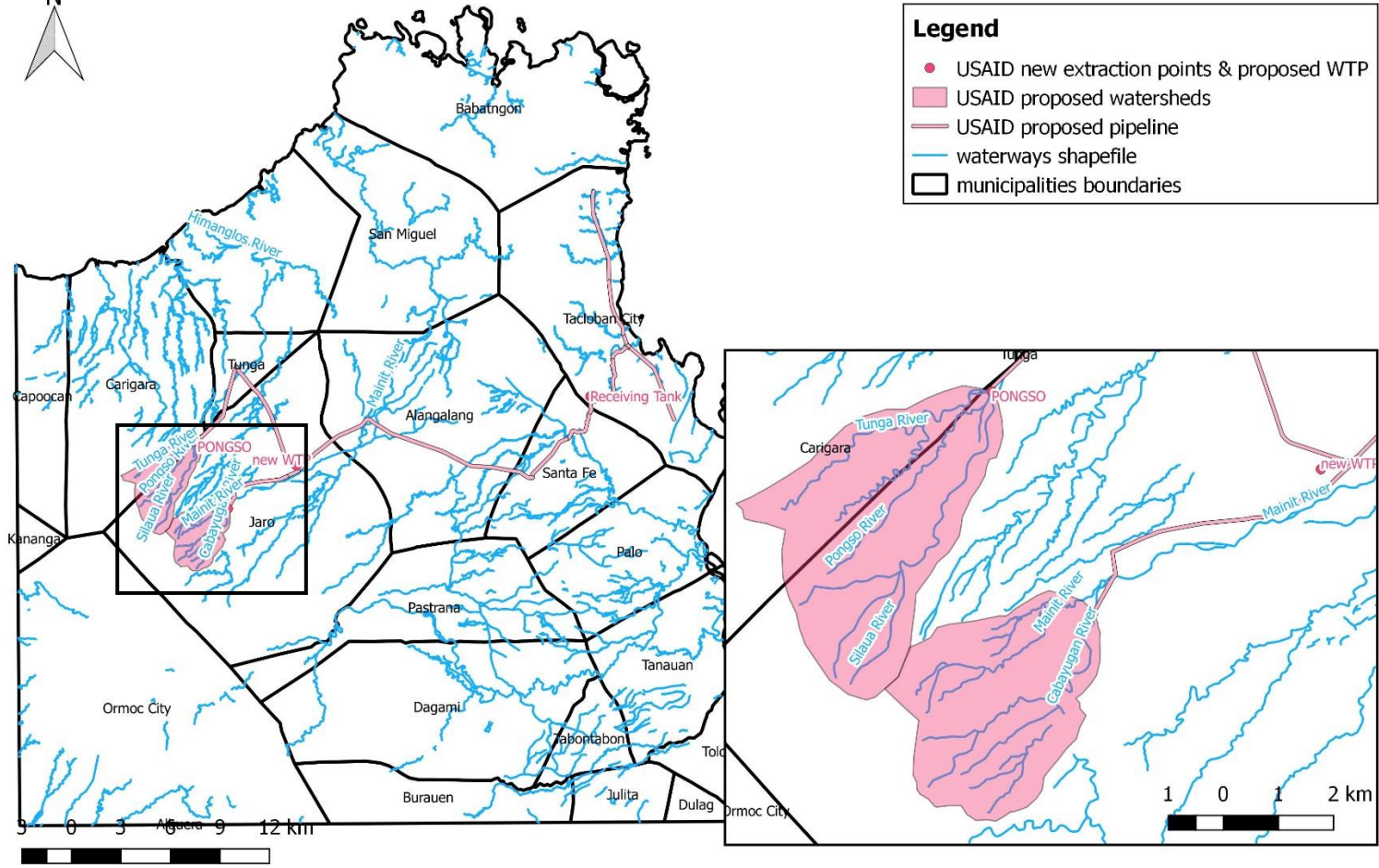


Figure 2.32 - USAID proposal for water supply based in Pongso and Cabayugan Rivers

In this proposal, raw water harvested on both intake structures would merge in a new water treatment plant, with a capacity of 50 000 m³/day located in the village of Jaro (see Figure 2.32 for the northern supply proposal scheme). This new WTP would operate on a compact conventional chemical treatment, according to the quality of the two rivers raw water, consisting of in-line coagulation and flocculation, plate clarifiers and filtration. Forwardly, the recommended route for the treated water would start in Jaro, traversing the municipalities of Alangalang and Sta. Fe and then turns left from the junction going to *Barangay* Salvación, Tacloban City. From the receiving tank, a control valve would regulate water towards a 11 km transmission line to Tacloban North, and towards the 7 km line to Tacloban South (downtown).

This is an alternative route to the one currently used by LMWD as a transmission route from Binahaan River. It has the advantages of traversing Brgy. Salvacion, which is under the jurisdiction of Tacloban City and not the municipality of Palo – political issues between Tacloban and Palo were feared to affect the project acceptability and could hinder or push back the construction/operation. Moreover, this alternative track would pass on less urbanized areas, so its construction would affect less residents and would be 13 km shorter than the existing line. However, the track along *Barangay* Salvacion has a peak elevation of 72 m, which could be a hindrance in the hydraulic design.

3. WATER RESOURCES RESILIENCE

Chapter Abstract

Bearing in mind the water supply constraints affecting Tacloban, namely the northern relocation areas, the need of a detailed hydrological study of that region becomes compelling. On this chapter, the coupled hydrological model and GIS, QSWAT, was used to quantify the impacts of climate change on the region's water resources. Starting from the local historical data series and affecting it with the PAGASA-projected changes of rainfall and temperature, the flow variation of the three most relevant waterways was determined. This included Binahaan River, where the current LMWD catchment is located, and also the two northern rivers, Pongso and Cabauygan, representing potential alternative water sources for Tacloban North – as previously considered by the city and studied more thoroughly by USAID after Haiyan. The resilience of these waterways as water sources was thus quantified through one single indicator: the percentage of days in which the river flow could not meet the proposed water extraction rate.

The modeling results have supported the initial premise that Binahaan River is not a resilient water source, particularly on the period of March to August, when on a significant number of days the river flow is insufficient to meet the demand – with 16.2% and 20.3% of days for MAM (March, April and May) and JJA (June, July and August), respectively. Despite the overall increase of water availability consequent of the increase of rainfall, climate change is likely to aggravate the water scarcity situation, in the sense that it could accentuate the seasonality of these rainfall patterns. Similar results were obtained for the resilience of the two northern rivers, leading to the conclusion that, regardless of the supply scheme chosen, the construction of a flow regulation structure is strongly advised to address the seasonality felt on these waterways.

3.1. Introduction and Objectives

The process of transposing climate model-generated information to a hydrological model is, as depicted by Xu and Halldin (2005), achieved by an alteration of the present hydrological conditions. To do so, one first needs to determine parameter values of the hydrological model in the study basin, recurring to climatic inputs and observing river flow records for validation. The second step consists of imposing a perturbation on an historical time series of climatic data, in accordance with climate change projections for the region. From here, the calibrated hydrological model runs with this altered series and the process is finalized with the comparison of the current and future hydrological characteristics.

In order to determine the climatic changes impacts on northern Leyte water resources, a hydrological modeling exercise was performed. To do so, following the method referred on the previous paragraph, the historical precipitation and temperature data records were affected by the PAGASA's projected impacts of CC in the region. The main objective of this analysis was, therefore, to assess how the variation of these two climate variables would quantitatively affect the local rivers flows. In this regard, the resilience of Binahaan River as a water source for LMWD network was determined. Responding to the water scarcity in Tacloban relocation areas, two northern rivers were included on this analysis – Pongso and Cabayugan Rivers. The inclusion of these rivers behavior had the parallel purpose of determining their resilience as water sources, if they were ever to be used as such by the local water utility.

Finally, in a more academic perspective, this chapter had the goal of reinforcing the increasingly significant role of hydrological modeling on climate change impact studies – specifically on resilience enhancing projects.

3.2. Methodology

3.2.1. Model introduction

The hydrological model designed as SWAT (an acronym standing for Soil and Water Assessment Tool) was developed by Dr. Jeff Arnold in the early 1990s, as a request of the United States Department of Agriculture's - Agricultural Research Service (USDA-ARS) to help predict the impacts of land management practices on water, sediment and agricultural yields, comprising complex watersheds and a variety of soils, land uses and changing conditions (Neitsch, et al., 2011).

Since it has the nature of a continuous time model (i.e. not as adequate to simulate single-events, but rather long-term changes), SWAT enables users to address gradual environmental problems – being increasingly used for climate change impact studies, among others, all over the globe. For instance, the model can simulate the impacts of temperature changes and soil water deficit on vegetation growth or erosive response, besides the effects of global climate changes on the hydrological balance and, therefore, on the processes that determine surface and base flow generation (Serpa, et al., 2015).

In its turn, QGIS is an acknowledged open-source Geographic Information System (GIS), created in May of 2002 to make GIS tools accessible to anyone with a computer – in opposition to the traditional GIS paid softwares (QGIS Project, 2016). It supports several raster and vector formats and offers many common GIS functionalities, provided either by core features or plugins, such as QSWAT. QSWAT is, therefore, the interface of SWAT for QGIS, which was used on this dissertation (Version 3.4.5 and previous) . QSWAT interface presents a three-step configuration to be followed by the user in order to prepare the SWAT simulation (Dile, et al., 2016), followed by a fourth step for output analysis:

- **Step 1: Delineate Watershed**, where the user selects the elevation map grid to be used and can optionally burn an existing stream network and a

predefined watershed. The threshold for creating the subbasins is then set, either by area or number of cells defined, as the minimum number of cells (or area units) required to form a stream - considering that a cell will be made part of a stream if it has at least this defined number of cells draining to it. Accordingly, a subbasin is delineated as the area draining into a stream and the user is given the option of merging resulting subbasins if required;

- **Step 2: Create HRUs**, in which the user sets the Hydrological Response Units. In modeling exercises is common to divide the studied watershed into smaller sub-watersheds, or subbasins, especially when they differ in terms of soil and land use properties, which can have different impacts on the site's hydrology. SWAT offers the possibility of dividing these subbasins into yet smaller partitions, defined as Hydrological Response Units (HRU). These HRUs are areas within the subbasin which share a unique land use, soil, and/or slope. This subdivision enables the model to reflect, for instance, differences in evapotranspiration for several crops and soils. Thus, runoff is predicted separately for each HRU, which is believed to increase accuracy and give a better physical description of the water balance equations (Neitsch, et al., 2011). On this step, both land use and soil maps are required, together with their respective look-up tables that should be previously loaded to the program. The higher the number of HRUs, the more representation of the spatial variability of land use, soils and slope. At this point, Elevation and Land Use/Soil reports become accessible: whilst the elevation report gives information about how much land there is for some given elevation, the land use and soil report lists the land use, soil and slope-band areas for each subbasin;

- **Step 3: Edit Inputs and Run SWAT**, is the final step in which the input tables regarding climatic data are provided by the user – such as the Weather Generator table and several table files for rainfall, temperature, solar radiation, wind speed and relative humidity. Posteriorly, the user can run different SWAT simulation conditions and implement different management scenarios. To run SWAT, it is required to define the period of simulation, the time step (daily, monthly, yearly), and the desired output file variables;
- **Step 4: Visualize**, in which, to analyze the simulation outputs, the user may choose from: Static Data (where a single summary value is created for each subbasin, reach or HRU and displayed as a map), Animation (in which there is an animated display at each time step) and Plot (supporting the creation and display of plots of selected variables). Plotting option can be very useful hence it allows the rapid display of output data in graphical form, plotting values against time. Moreover, data can be saved in a comma-separated value (.csv) format and further opened on a spread sheet software like Microsoft Excel, supporting a more extensive analysis. SWAT output visualization can also be done through **SWAT-Check**, an embedded tool used to summarize results, which can also provide warnings that can help to improve them. This tool includes graphically summarized information on the Hydrology (the most relevant for this dissertation), but also on Sediment, Nitrogen and Phosphorus Cycles, Plant Growth, Landscape Nutrient Losses, Land Use Summary, Instream Processes, Point Sources and Reservoirs. For more detail on QSWAT functioning, set up and outputs visualization options, refer to the work of Dile, et al. (2016).

In QSWAT, as for most hydrological models, water balance equations are the driving force behind the simulation of the watershed dynamics. A hydrological system can be separated into two main components: the land phase and the water phase. The **land phase** which controls the amount of water, sediment, nutrients and/or pollutant loadings to the main channel on the basin simulated by SWAT is based on the following equation:

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (\text{Equation 1})$$

where SW_t represents the final soil water content (mm H₂O) on the end of day i , SW_0 the initial soil water content on the same day (mm H₂O), t is the time (days), R_{day} is the amount of precipitation (mm H₂O), Q_{surf} is the amount of surface runoff (mm H₂O), E_a represents the parcel of evapotranspiration (mm H₂O), W_{seep} is the amount of water infiltrating the vadose zone from the soil profile (mm H₂O), and finally Q_{gw} represents the amount of return flow for that day (mm H₂O). For further detail on these variables calculation, refer to the work of Neitsch (2011).

Once determined the flow of water to the main channel through the land phase equations, SWAT starts computing the **water phase**. The water or routing phase, is defined as the movement of water and sediments through the channel network of the watershed until the basin outlet (Neitsch, et al., 2011). Although, for the present dissertation, attention being given only to water quantification and hydrodynamics, it should be noticed that SWAT model is capable also of simulating water quality variables, sediments, nutrients, pesticides and other pollutants behavior within the watershed. The model is capable of simulating not only the masses flow in the channel (transport, deposition, diffusion and dilution) but also other reactions that take place in the streams (such as biodegradation and

chemical transformation). As water flows downstream, a portion might be lost due to evaporation and transmission through the channel bed, or it might be captured for agricultural or human uses. Alternatively, flow on a stream might be augmented by the fall of rain directly on it, or through the addition of water from alternative point source discharges. SWAT uses Manning's equation to define the rate and velocity of the open channels flows (Neitsch, et al., 2011).

3.2.2. Input data

Elevation and waterlines maps

On Step 1 of the QSWAT Setup, the watersheds are created based on elevation layers (required) and a stream network shapefile (optional). The DEM (Digital Elevation Model) raster file used for Tacloban simulations was obtained from the Earth Explorer platform - a database from the United States Geological Survey (USGS, 2015). The obtained 30 m grid was then clipped in QGIS to show only Tacloban City and northern Leyte (Figure 3.1). This allowed for more rapid simulations hence the model had a smaller area to process. The same clipping window was used for the remaining maps.

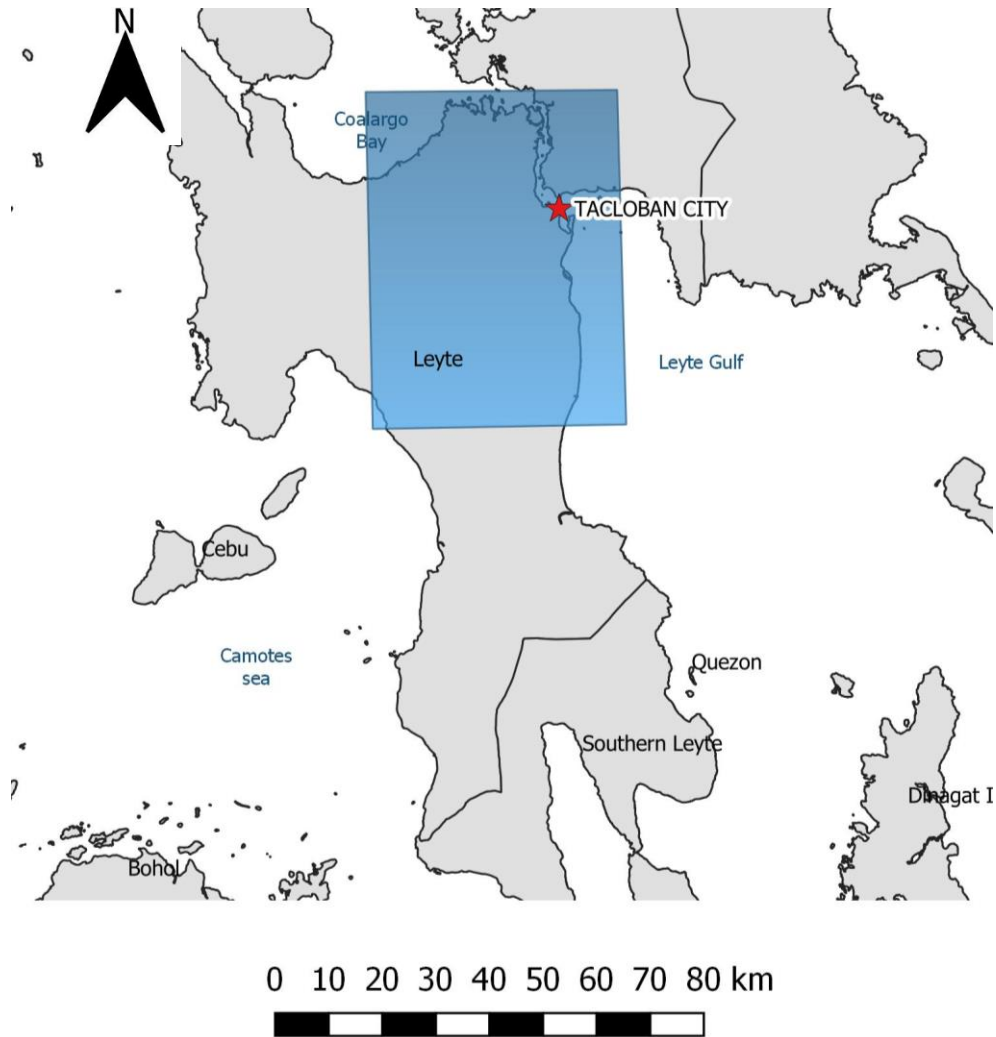


Figure 3.1 - Clipping window executed for SWAT analysis

As can be seen on Figure 3.2, this DEM represented the existing orographic features for Leyte, namely Sta. Helena, the highest mountain range in central Leyte, and the coastal range of Naga-Naga. It is also evident the low altitude of the coastal stripe where Tacloban City is located (most of it below 12 m), which was determinant for the inland propagation of Typhoon Haiyan’s storm surge, as referred.

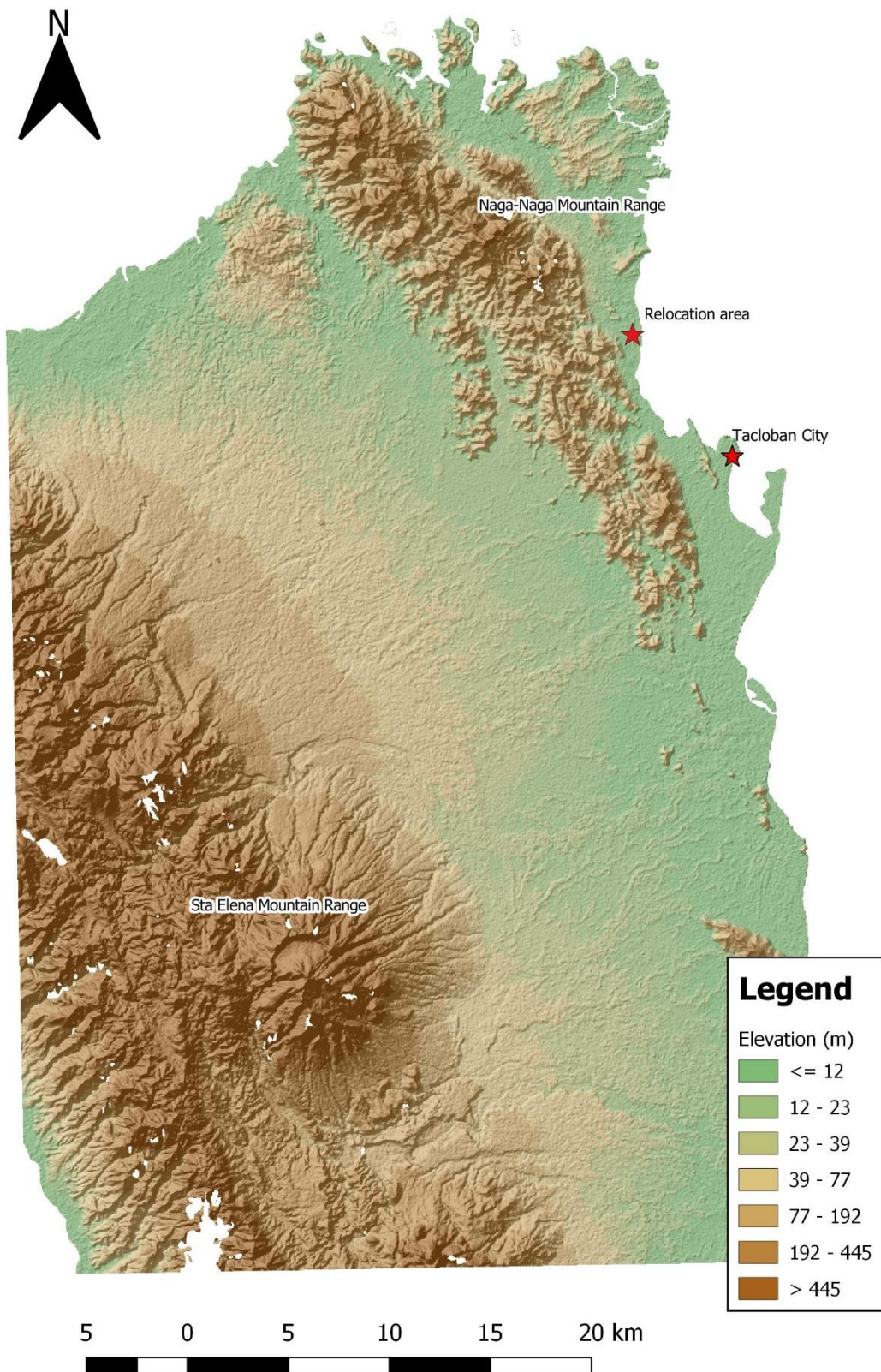


Figure 3.2- Input DEM used by QSWAT simulation (original map extracted from USGS, 2015)

Although not required, a stream network shapefile was used, to give the model some guidance for drawing the waterlines in the study area – otherwise they would be based only on the DEM file. This waterlines shapefile was obtained from the database DIVA-GIS, available online (DIVA-GIS, 2015). Again, it was clipped to show only the study area (Figure 3.3). The existing waterways seemed coherent with the chosen DEM, with the springs located on the deeper slopes and flowing towards the coastline. It is notorious the presence of the Binahaan River, one of the most prominent rivers on the region, and Pongso River, in Northern Leyte.

It was then required to define a threshold for the watersheds delimitation: the threshold of 50 km² was considered adequate to match the created stream network, providing sufficient detail for the objectives of this study. If a smaller threshold was used, a higher number of subbasins would have been created, making the simulation too complex for the scale of analysis intended.

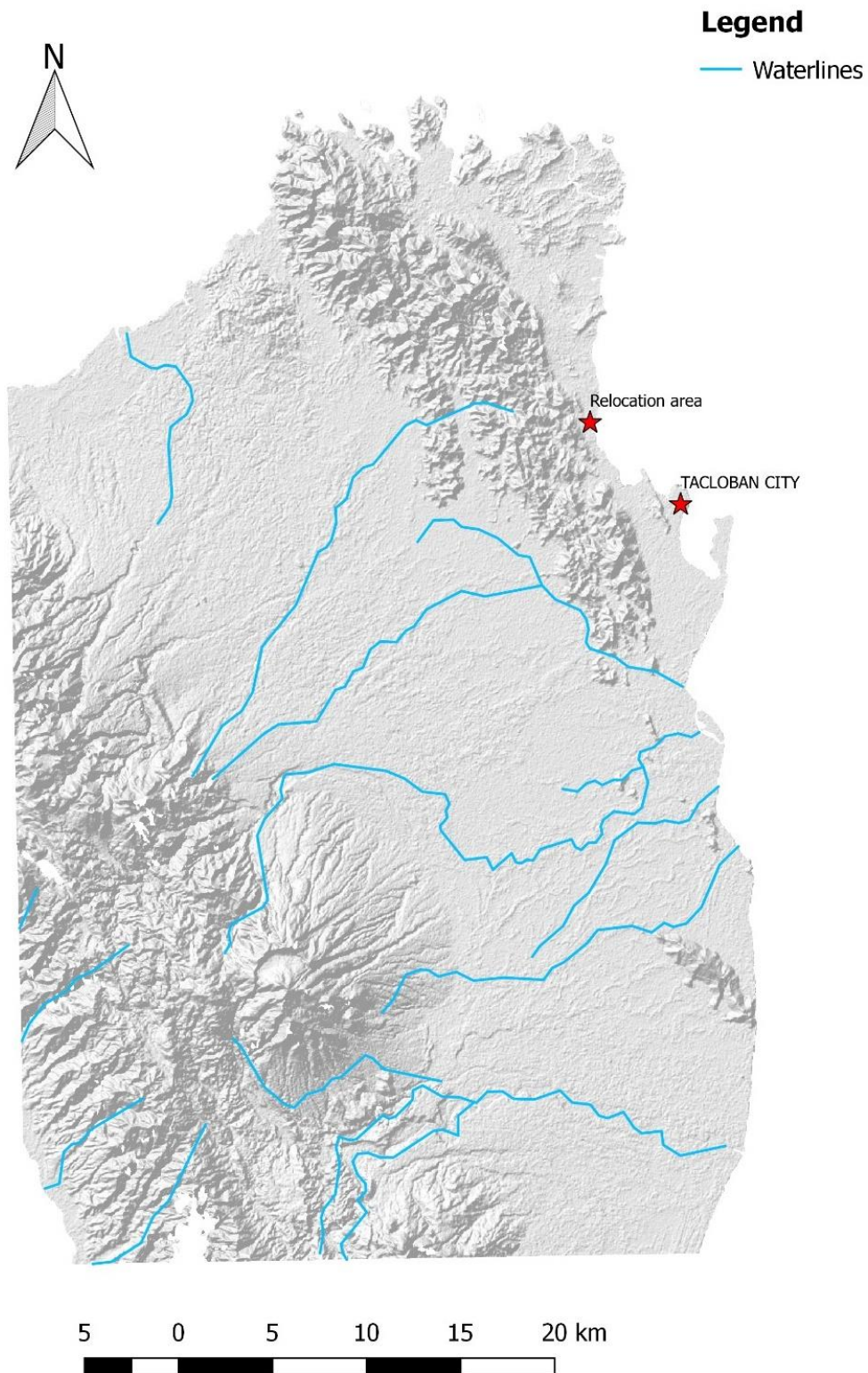


Figure 3.3- Input waterlines shapefile used by QSWAT simulation (original map extracted from DIVA-GIS, 2015)

Soil and land use maps

Land use and soil maps are required in Step 2 for the creation of HRU. Land use data was downloaded from the WaterBase database, a service provided by the United Nations University with the aim of advancing the practice of Integrated Water Resources Management in developing countries. This data base reads the land use data from GLCC – Global Land Cover Characterization, a series of global landcover classification datasets. These are based primarily on the unsupervised classification of 1 km AVHRR (Advanced Very High-Resolution Radiometer) 10-day NDVI (Normalized Difference Vegetation Index) composites. The AVHRR source imagery dates from April 1992 through March 1993 (UNU-INWEH, 2016), meaning that these land use maps can be outdated. Moreover, they do not reflect the devastation left by the passage of super Typhoon Haiyan in Leyte (and subsequent reconstruction) which affected both urban and agricultural uses.

The land cover map utilized (Figure 3.4) depicted a majority of croplands, mostly the subclasses of ‘woodland mosaic’ and ‘irrigated cropland and pastures’. Some forested areas were identified, mostly located on the deeper-sloped areas on the two main mountain ranges. As expected, for the whole island of Leyte the area classified as urban was minimal.

As for the soil map (Figure 3.5), it was used the 250 m grid from the database SoilGrids. SoilGrids is a system for automated soil mapping based on global soil profiles and environmental data, generated by machine learning algorithms. It contains predictions for a selection of soil properties (such as organic carbon content, pH, texture fractions, bulk density, coarse fragments and cation exchange capacity) and also soil classes, recurring to FAO’s World Reference Base soil classes and USDA Soil Taxonomy suborders. This project is owned by the International Soil Reference and Information Center (ISRIC), based on the campus of Wageningen

University and Research, Netherlands, and is updated on a regular basis, with its data being increasingly used to support environmental studies (ISRIC, 2016).

The soil map hereby utilized as input revealed a majority of Acrissoils and Ferrasoils, which is coherent with the information found in literature regarding the soil classes present in Leyte. Only clipping and re-projecting were then necessary to have these maps ready for the simulation. The standard land use and soil lookup tables (namely `global_landuses` and `global_soils`), compatible with the maps from these sources, were by default included as QSWAT options.

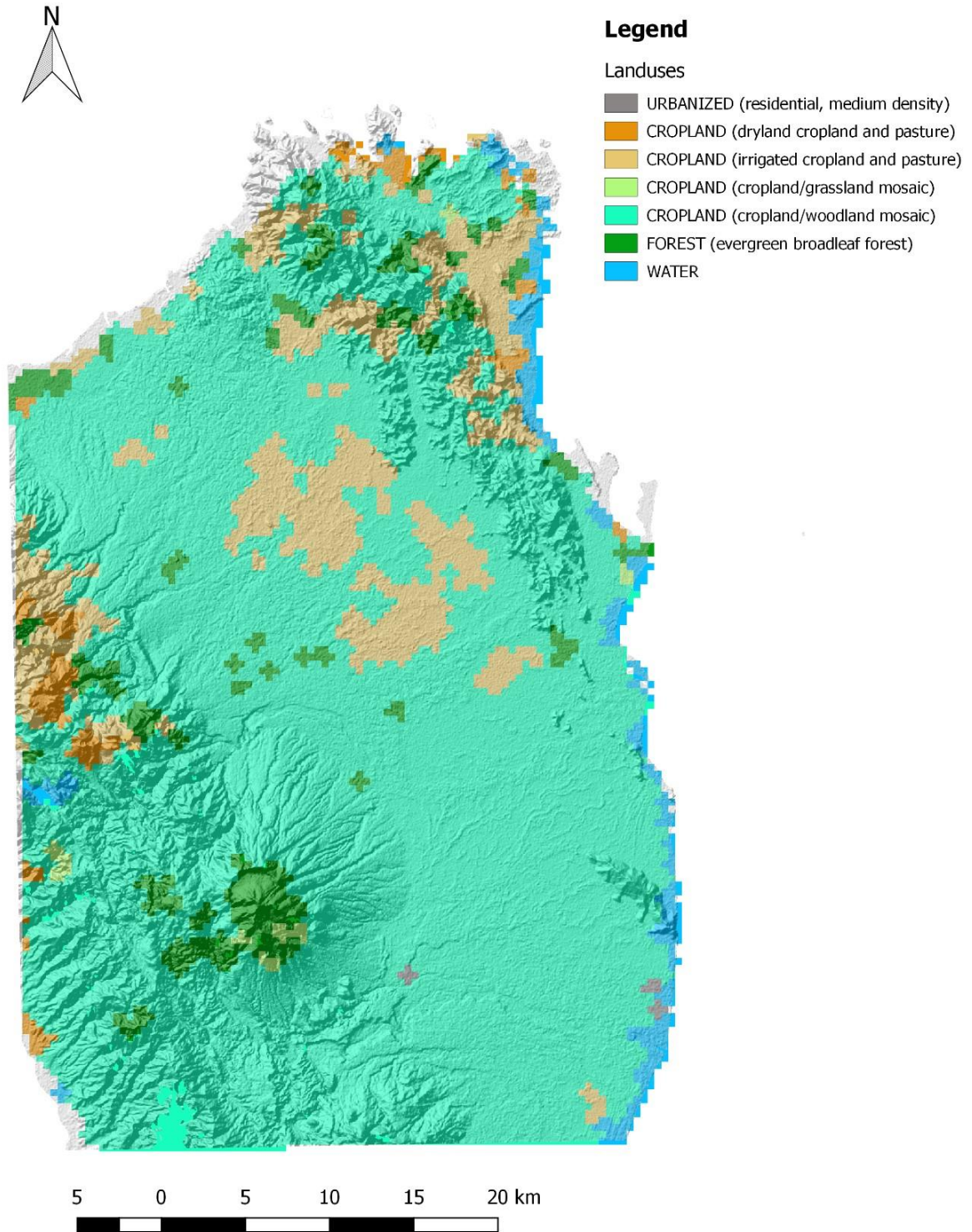


Figure 3.4 – Input land use map used by QSWAT simulation (original map extracted from UNU-INWEH, 2016)

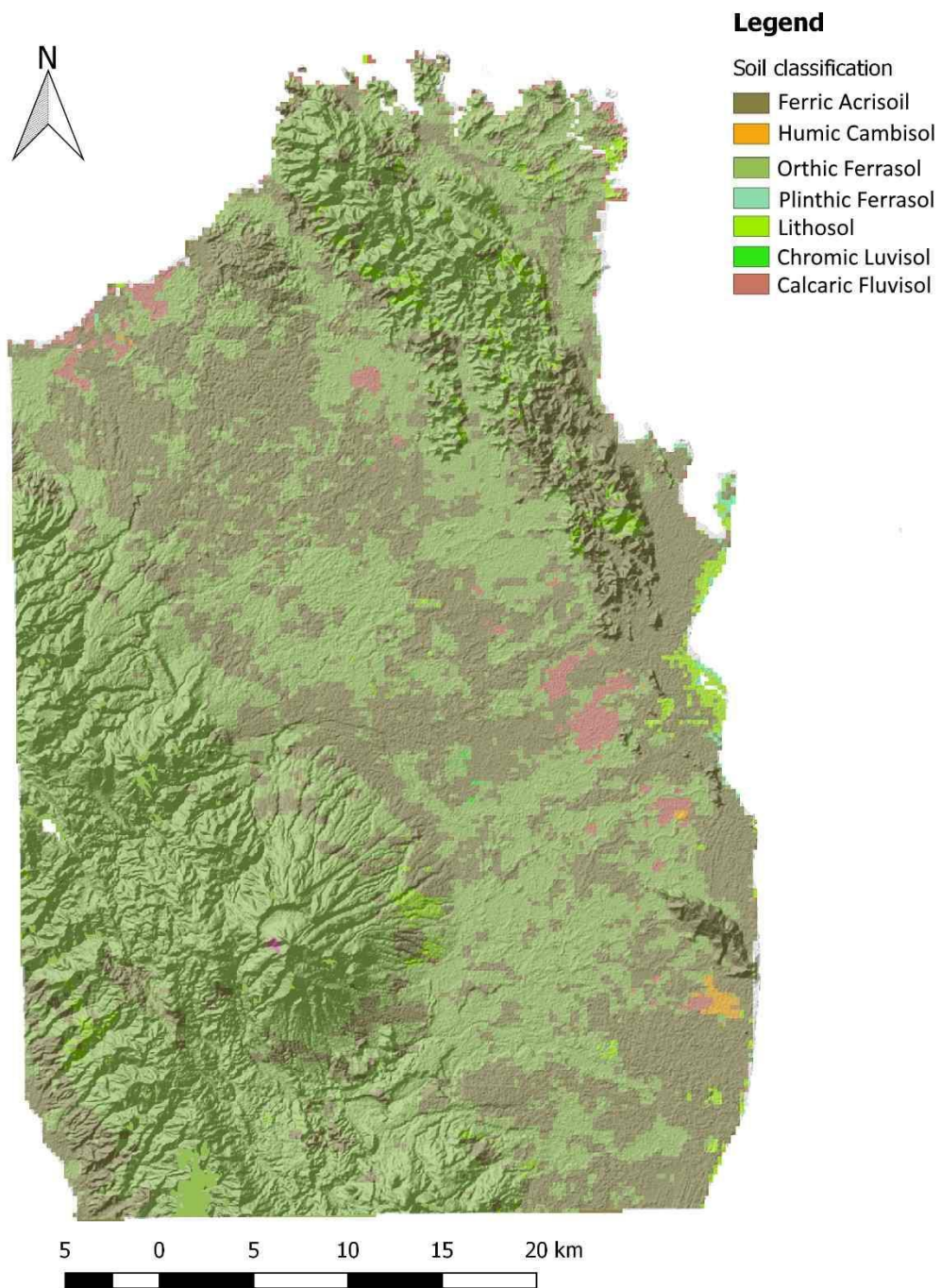


Figure 3.5 - Input soil map used by QSWAT simulation (original map extracted from ISRIC, 2016)

Climate variables data

On SWAT simulations the climate variables provide the moisture and energy inputs that affect the water balance (Equation 1, above) and determine the relative importance of its various components. The user may choose to read these inputs, introduced as table data, from an existing file or generate them recurring to WGEN (Weather Generator), a model incorporated in SWAT which was developed for the US watersheds only (Arnold, et al., 2012). Since the location of this case study was not in the US but in the Philippines, a personalized weather generator file was created. This file creation was guided by the work of Arnold et al. (2012) and Neitsch et al. (2011), and further detail on the climatic variables considered can be consulted on Annex III of this dissertation.

Climatic empiric data was obtained from the Tacloban PAGASA's synoptic station to serve as input for the modeling with QSWAT. Tacloban city station operates since 1951 in the peninsula that hosts the city airport (11°13'32.21" N, 125° 01' 29.92" E), at an elevation of 2.71 m above the sea level. The extracted data included daily records of:

- rainfall (mm);
- maximum and minimum temperature (°C);
- relative humidity (%) and
- maximum wind speed (m/s).

These series were obtained from January 1st, 1971, to December 31st, 2010, registering only one invalid record for rainfall in 2007, which was ignored. As explained forwardly, from the required data, only solar radiation records had to be obtained from a different station. Nonetheless, prior to using rainfall data for modeling purposes, the validation of the data series robustness is strongly advised.

The statistical validation of the rainfall series used can be consulted with detail on Annex II of this dissertation.

Correlation of weather data from different stations

The Tacloban data set from the local synoptic station included daily records of rainfall, maximum and minimum temperatures, relative humidity and wind speed but no daily solar radiation series. These records had then to be extracted from the Global Weather database (Global Weather, 2016). This is a digital database that hosts global weather data for SWAT, for a given location, already displayed in a compatible format. Its datum source is the Climate Forecast System Reanalysis (CFSR), from the National Centers for Environmental Prediction (NCEP), from the NOAA, US, which was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to estimate the state of these coupled domains. From the referred database, as shown on Figure 3.6, the closest 'station' to Tacloban was 1111250 (see Table 3.1). It should be noted that it does not correspond to a real station with empirical data, but only to a point of a model-generated matrix of this GCM. This point was located circa 16 km from Tacloban and reported a similar elevation (of 4.00 m, comparable to 2.71 m of PAGASA's Tacloban station).

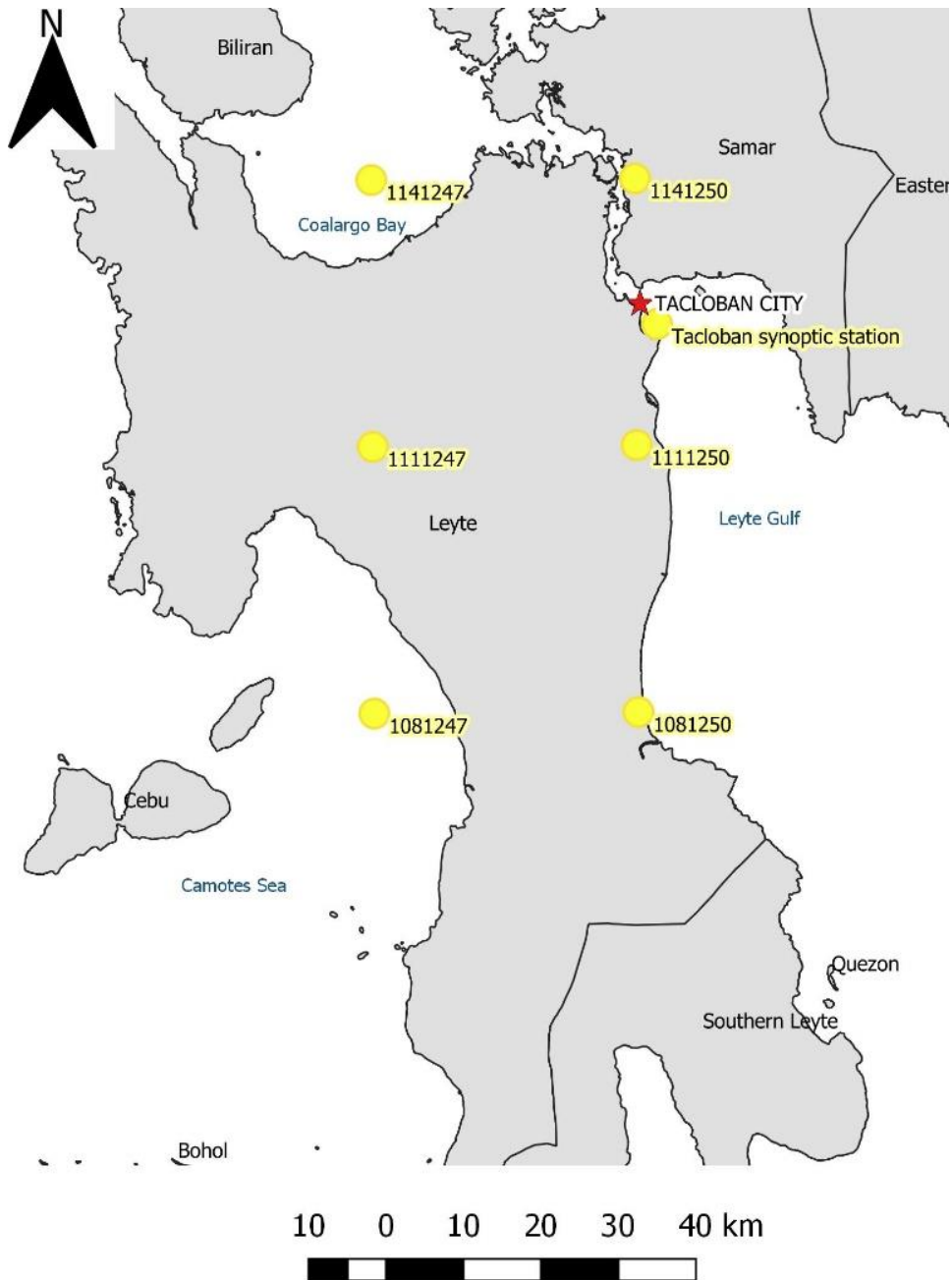


Figure 3.6 - Location of PAGASA's Tacloban synoptic station and surrounding Global Weather stations

Table 3.1 - Tacloban and 1111250 stations comparison

Station	Latitude	Longitude	Elev.	Data period	Source
Tacloban	11°13'32.21" N	125°01'29.92" E	2.71 m	01/01/1971 – 31/12/2010	PAGASA
1111250	11°5'2.76" N	125°0'0" E	4.00 m	01/01/1979 – 31/07/2014	Global Weather

A time frame adjustment was then necessary to match the data from the two stations (the real synoptic station and the GCM grid point 1111250). Although Tacloban station had weather data records starting from 1971, station 1111250 series started only in 1979. Thus, some of Tacloban's early records were ignored on this analysis since it only made sense comparing data from the same time frame. Similarly, 111250 station had records until July 31st of 2014, but only those up until December 31st of 2010 (coincident with the most recent data for the synoptic station) were considered.

These data limitations conditioned the baseline scenario conception, which was then defined as the time period from January 1st, 1979, to December 31st, 2010 – a sufficiently long series according to the literature-recommended length of 30 years for climate studies. Thereon, a total of 11 590 daily records for rainfall, temperature, wind speed and relative humidity were used (N= 11 590).

To validate the use of the Global Weather solar radiation series, a simple correlation function was applied to determine the correlation coefficient (r) between the Tacloban and 1111250 data. The compared variables were: daily rainfall, maximum and minimum temperatures, wind speed and relative humidity.

Table 3.2 shows the values of r obtained for the weather data series of Tacloban and 111250 stations.

Table 3.2 - Correlation coefficient results for Tacloban and 1111250 stations

	Daily series	Monthly series
Rainfall (mm)	0.301246	0.487289
Tmax (°C)	0.566159	0.722184
Tmin (°C)	0.357204	0.68648
Rel Humidity (dec)	0.452234	0.486042
Maximum wind Speed (m/s)	0.253396	0.188067

Despite these correlations being somewhat weaker than desirable and hence PAGASA's Tacloban station did not provide the required solar radiation data, this

information had to be extracted anyway from the 1111250 point record, for the period of 1979-2010. It is believed, however, that the fact of using solar radiation data from a different station should not have significant impacts on the modeling results, considering that the two stations are closely located, have a similar elevation and no relevant orographic occurrences between them. Moreover, from all the climatic variables enunciated, solar radiation is the one with the lowest spatial variability expected, as it is not influential by local factors as, for example, the wind speed could be affected by natural elevation or manmade infrastructures.

Likewise, maximum half hour rainfall records were not available from PAGASA's station, so they were too extracted from the same 1111250 grid point for the composition of the Tacloban's WGEN file (refer to Annex III for details).

3.2.3. Model calibration and validation

The calibration, and posteriorly, the validation of any modeling exercise outputs is an essential step to assure that the chosen model is accurately describing the real system. On a simplistic perspective, the calibration can be described as the tuning process of the model coefficients in order to adjust its results to real observed data (Coelho, 2009). In its turn, the validation of results is often processed by simply comparing them with real empiric data (without further adjustment of the coefficients). As referred by Coelho (2009), however, some authors defend that the separation between validation and calibration processes is artificial and they should be applied simultaneously.

The QSWAT modeling results for Tacloban were validated using a series of observed monthly average flow gauge records for the Sapiniton Gauging Station (in m^3/s), from 1985 to 2003, available on the aforementioned USAID report – these authors utilized Sapiniton river flow for the estimation of river capacity for Cabayugan and Pongso Rivers at their extraction points. These records were used considering the lack of other flow data from PAGASA, whose nearby water level

stations only held records starting in 2014. To assess the similarity of observed and obtained results, simple correlation functions were applied, either to monthly average flow records (m^3/s), either to the estimated total monthly superficial runoff (mm) for both basins.

3.2.4. Climate change scenarios

According to the Neitsch et al. model description (2011), climate change can be simulated with SWAT by manually manipulating the historical daily data series, and then running the model using them as input data to assess changes in the hydrological system.

This method is frequently defined in specialized literature as the **Change Factor (CF) Method**. In essence, this method modifies the observed historical time series, inflicting the projected differences between future and current climates, computed by climate models (either GCM or RCM) (Chen, et al., 2011). These perturbation factors are usually computed in a monthly basis, for each future time period (Minville, et al., 2008). With regards to generating future temperature daily series ($T_{fut,d}$), the CF method involves adjusting the observed daily records ($T_{obs,d}$) by adding the difference between future and current monthly averages ($\bar{T}_{fut,m}$ and $\bar{T}_{obs,m}$).

$$T_{fut,d} = T_{obs,d} + (\bar{T}_{fut,m} - \bar{T}_{obs,m}) \quad \text{(Equation 2) (Minville, et al., 2008)}$$

In its turn, as pointed out by Chen (2011) and Minville (2008), for the precipitation series the adjusted precipitation on the horizon period ($P_{fut,d}$) is obtained by affecting daily observed records ($P_{obs,d}$) with the precipitation ratio between monthly averages ($\bar{P}_{fut,m}$ and $\bar{P}_{obs,m}$).

$$P_{fut,d} = P_{obs,d} \times (\bar{P}_{fut,m} \div \bar{P}_{obs,m}) \quad (\text{Equation 3}) \quad (\text{Minville, et al., 2008})$$

Despite being frequently used in strategic-scale assessments of the hydrological impacts of CC, this method is not without problems: statistically, the baseline and scaled series are different in their mean, maximum and minimum, but all the other properties of the data remain unchanged (such as the range and variability). For example, the CF method application to one precipitation series does not affect the number of rainy days – meaning that the temporal sequence of wet and dry days remains unchanged, limiting the method’s efficiency in the study of persistent droughts. Hence, the procedure fails by admitting that the spatial pattern of the present climate remains unchanged (Diaz-Nieto & Wilby, 2005). Nonetheless, as long as it is not used to make projections of precipitation on a daily basis, the Change Factor method is still largely used in quantifying the impacts of CC on hydrology and its application is enforced when equivalent observational and/or GCM/RCM data exist for comparison purposes.

Climate change scenarios for the Tacloban region were hereby created recurring to the CF method, consistently with PAGASA’s official projections for Leyte, already referred on Table 2.3. Starting from the Tacloban’s weather station baseline series (1980-2010)¹² for precipitation, maximum and minimum temperatures, the daily records were affected by these variations to obtain two new series of projected CC scenarios for 2007-2036 and 2037-2065 – designated **CC2020** and **CC2050**, respectively. As for the remaining climatic variables (relative humidity, wind speed and solar radiation), the same records as the original series were used, due to the unavailability of projections for those.

¹² Despite the baseline series first year being 1979, by default the SWAT model excludes the first year of any series; thus, from hereon, the baseline scenario is defined as starting in 1980

3.2.5. Water resources resilience

The quantitative indicators of water supply are often limited by the premise that either there is or there is not sufficient water to satisfy a certain demand. This constitutes an obstacle for the quantification of water resources resilience, hence the definition of specific indicators is still scarce.

For the Tacloban case study, the output daily flows from the three rivers were subject to a resilience analysis which comprised the three modeled scenarios: baseline (1980-2010), CC2020 (2007-2036) and CC2050 (2037-2065). As a primary resilience indicator, it was determined the number of days in which the rivers flows were lower than the proposed water catchment rate, expressed as a percentage of the total number of days and discretized into four trimesters to assess possible seasonal variations of the water availability (Equation 4):

$$\% \text{ of days} = \frac{\text{Nr of days where flow} < \text{extraction threshold on trimester}}{\text{Total nr of days of the trimester}} * 100 \quad (\text{Equation 4})$$

Thus, in accordance with the water supply constraints that Tacloban faces and the supply proposals currently considered, two supply solutions were evaluated:

- the ‘business-as-usual’ scenario, in which LMWD keeps extracting water from the Binahaan River to supply the whole community (including Tacloban City and the seven supplied municipalities of Dagami, Palo, Pastrana, Sta. Fé, Tabontabon, Tanauan and Tolosa, plus the Tacloban North resettlement areas), considering current extraction rate of 0.72 m³/s;
- and the USAID-proposed solution of recurring to the northern Leyte rivers, Pongso and Cabayugan, as a complementary solution to supply the new resettlement areas (with an extraction rate of 0.58 m³/s, according to this organization’s report), whilst the City of Tacloban and surrounding municipalities continued to receive water from the Binahaan River.

3.3. Results and Discussion

3.3.1. Climate change scenarios

The daily rainfall series was obtained from Tacloban PAGASA’s synoptic station to serve as input for the modeling with QSWAT, for the period of January 1st, 1971, to December 31st, 2010¹³, adding up to 14 610 records¹⁴. The monthly averages obtained for this series and its respective standard deviations, are shown on Figure 3.7: the distribution of these averages is coherent with PAGASA’s Climatic Normals for 1951-1987 and 1987-2006, presented before. Moreover, it becomes evident the classification of Tacloban’s rainfall patterns as a Type II climate from the Corona Climate Classification, with a wet season from March to October and a period of more intense rainfall (the so called ‘wetter’ season) from November to February.

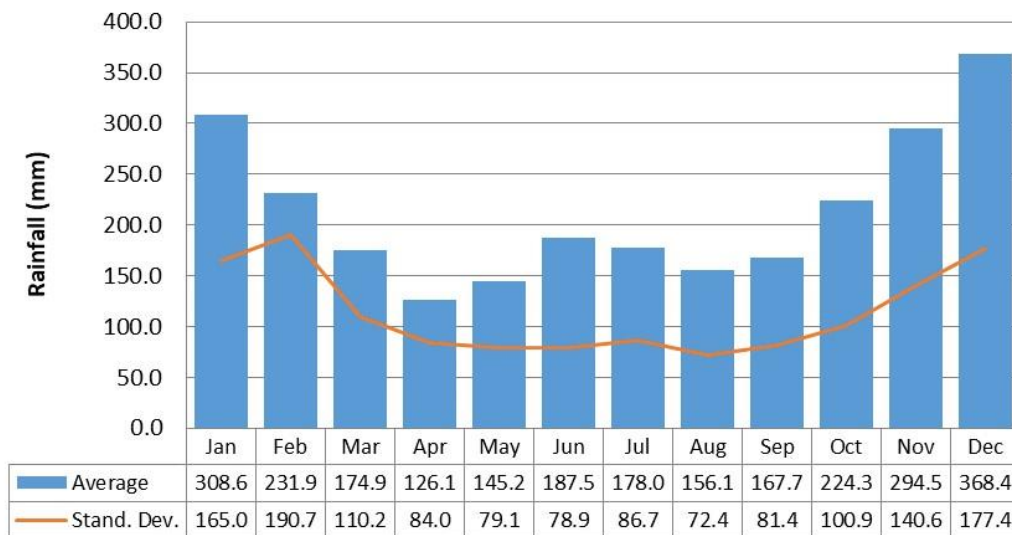


Figure 3.7 - Tacloban's synoptic station monthly rainfall data (1971-2010) - average and standard deviation analysis

¹³ In hydrological studies conducted in temperate climates, it is common to distinguish between the civil and the hydrological year, defined according to the rainfall seasonality (for example, in Portugal, starting on October). Hence this case study refers to a tropical climate, this distinction was therefore not necessary and the civil year was considered.

¹⁴ Despite, for modeling purposes, only 1979-2010 (due to the different time frames of considered stations) having been considered, hereby for the validation of the hydrological series the complete data set was analyzed.

Prior to using the rainfall data series for modeling purposes, its statistical robustness was evaluated by the adjustment of a distribution function. The annual average rainfall series obtained positive adjustments to the Gaussian Law (refer to Annex II for more detail). The viability of the rainfall records was therefore corroborated, and its use validated for the subsequent hydrological analysis.

From thereon, the rainfall climate change projections for CC2020 and CC2050 (Figure 3.8), in its turn, were generated via the CF method, applied to the synoptic station's data (as explained, only for the period of January 1st, 1979 to December 31st, 2010, used as a baseline scenario). Coherently with PAGASA's projections for rainfall, for the December-January-February, June-July-August and September-October-November trimesters the rainfall tends to increase, and it decreases for the March-April-May trimester.

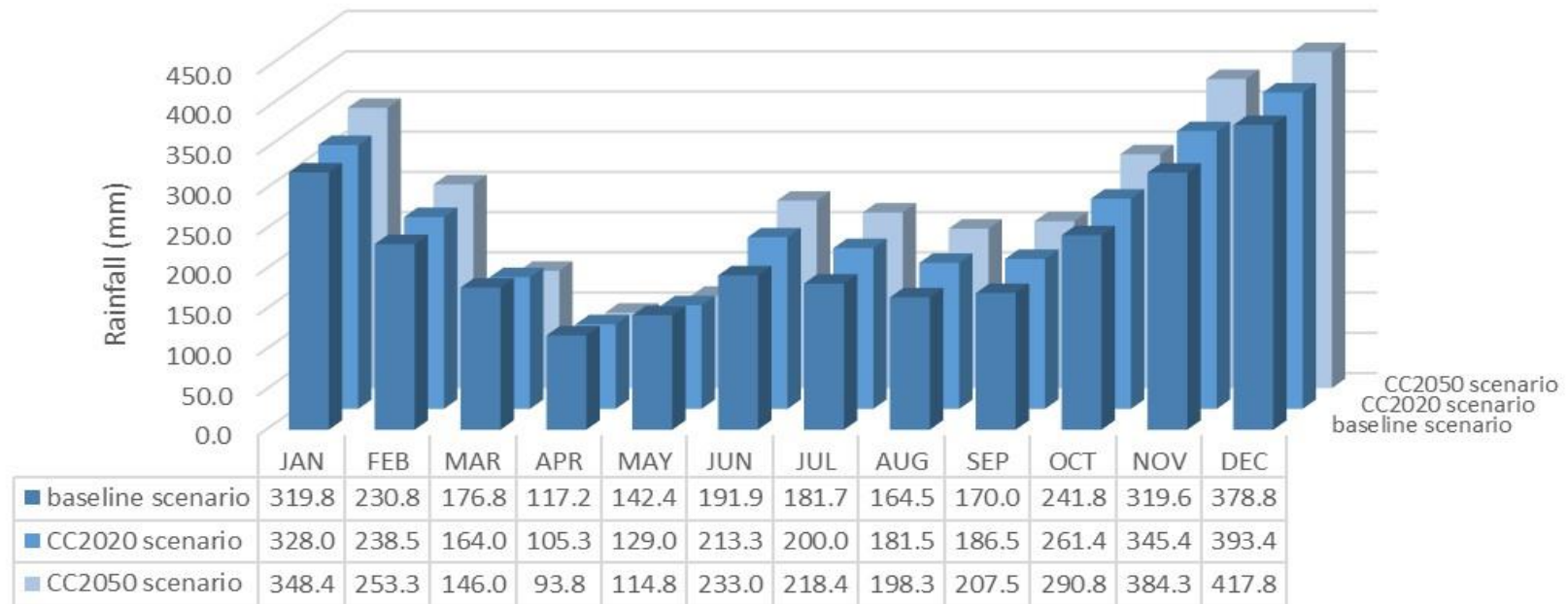


Figure 3.8 - Total monthly rainfall for baseline scenario (1980-2010) and projections for CC2020 and CC2050

3.3.2. QSWAT modeling outputs

On an initial stage, QSWAT delineated the hydrological system watersheds using the provided DEM as a baseline. For the whole study area, the model returned a minimum elevation of -2.00 m and a maximum of 1 329.00 m, with a mean elevation of 144.78 m and a significant standard deviation of 207.25 m, evidencing the significant variation of this territory's topography.

Likewise, the region stream network was also computed. As evidenced in Figure 3.9, the input (provided by the user) and output (generated by SWAT) waterlines shapefiles were not exactly coincident. This is due to the fact that SWAT traces the waterlines network based on the DEM provided, and the input waterlines shapefile serves only as a guideline to do so. It should be referred, however, that some of Leyte existing waterways have a minimal width and, in some cases, an intermittent nature, which makes their exact location difficult to determine. However, for the most expressive waterways, such as the Binahaan River, the traced stream was drawn nearer the input lines, proving the model accuracy to represent this hydrological system.

The threshold of 50 km² returned 12 watersheds for the study area (Figure 3.10). Other thresholds (20 km² and 100 km², for example) have been tested but either generated too many small basins or bigger ones that did not provide the required detail for this analysis. From these 12 subbasins, therefore, the most relevant ones were subbasins 1, 3 and 5, the first two corresponding to the USAID-proposed supply solution for Tacloban North (from Pongso and Cabayugan Rivers, respectively) and the third one to Binahaan River, the larger basin where the current catchment is located. The characteristics of these basins are summarized on Table 3.3.

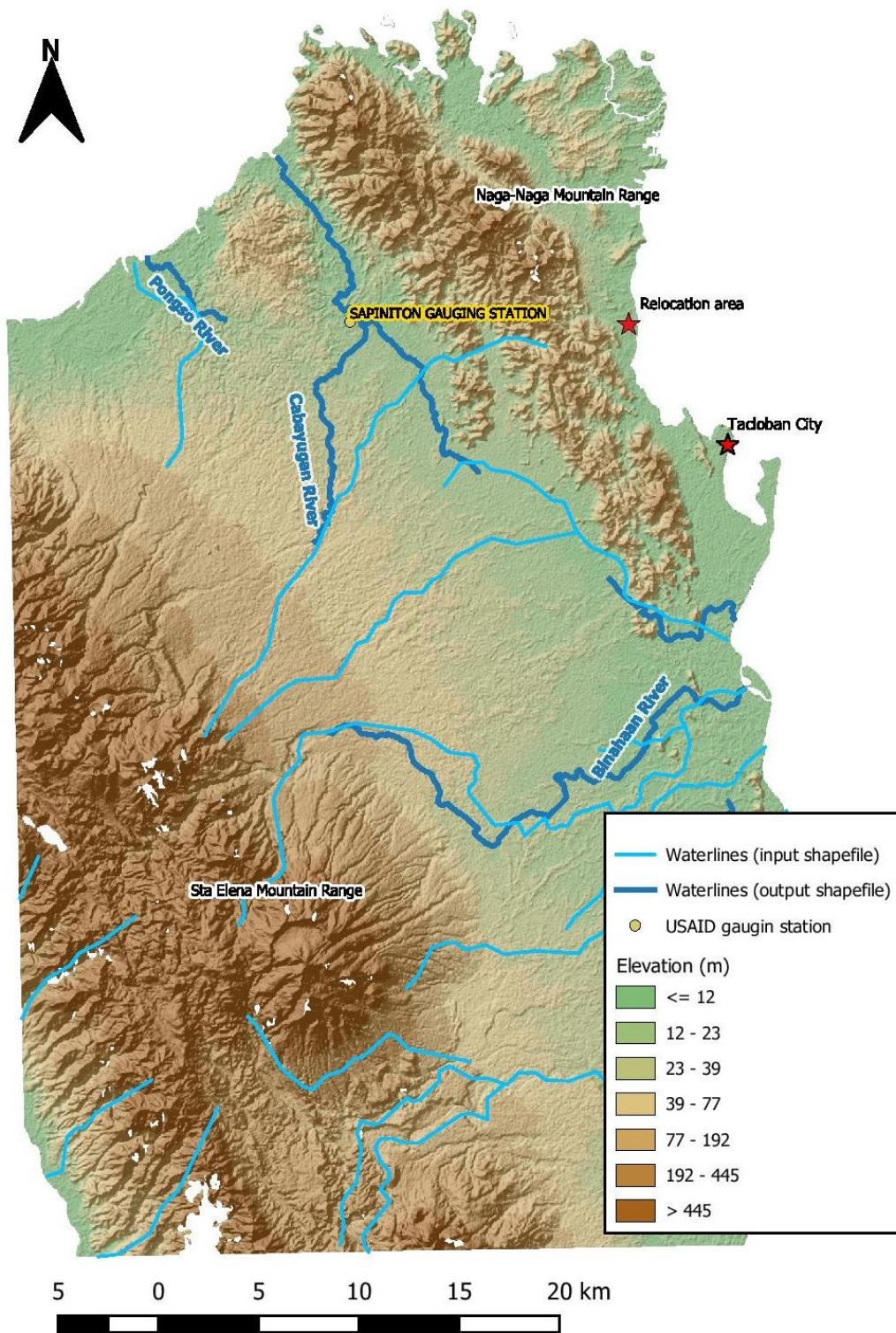


Figure 3.9- Comparison between input and output waterlines shapefiles

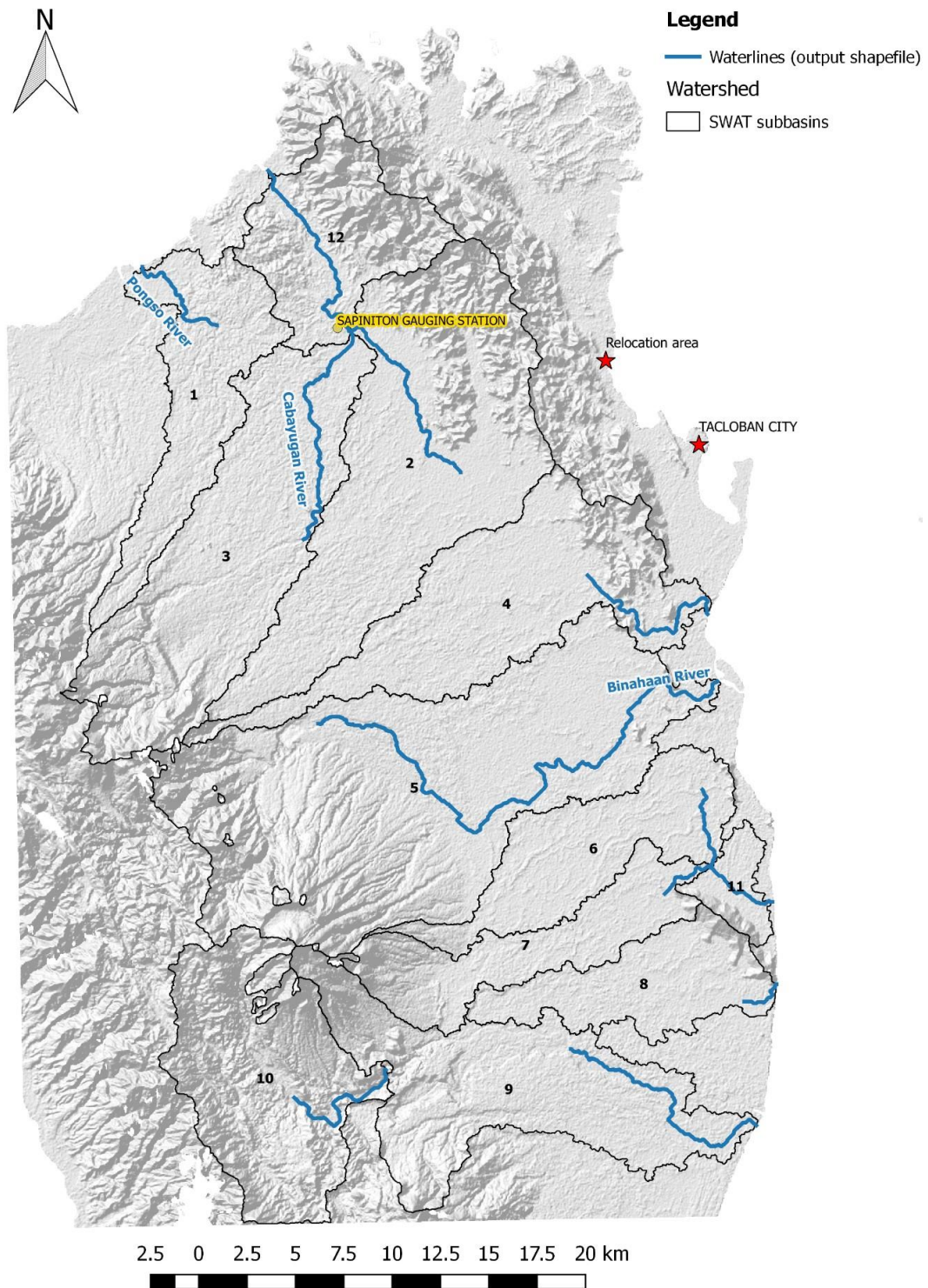


Figure 3.10 - QSWAT output watersheds¹⁵

¹⁵ Due to the chosen threshold for tracing the basins, basins 9 and 10 appear separated when it appears that they share the same waterway. Acknowledging this imprecision but considering that these basins were not relevant for the results, they were kept separated.

Table 3.3 - Selected subbasins characterization

Subbasin #	Elevation summary	River	Area (km ²)	Landuse Classes*	Main Soil Classes**
1	Min= -2 Max= 528 Mean= 68.36 St dev= 85.77	Pongso River	70.6	89.33% CRWO 19.00% CRDY 6.97% CRIR 1.19% FOEB	55.75% Af14-3-c 39.77% Fo8-2ab 2.17% Jc4-2a
3	Min= 8 Max= 1231 Mean= 198.27 St dev= 227.97	Cabayugan River	146.9	76.63% CRWO 15.32% CRIR 6.60% FOEB 1.45% CRDY	56.67% Fo8-2ab 42.75% Af14-3-c 0.58% Jc4-2a
5	Min= -1 Max= 1318 Mean= 207.27 St dev= 263.88	Binahaan River	262.5	92.36% CRWO 4.97% FOEB 2.66% CRIR	55.69% Fo8-2ab 38.63% Af14-3-c 3.62% Jc4-2a

*Landuse classes: CRDY – Dryland cropland and pasture; CRIR- Irrigated cropland and pasture; CRWO- Cropland/woodland mosaic; FOEB- Evergreen broadleaf forest

**Soil classes (FAO Classification): Af14-3-c - Ferric Acrisol (Hydrologic group C); Fo8-2ab - Oitic Ferrasol (Hydrologic group C); Jc4-2a - Calcaric Fluvisol (Hydrologic group D)

Noticeably, for the three basins, the most common land use occupation was cropland, mostly a mix of crops and woods, also with a small percentage of forest. This non-urban occupation of the watersheds can be beneficial in terms of watershed management and to the safeguard of the water quality, especially from point pollution sources. As for the soil classes present on these watersheds, the hydrologic groups varied between C and D – the first corresponding to fine to very fine textured soils, with characteristically low permeability, and the group D to clay soils with characteristically high-water tables and very low infiltration rates (Neitsch, et al., 2011).

As a complex hydrological model, SWAT generated significant amounts of tabled information, grouped on a Microsoft Access database (SWATOutput). This includes daily estimations of runoff, percolation, evapotranspiration, lateral flows and groundwater contribution. The schematic representation of the region’s hydrological balance, schematized on the hydrology tab of SWAT Check, is shown on Figure 3.11 (for the baseline scenario, to serve as an example). The annual

average of its components is summarized on Table 3.4 (for the three modeled scenarios).

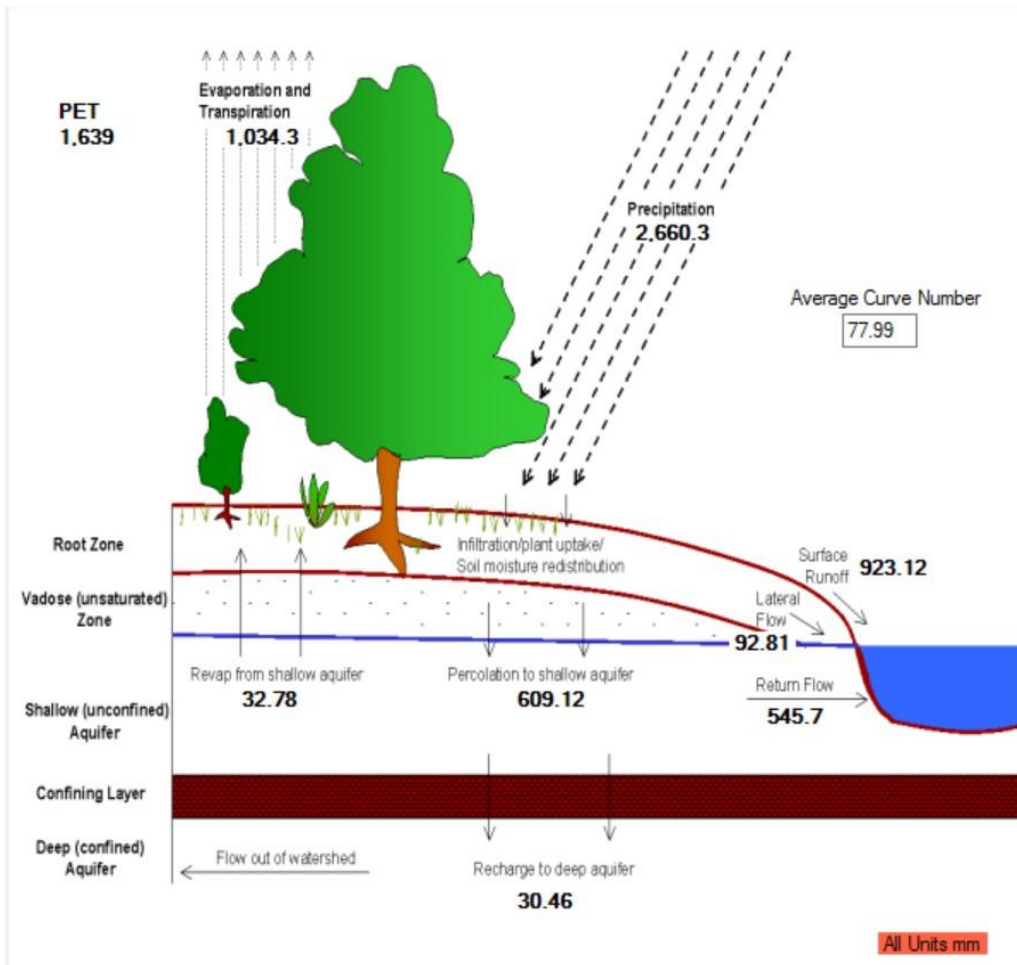


Figure 3.11 - SWAT-Check hydrology tab summary for baseline scenario

Table 3.4 - Summary of hydrological balance components for Baseline, CC2020 and CC2050 scenarios

Average flows	Baseline	CC2020	CC2050
Precipitation (mm)	2 660.3	2 770.1	2 932.1
Evaporation and Transpiration (mm)	1 034.3	1 030.1	1 038.0
PET (mm)	1 639.0	1 670.7	1 720.4
Surface Runoff (mm)	923.1	996.9	1 108.0
Lateral Flow (mm)	92.8	96.4	100.7
Return Flow (mm)	545.7	577.8	613.5
Percolation to shallow aquifer (mm)	609.1	644.3	682.8
Recharge to deep aquifer (mm)	30.5	32.2	34.1
Revap from shallow aquifer (mm)	32.8	33.4	34.4
Average curve number (non-dimensional)	77.99	77.99	77.99

As expected, overall annual precipitation flows seem to increase for Tacloban’s region in CC2020 and CC2050 scenarios, as a consequence of the PAGASA forecast-based series generated and used as input data. The same increase is notorious for the evaporation and transpiration or potential evapotranspiration (PET) flows¹⁶, even more significantly for the various runoff flows.

Moreover, SWAT-Check returned the ratios between these flows (Table 3.5). The variation of those amongst scenarios was also examined, as explained below.

Table 3.5 - Water Balance Ratios returned by SWAT-Check for Baseline, CC2020 and CC2050 scenarios

Water Balance Ratios	Baseline	CC2020	CC2050
Streamflow/Precipitation	0.59	0.60	0.62
Baseflow/Total Flow	0.41	0.40	0.39
Surface Runoff/Total Flow	0.59	0.60	0.61
Percolation/Precipitation	0.23	0.23	0.23
Deep Recharge/Precipitation	0.01	0.01	0.01
Evapotranspiration/Precipitation	0.39	0.37	0.35

Surface runoff volume is computed in SWAT using a modification of the SCS curve number method, in which the curve number varies non-linearly with the moist content of the soil (near 0 as the soil approaches the wilting point and near 100 as it approaches saturation) (Neitsch, et al., 2011). The model returned an average curve number of 77.99, which is consistent with the obtained ratios (namely the surface runoff/total flow). The clay-like texture of the majority of soils in the watersheds can, for example, be a factor in the appreciable streamflow/precipitation or surface runoff/total flow ratios, as well as in the lower percolation/precipitation ratio and for the deep recharge/precipitation index.

¹⁶ SWAT computes PET and evaporation/transpiration flows separately. The PET, defined as the potentially maximum amount of water transpired by a reference crop is determined by the Penman-Montheit method, for example. Once PET is determined, the actual evaporation is calculated: first by evaporating any rainfall intercepted by the plant canopy, and then calculating the maximum amount of transpiration, sublimation and soil evaporation.

Some of the ratios tend to rise for CC scenario for 2020, and subsequently for 2050, which may be explained by the overall increase of rainfall. In its turn, however, the evapotranspiration ratio tends to drop, despite the general temperature increases, possibly due to an increase of the amount of water that integrates the immediate runoff and thus does not reach evapotranspiration processes.

3.3.3. Model calibration and validation

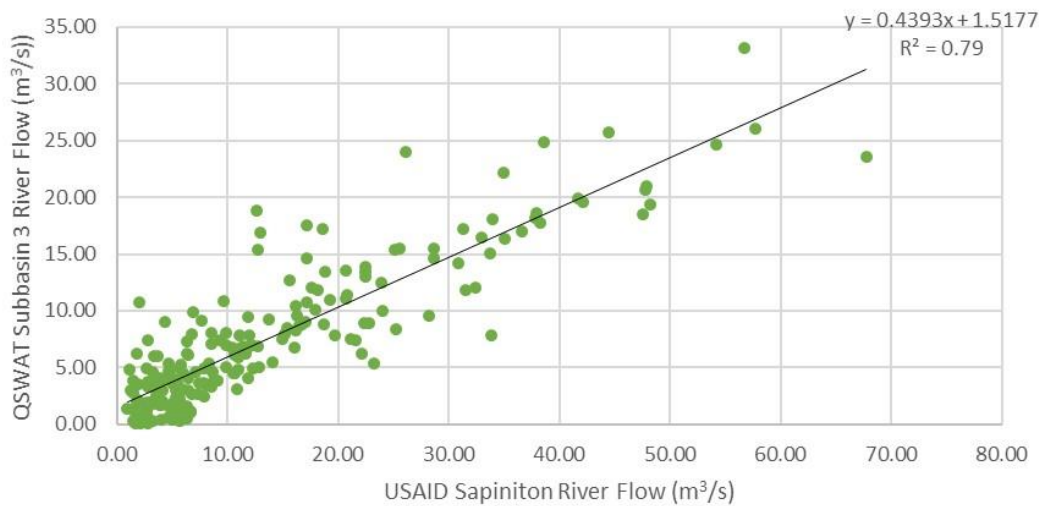
QSWAT output river flows were subject to calibration using the USAID flow measurements for Sapiniton gauging station, in Leyte. To this station (refer to Figure 3.10 for its location), corresponded a drainage area of 204 km². None of the basins delineated by QSWAT matched exactly this watershed, which led to the necessity of an approximation to one of the obtained basins, a process that may have conferred some inaccuracy to the comparison performed. Regardless being relatively smaller (with only 147 km²), for calibration purposes subbasin 3 was considered to be coincident with the USAID's drainage area.

The comparison between the flow series generated by QSWAT and the USAID measurements returned encouraging correlations (Table 3.6). This was true for the monthly average series, in m³/s, which returned a correlation of 0.899 and for the watershed runoff series, in mm, posteriorly determined for the two subbasins obtaining a correlation of 0.830 (refer to Figure 3.12 a) and b), respectively).

Table 3.6 - Calibration Results Summary

	QSWAT (subbasin 3)	USAID (Sapiniton River gauging station)	ratio
Basin area (km ²)	147 km ²	204 km ²	0.721
Flow series (m ³ /s)	-	-	Correl = 0.899
Watershed runoff series (mm)	-	-	Correl = 0.830
Average runoff (mm)	132.9 mm	167.2 mm	0.795

a)



b)

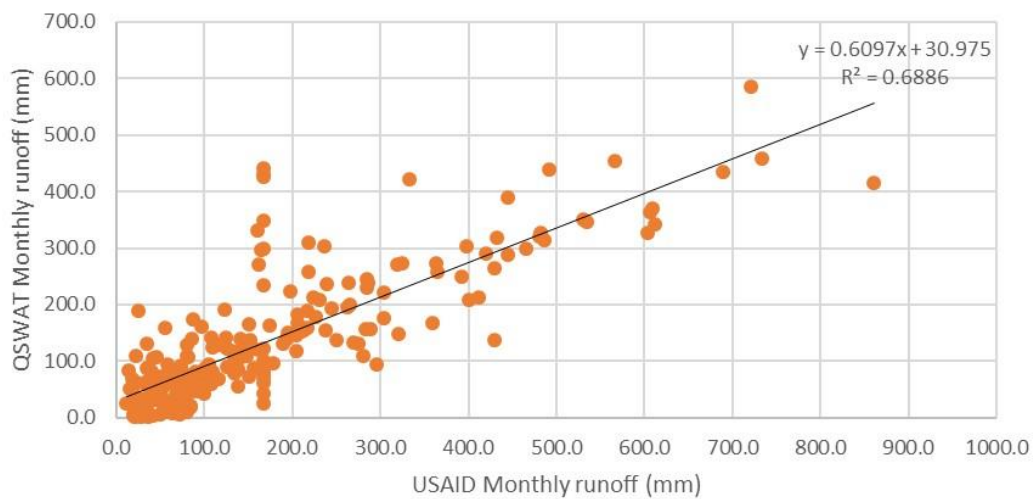


Figure 3.12 - Linear regression between QSWAT and USAID's: a) average monthly flows (m³/s) and b) total monthly superficial runoff (mm) series

Moreover, the ratio between the average annual runoff determined for the two series (167.2 mm and 132.9 mm for the USAID and QSWAT series, respectively) was of 0.795 – which was of the same order of magnitude of the ratio between the two compared subbasins' areas, of 0.721. Intuitively, hence the subbasin delineated by QSWAT was relatively smaller, so it should be the amount of superficial runoff generated to the same extent - which was verified.

Based on these satisfactory correlations, it was assumed that no further calibration measures were required and that the modeling results were valid and trustworthy.

3.3.4. Water resources resilience

The resilience of Binahaan, Pongso and Cabayugan rivers as water sources to supply the study area was evaluated, for a certain period of time, as the percentage of days in which the rivers flows did not meet the water extraction rates predefined for each catchment. Table 3.7 summarizes the obtained results.

Table 3.7 - Resilience of supply results: percentage of days below extraction rate

		Baseline	CC2020	CC2050
Binahaan River (Extr. rate 0.72 m ³ /s)	DJF	0.7%	0.7%	0.5%
	MAM	16.2%	17.7%	19.3%
	JJA	20.3%	16.7%	15.2%
	SON	1.3%	0.8%	0.2%
	TOTAL	9.7%	9.0%	8.9%
Pongso + Cabayugan Rivers (Extr. rate 0.58 m ³ /s)	DJF	0.6%	0.5%	0.3%
	MAM	16.8%	18.1%	19.5%
	JJA	26.4%	21.6%	20.2%
	SON	1.2%	0.9%	0.4%
	TOTAL	11.3%	10.4%	10.2%

For the supply solution based solely on Binahaan River, on the baseline period, altogether 9.7% of days did not match the water extraction rate of 0.72 m³/s, with DJF and SON being the most favorable trimesters (only 0.7% and 1.3% of days, respectively). However, for this 1980-2010 series, the MAM and JJA trimesters evidenced already some water shortage probability, with 16.2% and 20.3% of days, respectively, with the river flow of Binahaan being insufficient to supply the LMWD network.

On a yearly basis, nevertheless, this situation tended to evolve favorably (even so discreetly) due to the general increase of precipitation associated with CC, with the

yearly number of supply gaps decreasing from 9.7% to 9.0% for the CC2020 scenario and to 8.9% for CC2050. However, the breakdown in trimesters revealed that, for the MAM period, due to the PAGASA's forecasted decrease in rainfall, the availability of water actually worsened, reaching up to 19.3% of days with insufficient flow on Binahaan River, for CC 2050. It should also be noted the shift of the most unfavorable trimester due to precipitation variation: whilst, for current climate, water scarcity is more severe in the June to August trimester (20.3% of days), for future climate scenarios the driest trimester could be MAM, as mentioned. On the other hand, the most favorable trimester also tends to shift from DJF to SON.

From these results, it becomes evident that Binahaan River, during the March to August period, cannot be considered a resilient water source. This is true considering the significant percentage of days where its flow does not meet the proposed extraction rates of 0.72 m³/s. For this reason, the proposed plans of expanding the city's water pipelines towards north to supply the resettlement areas relying solely on Binahaan River are unadvisable, as it would represent an extra pressure on an already troubled system.

From thereon, considering an additional water catchment on the northern rivers to supply Tacloban North, as proposed by the development agency USAID, may be seen as a pertinent alternative. Assuming an extraction rate of 0.58 m³/s, however, a similar response to the one obtained for Binahaan River was observed: the yearly resilience of these rivers to be used as supply sources evolved from 11.3% of days not meeting the demand for baseline data to 10.4% for the CC2020 scenario and 10.2% for CC2050 – results of the same order of magnitude as the ones obtained for the Binahaan River, assuming also a similar seasonal behavior. For example, the percentage of days with insufficient water in JJA (26.4% for the baseline scenario)

also tends to decrease due to more rainfall on this trimester for future climate scenarios, but the situation in MAM tends to worsen.

In this context, it can be pointed out that either for Binahaan or Pongso and Cabayugan Rivers' solutions, the significant percentage of days pointing to water scarcity for the MAM and JJA trimesters is indicative of the necessity of a flow regulation infrastructure, such as a small dam. The pre-dimensioning of such structure as a function of the existing flow regimes, is one possible future development of this work, which's viability analysis is presented forwardly.

3.3.5. Flow regulation infrastructure viability analysis

The design of a flow regulation structure can be achieved recurring to a multitude of methodologies, some more complex than others. In its essence, the sizing of such construction depends on the determination of the useful storage volume, which was hereby achieved through a tabular process. This method consisted on determining the storage volume necessary at the beginning of each time span (usually on a monthly basis) to meet the consumptions of that and of subsequent time periods. This estimation followed retroactively, since the end of the affluent volumes series, and the final useful volume corresponded to the maximum value determined for satisfying the correspondent uses. Hence, it serves only as an approximation and not an actual design method. Other variables such as the losses by evaporation on the water surface and infiltration were not considered and consequently the results may be biased. The following equations summarize this method, where V_{useful} corresponded to the final volume of the infrastructure, $V_{necessary}$ to the delta between the month consumption ($V_{consumption}$) and the correspondent affluent flow ($V_{affluent}$).

$$V_{useful} = \max(V_{necessary}(t)) \quad (\text{Equation 5})$$

$$V_{necessary}(t) = V_{consumption}(t) - V_{affluent}(t) \quad (\text{Equation 6})$$

The aforementioned method was applied to Binahaan River only, hence this is the water line where current catchment is located and one that will be the main water source for the studied water supply system in times ahead. The water extracted rate considered was 1 m³/s, corresponding to the maximum licensed for LMWD. Moreover, the affluent volumes considered corresponded to the river flow series returned by QSWAT for Binahaan for the CC2050 scenario. The choice for this projection scenario instead of the baseline series was due to the fact that, as depicted by PAGASA, the seasonality of rainfall patterns will be mostly felt in the future. Hence, as confirmed by QSWAT, the variability of available flows in the studied waterlines will also be most felt in this scenario, with the dry trimester of March-April-May showing its lowest records.

In fact, the results returned 26 months (7% of the 30 years series) where the available flows could not meet the extraction demand, the majority of them in MAM (sometimes extended until June). For this scenario, the maximum necessary volume obtained was of 6.7 hm³, which was considered a feasible number that did not imply the construction of an excessively heavy infrastructure. On the contrary, it was demonstrated that, with a reasonable investment, the seasonal water shortage affecting Tacloban City and aggravated by climate change could be minimized.

3.4. Conclusions

Prior to using the rainfall data series for modeling purposes, its statistical robustness was evaluated by the adjustment of distribution functions. The viability of the rainfall records was therefore corroborated, and its use validated for the subsequent hydrological analysis.

Overall, the model has described positively the studied hydrological system, delimiting twelve watersheds and marking the main waterways. This satisfying

adjustment was reflected on the SWAT-Check tool ratios, with the model returning a consistent average curve number of 77.99. Moreover, the calibration performed with the USAID gauging station measurements has also supported the liability of the obtained results. Despite the compared basins being less than an exact match (which could bring some inaccuracy to the calibration process), the calibration returned encouraging correlations between real and simulated data (0.899 for the monthly flows, in m³/s, and 0.830 for the runoff series, in mm).

QSWAT outputs have supported the initial premise that, even for the historical series (baseline scenario), Binahaan River is not a resilient water source. This is particularly true in the trimesters of MAM and JJA, when the river flow is insufficient to meet the water intake in 16.2% and 20.3% of days, respectively. Despite the yearly increase of water availability resultant of the increasing rainfall, the river flow seasonality will be severely aggravated: the MAM trimester will become the most problematic with 19.3% of insufficient flow days in 2050. It should be highlighted the progressive shift of the driest trimester, from JJA to MAM, evidenced by the model. Therefore, the proposed plans of expanding the city's water pipelines towards north, relying solely on this watershed are unadvisable, as it would represent an extra pressure on an already troubled system.

The alternative proposal of supplying Tacloban North with Pongso and Cabayugan catchments, however, returned similar results (i.e., an overall yearly improvement of water availability, but an aggravation of its seasonality, particularly with a significant water deficit in the MAM trimester). One can conclude that regardless of the supply solution chosen, the significant percentage of low flow days in the March to August months is indicative of a low resilience of these water sources.

To address this problem, a possible solution would be the construction of flow regulation infrastructures (such as a small dam) on these waterways. Although not

responding to the complexity of such study (which can be pointed out as a future development of this work), the viability the implementation of such a structure in Binahaan River was hereby drafted. Recurring to the river flow series obtained for 2050, the required storage volume obtained was of 6.7 hm³, which was considered a feasible investment that could help minimize the CC impacts on the city of Tacloban and improve LMWD system resilience.

Some possible weaknesses of this modeling exercise, which may therefore be seen as future developments of this dissertation, are the water demand estimation (considering Tacloban population's growth, instead of considering only the water catchment rates) and evaluation of land cover changes impacts on the local hydrology.

4. COMMUNITY RESILIENCE

Chapter Abstract

The social component is essential to successfully enhance the resilience of a community towards climate change impacts. In fact, more than the socioeconomical indicators that are commonly used to characterize a community, the perception of its members about the hazards they face has been increasingly considered.

Following the destruction of super typhoon Haiyan in Tacloban, a household survey was conducted to better understand resilience at the household level. Later, these findings were related with the lessons learned from the typhoon. Furthermore, some questions focused on assessing the perception of the water scarcity situation of the city.

Overall, there seemed to be a generalized confusion between the significance of resilience and preparedness. The results of the survey have also confirmed that Taclobanons were aware of the immediate impacts of climate change (such as the tropical cyclones increasing frequency and their storm surges), towards which they felt they needed immediate protection, but were not as conscious of the long-term consequences (such as flooding and specially droughts, a phenomenon that entails severe consequences for the local water supply, as evidenced on chapter 3).

However, an important conclusion withdrawn from this survey was the fact that the majority of respondents preferred the water supply improvements over other services' as the mean to confer their household greater resilience. This preference was most evident in Tacloban northern relocation areas, where a potable water supply network was, to date, inexistent.

4.1. Introduction

In the city of Tacloban, after the devastation caused by typhoon Haiyan, several research groups have addressed the importance of resilience in the city's recovery strategies. The term was present on several NGO slogans and National and Local Government Units initiatives (including the aforementioned RAY).

One of them was a project from the University of Nottingham and the University of the Philippines, designed 'Poverty Alleviation in the wake of Typhoon Yolanda'. As stated on their fifth working paper, in Tacloban the term resilience was an "overused, poorly understood and contested term" (Eadie, 2017). In fact, Tacloban's LGU members, when interviewed on the January 2018 fieldtrip, reinforced this idea by claiming that communities did not fully understand the meaning of the term. All the more, they argued the fact that people did not fully understand the term 'storm surge' on Haiyan's warnings was responsible for their lack of preparedness. The city LGU, therefore, advocated that a comprehensive and practical definition of resilience would be of the utmost importance in Tacloban's recovery.

This was addressed by project WaCE, which was entwined with the development of this dissertation - a project developed by the Oscar M. Lopez Center (OML Center), a non-profit research center based in Manila, Philippines, which aims to support science-based solutions that help communities adapt to climate change. It aims to build resilience by making climate information usable and reinforce the communication between the scientific and local communities. The center had an interventive role after Haiyan's devastation of Tacloban, having conducted several studies in Tacloban City and its surrounding municipalities. On an initial stage, the center research activities were focused on the project named "Evidence-based Rehabilitation of the Yolanda-Affected Areas", in support of the recovery after Haiyan, but later shifted the focus to resilience. This was the framework for the

creation of the project WaCE – Weather, Climate and Ecosystems Program, which aimed at improving Leyte communities’ resilience.

With WaCE, the center aimed to better understand resilience and its components on both community and household levels, to later relate those findings with the lessons learned from typhoon Haiyan. A survey was applied to generate baseline information in terms of resilience and preparedness, assessing the vulnerability and risk felt by Taclobanons. It intended to list the variables capable of influencing resilience and propose a methodology to measure the social aspects of resilience. Prior to the survey, in October 2015, the center scheduled Focus Group Discussions with LGU representatives and community members (*Barangay* Captains, among others). These sessions had the objective of understanding these stakeholder’s perception of resilience and informing the design of the subsequent household survey.

Besides the household survey (applied on March 2016), Community Consultation sessions were conducted in order to test and finalize the “Climate and Disaster Resilience Scorecard” – designed to help identify the most important resilience factors for the community and provide recommendations on how the process could be best conducted for a more participatory way.

The project timeline extended from April of 2015 to September of 2017, with the final presentation and turn-over of results. It was expected that its results could inform the local LGU, with a possible integration of its recommendations on the city’s DRR and CCA policies, plans and programs. Indeed, in August of 2017, the OML team returned to Tacloban to share the study’s main conclusions with the LGU – an action that was much appreciated by the city hall several departments, that praised OML for giving back to the city, whilst from the remaining researchers who had contacted them to obtain data after the typhoon, none returned to share their findings.

The specific contribution of this study, in the narrower context of this dissertation, was to reiterate the community's perception of the local water constraints (learned on the field trips to Tacloban), in order to justify the need of the performed water resources modeling and help finding a solution. Moreover, its results allowed characterizing the denominated social resilience (using both socioeconomic and perception indicators), a branch of soft resilience that can complement the water resources resilience performed on Chapter 3.

4.2. Methodology

Prior to applying the survey, a Focus Group discussion was conducted with people from the LGU and some barangay captains, to determine how the community interpreted the term resilience and the several factors capable of affecting it. Based on these meetings, the questions were written to cover the following topics: household information; knowledge and awareness on extreme weather, climate change and hazards; social cohesion and community connectedness; personal wellbeing, beliefs and values; and household and community resilience. The household (HH) survey was conducted in the City of Tacloban from March 14th to 18th, 2016, comprising 282 of the 63 265 households, across 53 of the city's 138 *barangays*. These *barangays* were randomly selected, and the total number of necessary respondents was determined recurring to Equation 7, where n represents the number of respondents, N symbolizes the population or household size, which is affected by e , the margin of error (of 6%, conferring this study a confidence interval of 94%).

$$n = \frac{N}{1+Ne^2} \quad (\text{Equation 7})$$

Regarding the spatial distribution of respondents, the city was divided into three strata: coastal, inland and upland *barangays*. With this division, the goal was to be able to assess differences in the opinion of their residents regarding the impacts of natural hazards and resilience (parting from the assumption that different strata

have different vulnerabilities). The number of respondents per strata was first determined (103 from coastal *barangays*, 135 from inland *barangays* and 44 from upland *barangays*) and then the respondents selected from a list of available households. If the selected respondent was not available at the time of the interview, with no acceptable substitute from the same household, then a nearby household (from the same *barangay* and same *purok*) was invited. Although a key part in the general OML study, this division added little to this dissertation specific goals and was, therefore, not considered.

The survey was conducted door-to-door by hired enumerators, fluent in *waray*, the dialect spoken in Tacloban. This was expected to facilitate the communication and interpretation of each question, but also to leave the respondents more at ease to express their genuine opinions. However, as is standard practice when interpreting the results of a survey, it should be kept in mind that possible biases affected them. These biases could have various origins, such as a wrong interpretation of the question, an influence by other respondents, or fatigue due to the length of the survey, among others. The complete survey can be consulted on the Annex IV of this dissertation.

4.3. Results and discussion

Respondents and Household Characterization

The OML survey team interviewed a total of 282 households, 64.5% female and 35.5% male, across 53 *barangays* in Tacloban City (question 2 of the 'Information about the Respondent' part). The most representative age bracket was 45-54 years old (26.6%), followed by the precedent group of 35-44 years old (24.1%) and 25-34 years old (18.1%). The elderly population was significantly represented, with 14.5% of respondents being 60 years old or above (question 3 of the 'Information about the Respondent' part) – this fact was probably related to their availability to respond to the survey, conducted during working hours.

Overall, according to the results for question 4 of the respondent identification part of the survey, 54.3% of the interviewed households included at least one person requiring assistance or supervision (i.e. a child, an elderly person, a disabled person or a pregnant woman) which represented a higher vulnerability to hazards, an increased difficulty in evacuating operations and therefore, lower resilience.

Concerning education (question 4 from the household identification), almost 40.0% had finished high school, 30.2% had graduated from elementary school, and 14.6% were college graduates or held a college degree. However, the majority of respondents (question 5) claimed to be unemployed (30.5%) – which is, perhaps, again the reason why they were available for the day-time interviews. The most common source of income of this sample was the ‘non-agricultural entrepreneurs’, notoriously more significant for women, with 22.7% including themselves in that category, which encompasses includes the self-owned *sari-sari* shops.

As seen on Figure 4.1, the remaining sources of income had a scarce representativeness. In fact, a small percentage of 7.1% had agriculture (including livestock, fishing and forestry) as their main source of income, which is the reason why only 9.6% claimed to rely on the ecosystem for their livelihood (5.7% in marine ecosystems for fishing purposes). Also interesting on this figure, is the fact that it reveals the fragility of the economic structure, namely for women.

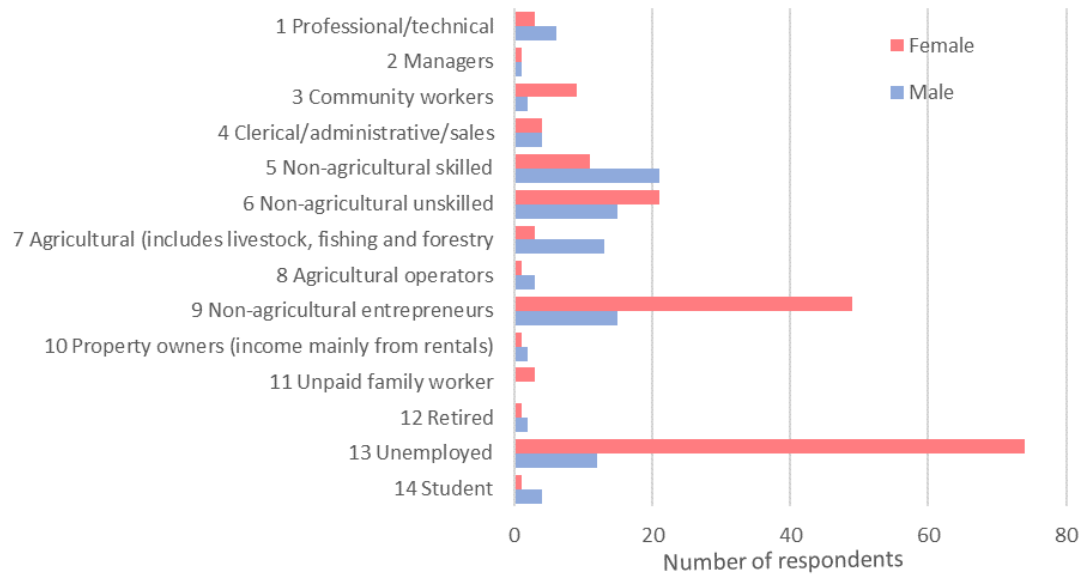


Figure 4.1 - Sources of income by gender

As observed on Figure 4.2 (based on the responses obtained question 7 from the respondent identification and detailed by occupation), for the most part, the residents earn PhP 7 500 or less per month. This salary is predominantly frequent for categories 3 to 5, 9 and 11. Whilst retired people earn an average of PhP 7 500 to 10 550 or more, the higher income category, of above PhP 10 551, is attributed almost exclusively to Professionals and Managers. Finally, from the 86 respondents assumingly unemployed, only 10 registered no income, with 53 reporting an income lower than PhP 7 500, 8 earning from PhP 7 500 to 10 550 and even 10 earning a monthly wage of over PhP 10 551.

An interesting aspect, in the context of this dissertation, was that 91 out of 282 respondents (32.3%) claimed not to have any alternative source of income (question 6), which may constitute a negative driver regarding the economical resilience of these families. From the ones that had a second wage, it was mostly based on category 5 'Non-agricultural skilled' (18.1%) and on category 6 'Non-agricultural unskilled' (12.8%). Additionally, 11.0% of respondents claimed to have an alternative income as a non-agricultural entrepreneur, which included the sari-

sari stores. This variety of alternative sources of income could be seen as a positive aspect regarding the economical resilience of these families.

Concerning sources of revenue other than labor, only 4.6% of respondents received monthly support from the government, although it was commonly lower than PHP 5 000. A similar percentage, of 4.3%, received money transfers from relatives living in other cities or provinces but it also amounted to less than PHP 5 000 per month.

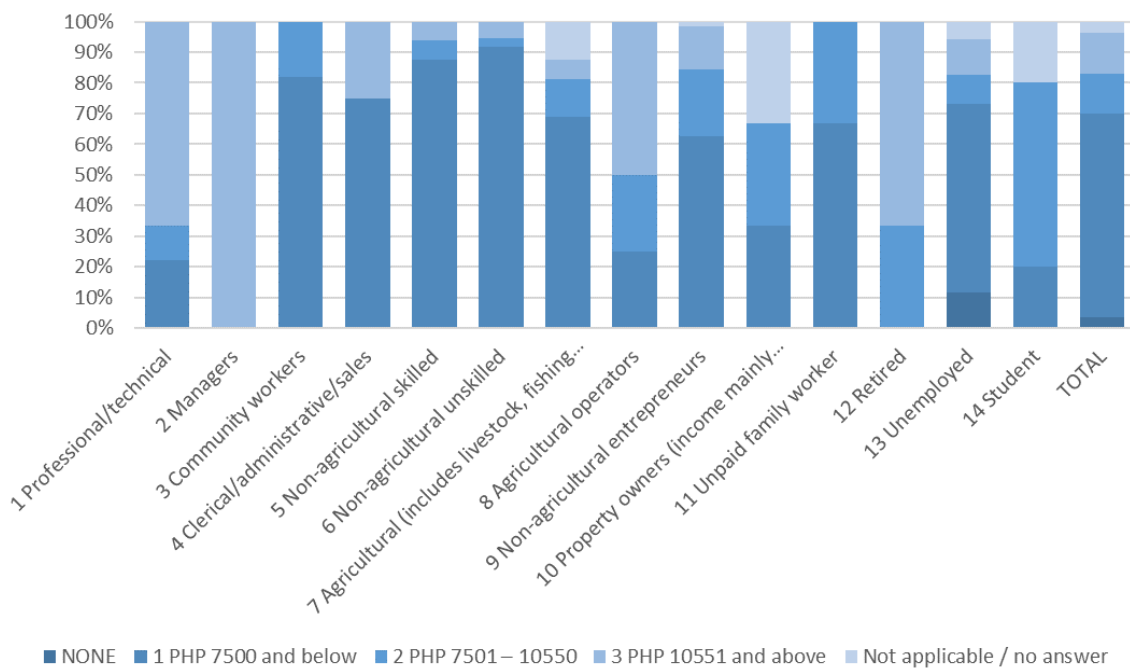


Figure 4.2- Income per employment category

Despite the apparent economic difficulties, 54.3% of respondents declared their current income to be sufficient to cover the household’s basic needs (questions 8 and 9 from the Information about the Household section), with 21.3% claiming it to be only partially sufficient and 23.0% reporting it as insufficient. However, as much as 30.5% of respondents assumed that their current household income was insufficient for food (with 43.6% assuming having ran out of food the previous

year), 25.5% that it was just enough for food but insufficient for other basic needs such as water and electricity. Moreover, 21.6% assumingly earned enough to pay for food and those utilities and 12.1% could afford those plus their children education. A little over 7% only classified their income as sufficient to cover all the referred and still have some money to spend in case of emergencies and home necessities. A negligible percentage of 2.5% (only 2 respondents) claimed to earn more than enough to cover all these expenditures.

A closer look to these results, classified by income categories, is present on Figure 4.3. As expected, the majority of unemployed respondents didn't have enough money for food, and this was also the case for the ones receiving less than PhP 7 500 (from which 35.8% had insufficient money for food, 27.3% just enough for food but not for utilities and 23.5% just enough for those basic needs). These two categories reported an incapability of paying for their children's education, which can mean a decrease in the household resilience – considering that more educated communities can better cope with hazards and adapt to livelihood changes. In fact, only the highest income category reported a significant margin of 15.8% for extra expenses such as house reinforcements, which may be critical to build the household resilience.

These results were corroborated by the responses of the families regarding their savings and insurances (questions 11 and 12). Hence, only 14.9% claimed to be able to do save some money, whilst 84.8% could not. From the former, 8.2% conducted their savings to education and the health emergencies purposes scored a similar percentage, with 3.5% saving for food purposes. These priorities in terms of savings are evidence of a good perception of the critical factors of resilience, hence education, food and health are amongst the fundamental ones. It should be noted, however, the negligible percentage of savings directed to natural hazard related emergencies (1.1%), even after the calamity caused by super typhoon

Haiyan. This apparent lack of interest in reinforcing their homes is curious given that 82.6% of respondents own the house they live in (questions 5 and 6), despite only 35.8% owning the land as well. In fact, when asked if they found their current houses to be 'strong enough' (question 7), only 35.8% claimed that they did, while 22.3% did not but were taking measures to reinforce it, and 37.2% did not and were not doing anything to improve it.

Considering the possession of insurances (question 13), over half of the respondents (50.7%) did not have any, but 45.0% had invested on a health insurance. Life insurance came second as the most popular ones, with 16.3% subscribers. The insurance of material goods, such as the house and car, scored only 1.1% and 3.2%, respectively. The slightly higher incidence of car insurances compared to housing could be explained by the precariousness of the houses, which leads people to prefer rebuilding them than to invest on an insurance. Indeed, 91.5% of the interviewed households claimed that their household insurance was insufficient in the event of a natural hazard.

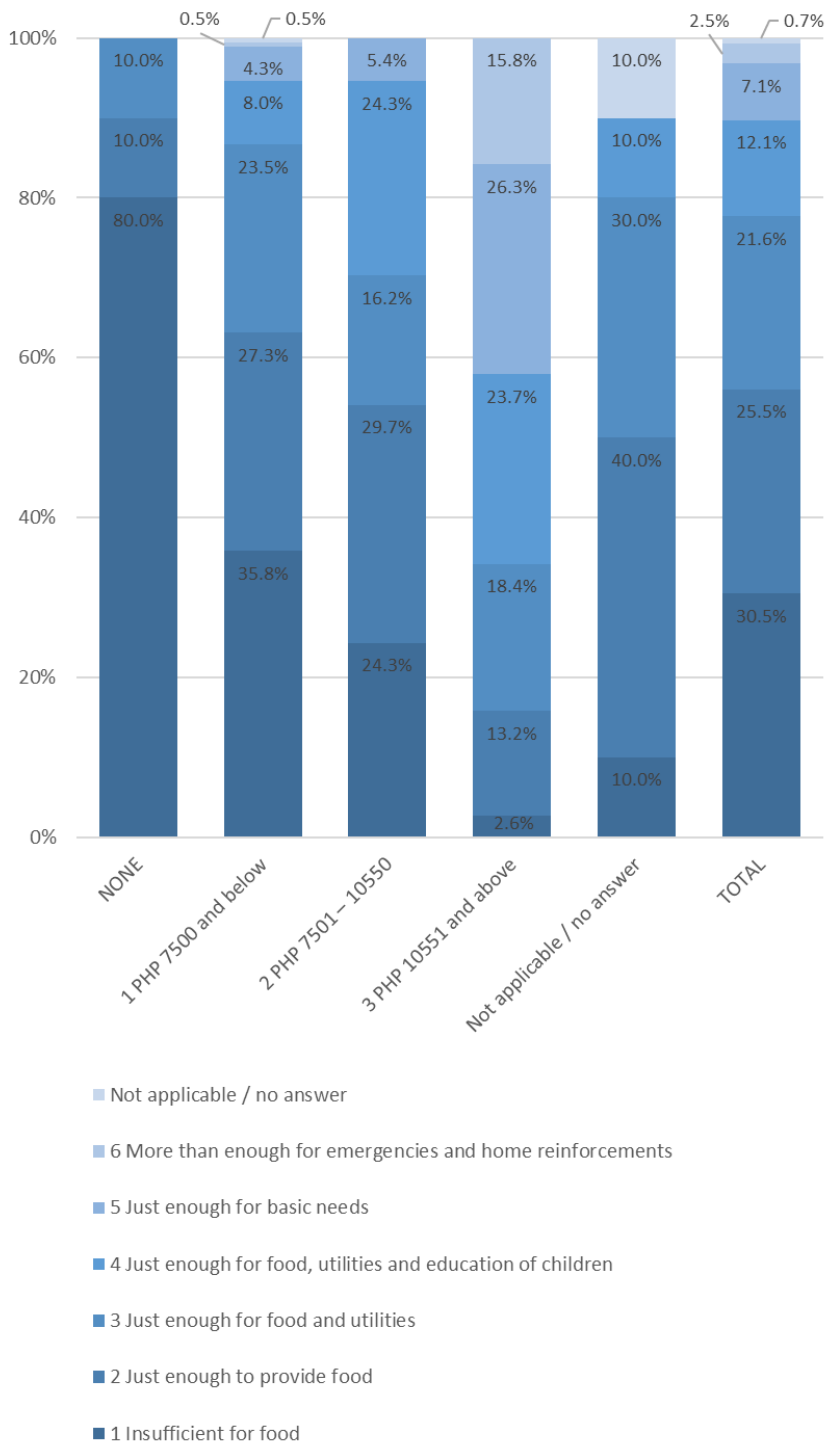


Figure 4.3 - Sufficiency of current income

Climate change perception

As referred, the Republic of the Philippines is one of the countries most exposed to natural disasters and climate change impacts. However, only 75.2% of respondents claimed to be aware of CC, whilst 23.8% said that they are not (and 1.1% preferred not to answer, in question 66). Moreover, in question 68, 57.1% affirmed that this major environmental problem is caused by human activities, 10.6% still believed that it has natural causes, 16.3% that is a mix of both and 14.5% claimed not to know the causes of CC (plus, 1.4% of respondents preferred not to answer). Overall, responding Taclobanons seemed to be aware of the main CC impacts, as shown on Figure 4.4, emphasizing the increasing temperatures and shifting of seasons as the most common. It was interesting to notice, however, that despite the survey being about resilience after Haiyan, the respondents did not seem to be influenced by it, as only 15.6% highlighted the intensity of tropical cyclones and 11.7% their frequency. Surprisingly, 66.0% of the respondents pointed CC as the cause of super typhoon Haiyan, against 25.5% that believed they were not related (and 8.9% who did not know, or rather not answer).

Regarding the impacts on water resources, 27.0% expected climate change to bring heavier rains and only 11.0% a delay onset of the rainy season¹⁷ (Figure 4.4).

¹⁷ Although it could be most interesting in the context of this dissertation, unfortunately drought and flooding did not appear as possible answers for question 70 of the OML Survey.

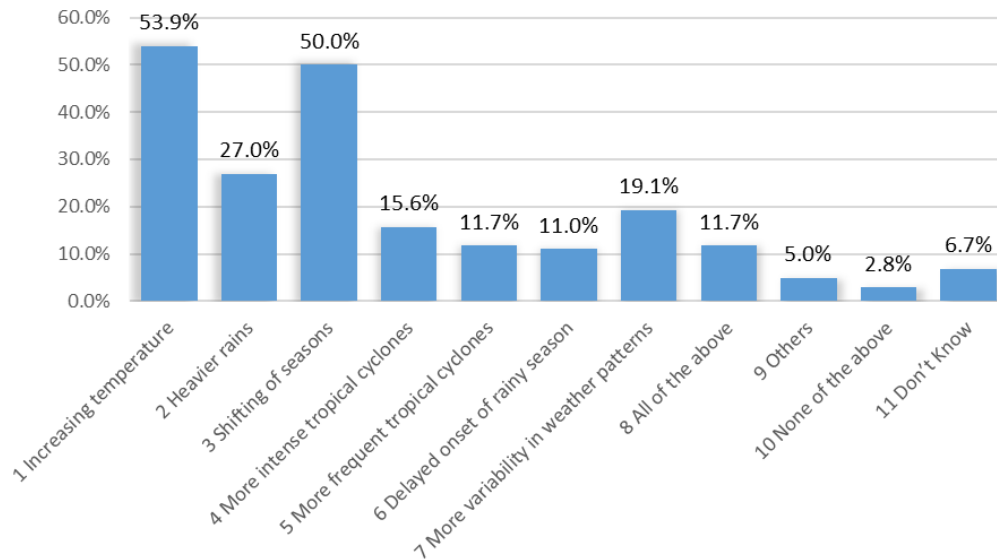


Figure 4.4 - Awareness of CC impacts (Q70)

Concerning the possible climate change adaptation measures (question 69), a prominent response was the planting of trees (49.6%), followed by waste management and recycling practices (30.9%, plus the majority of 'Others' 33.7%). However, only 11.3% claimed to be conserving water to face CC impacts – this is a relevant information in assessing the resilience of this community (specially focusing water resources), considering that drought is a reality for at least one trimester per year, and that water scarcity can worsen due to climate change – as demonstrated with the hydrological modeling exercise performed.

Natural hazards perception

When asked about which weather and climate-related hazards was their household most vulnerable to (question 25, Information about weather and climate-related hazards, events or disasters part), an overwhelming majority (270 respondents, 95.7%, Figure 4.5¹⁸.) answered that tropical cyclones were their main

¹⁸ Note: on these next figures, the size of the icons is indicative of the number of respondents that have, in a given area, pointed these hazards as potential threats to their households (i.e., the larger the icon, the higher the number of respondents)

concern – this result is not so surprising, considering that the survey was conducted not long after super typhoon Haiyan. However, a much smaller percentage of respondents (35.5%) pointed storm surge as a possible menace to their residence. This can be, perhaps, explained by the fact that the interviewed *barangays* were not the most affected by Haiyan storm surge, but more inland *barangays*, as shown in Figure 4.6. Possibly for the same reason, only 11.3% claimed to be vulnerable to sea level rise (Figure 4.7).

When overlapping these results with the Storm Surge Map of the CLUP (Figure 2.12), it became evident that most respondents that feared storm surges were, in fact, residing in the areas marked as of elevated risk for this hazard. This was the case, for example, of Anibong Bay: a low elevated area, densely populated by informally settlers and impoverished families which were severely affected by Haiyan’s storm surge in 2013. A similar distribution was obtained for the climate change impact of sea level rise, although less expressively.

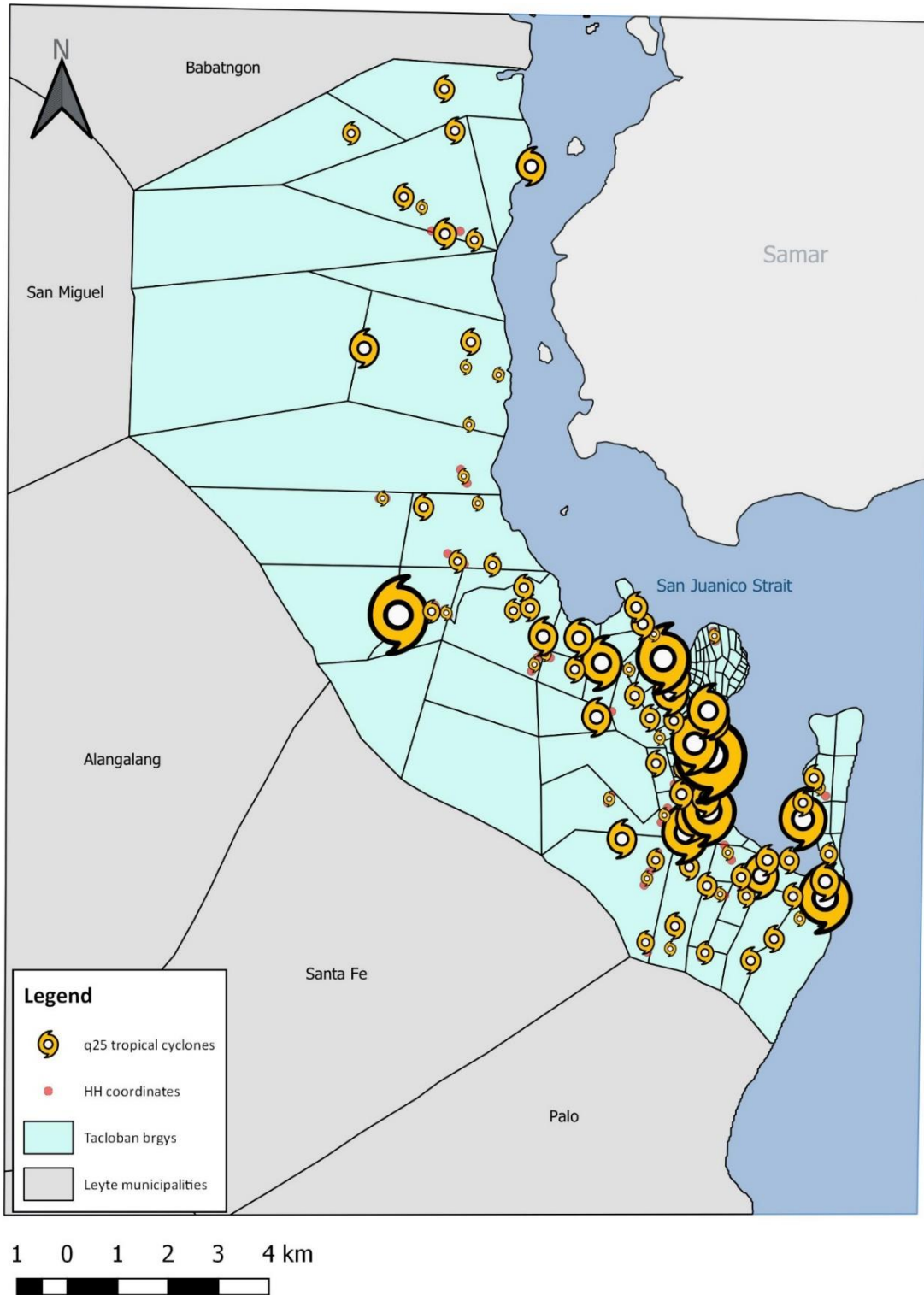


Figure 4.5 - Survey Q25 answers– vulnerability to tropical cyclones

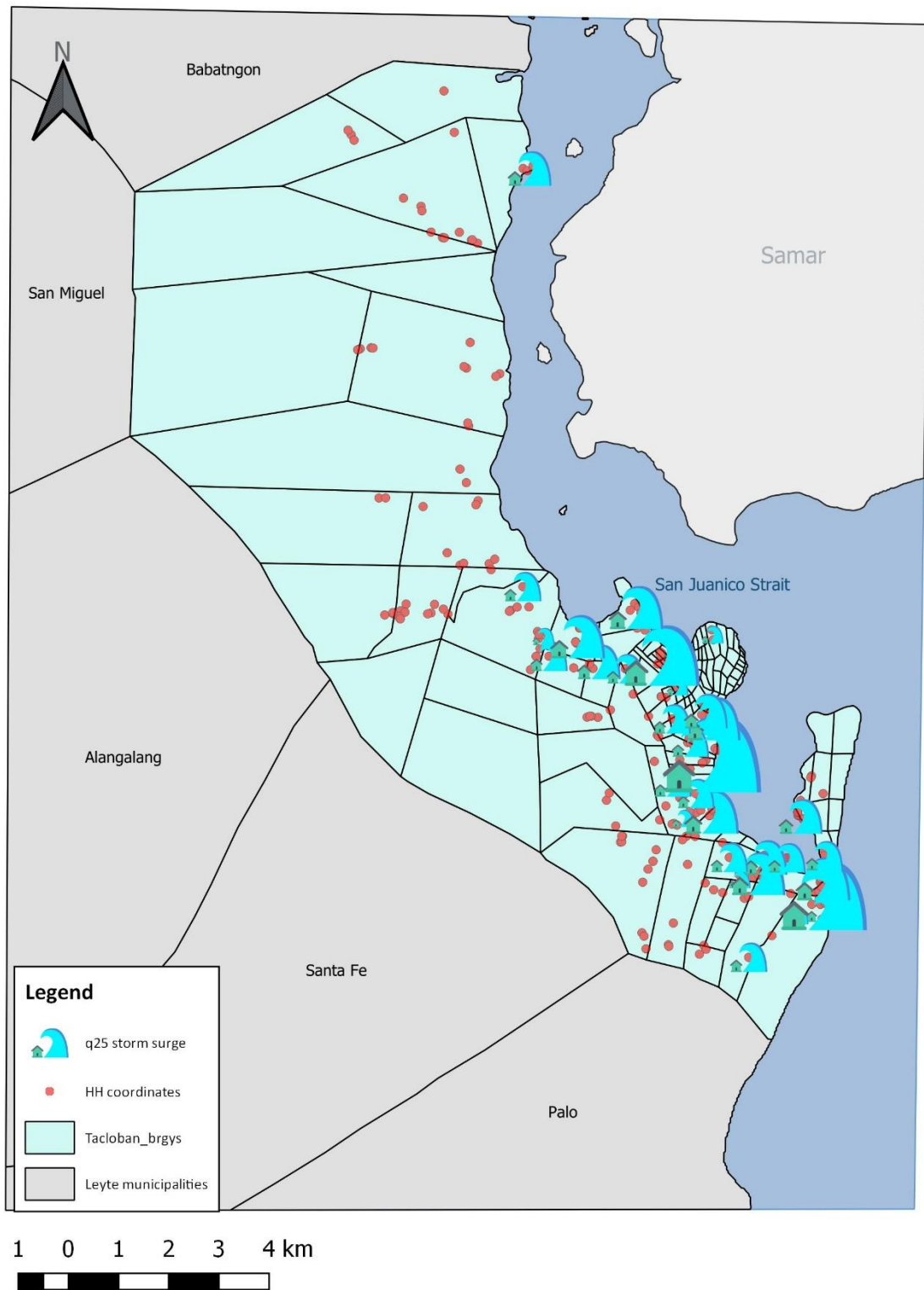


Figure 4.6 - Survey Q25 answers – vulnerability to storm surge

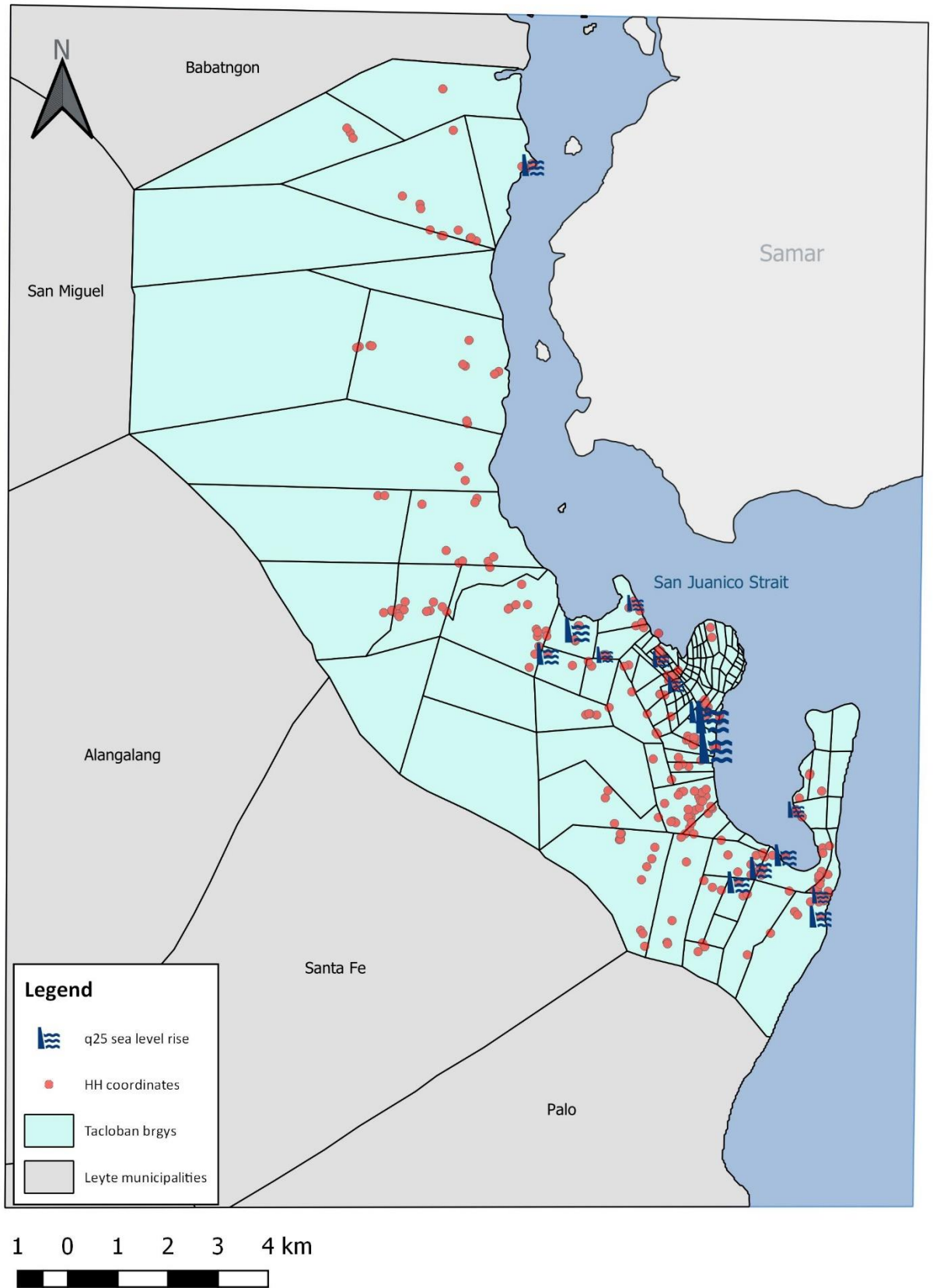


Figure 4.7 - Survey Q25 answers – vulnerability to sea level rise

Other than tropical cyclones, 62.4% of people raised heavy rainfall and thunderstorms as potentially destructive (Figure 4.8), with 44.3% assuming that flooding (Figure 4.9) could be of concern but only 14.5% considering drought (Figure 4.10). Despite being both related to the variation of rainfall patterns, flooding is therefore a more evident concern than droughts. The explanation behind this difference is related to the peoples' experiences: due to the deficient (or, in some parts of the city, inexistent) drainage system, flooding is a much more frequent phenomenon than drought. An example were the floods of December 2017, mentioned before. This result assumes a great relevance in the context of this dissertation, evidencing that Tacloban's population was, in fact, not aware of the real impacts of climate change on local water resources, and that water scarcity is expected to become more frequent in future scenarios - according to the regional projections of PAGASA and the hydrological modeling results hereby depicted.

The spatial distribution of the perception of the rainfall related hazards can be observed in figures below. It stood out that drought presented a larger concern to people residing on the northern extreme of LMWD's existing network (*Barangays* 99 and 93, for example), which were known to experience water shortage issues. The incidence of drought perception became scarcer in southern Tacloban, where heavy rainfall and, most of all, floods were enhanced as most menacing hazards. Much more dispersedly, some respondents (7.8%), probably those living near to steeper hills, reported their households to be vulnerable to landslides. Again, when overlapped with the city's flood map featured in the latest CLUP, one can observe that northern residents, despite feeling vulnerable to heavy rainfalls, resided in fact in much safer areas in terms of this hazard than their downtown neighbors.

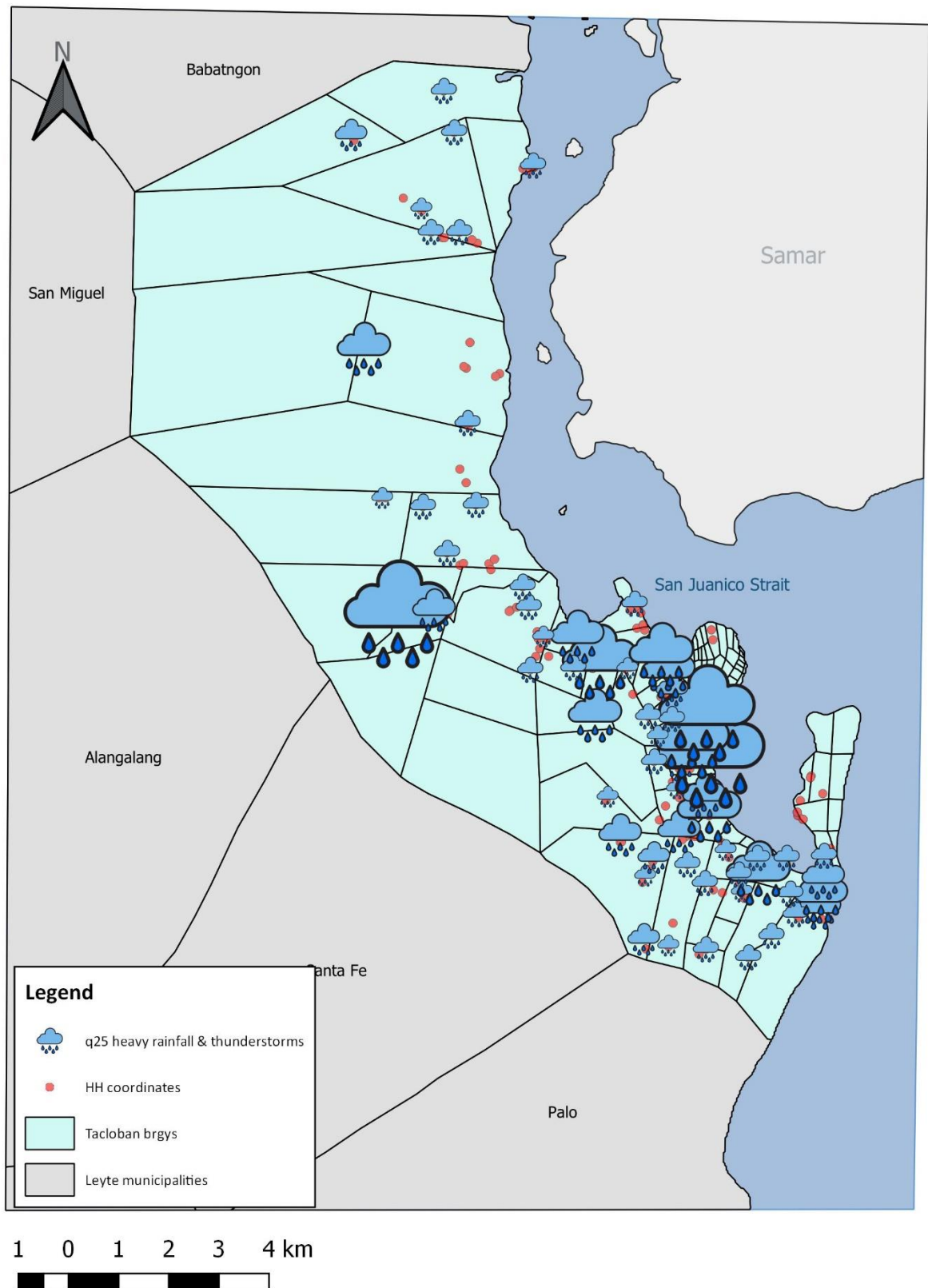


Figure 4.8 - Survey Q25 answers – vulnerability to heavy rainfall and thunderstorms

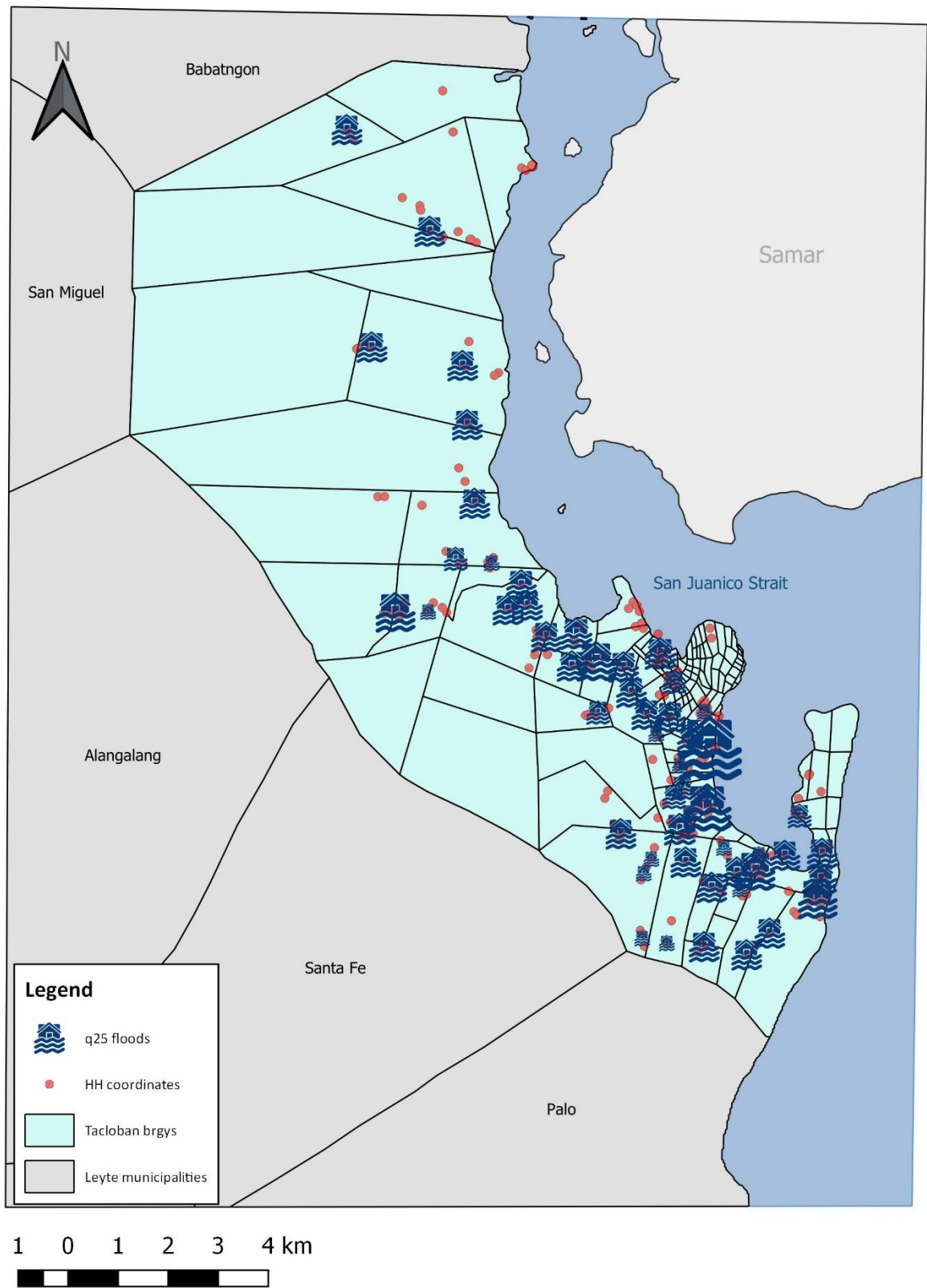


Figure 4.9 - Survey Q25 answers -vulnerability to flooding

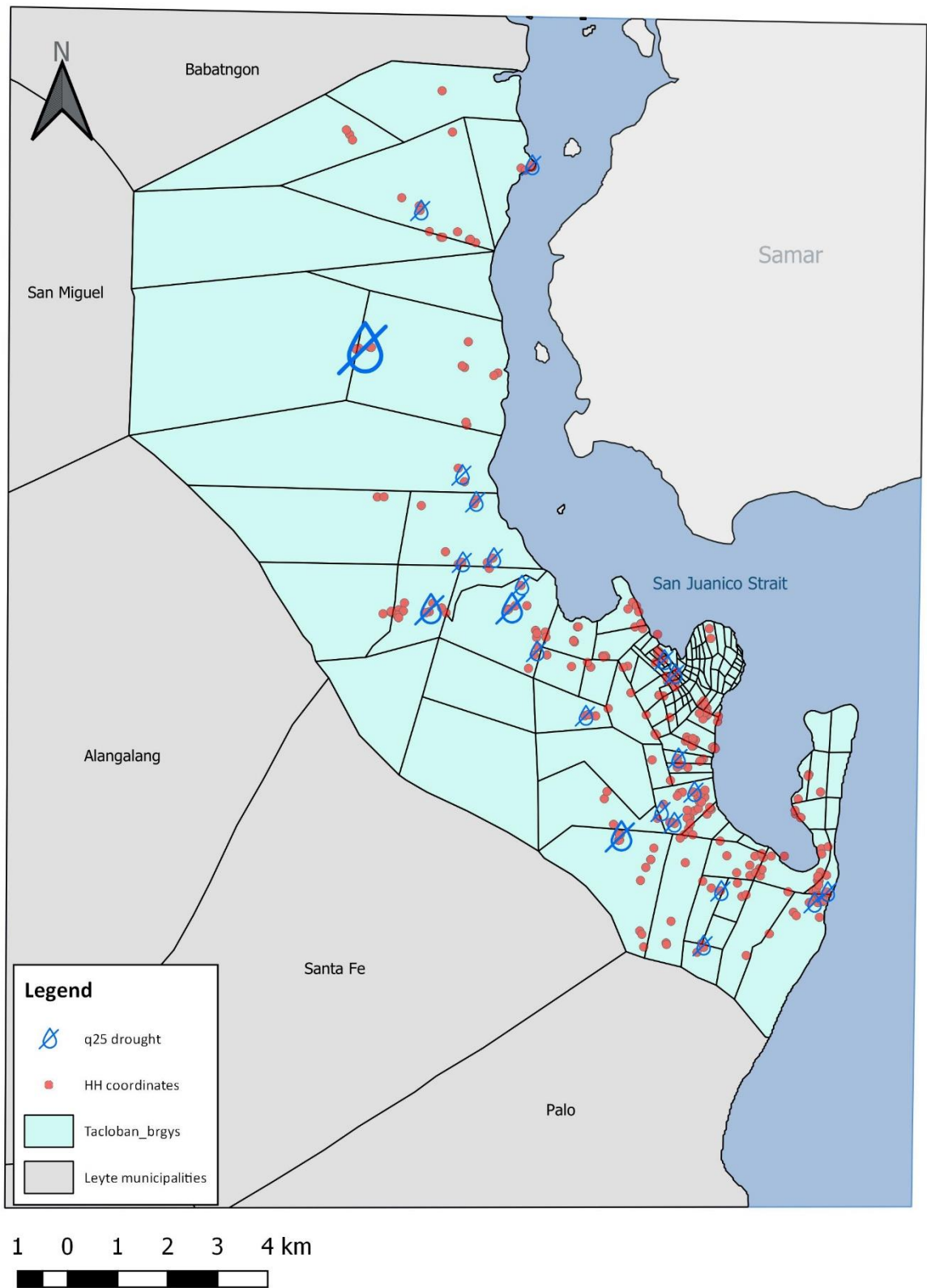


Figure 4.10 - Survey Q25 answers – vulnerability to drought

Typhoon Haiyan impacts and recovery

Oppositely to what was depicted in most post-disaster reports, the OML survey respondents chose Haiyan's fierce winds (85.5%, for question 29)) over its storm surge (49.6%) as the most destructive impact of the catastrophe. In addition, 24.5% stated that flooding caused the most damages to their household.

From the 282 households surveyed (question 30), 34.8% had an element suffering an injury, 24.8% developing some illness and 3.9% registering a casualty among the family. It is relevant to enhance, however, the importance of the psychological health impact of the typhoon, as 35.5% of respondents claimed to have suffered from a post-hazard depression or trauma. This is a relevant information in terms of the community resilience, hence, as referred by Jones and Tanner (2015), the psychological robustness of communities consolidates their resilience.

In terms of material damages (question 31), the results were much more homogeneous, with 69.5% of the houses being totally destroyed and 29.4% partially damaged. Consequently, 34.0% of these families had been moved to temporary shelters but were, at the time of the survey, already back in their original location (question 32). The situation was different for the 7.1% that were still staying at the temporary relocation sites. A small group of 10 households (3.5%) had already been relocated to a permanent shelter and 7 households were going to be permanently relocated soon. Considering that the survey was conducted 2.5 years after the typhoon, the delay on the relocation efforts (regardless of the inherent causes) could also be seen as a weak indicator for the city's resilience. The majority of respondents (52.1%), however, did not undergo any relocation.

Most respondents estimated that the costs of damages caused to their households would ascend from PhP 10 000 to PhP 100 000 (question 33). These costs represent a significant burden on these families, considering that most of them earned PhP 7 500 or less per month. Furthermore, considering the fact that most

families were incapable of saving up some of their income, the allocation of funds to the reconstruction of their households would, most probably, represent a decrease in other household expenses.

Moreover, 15.6% of the surveyed Taclobanons claimed to have had their livelihoods disrupted by the catastrophe and 10.6% lost their job or primary source of income (question 31). In fact, whilst 28.4% of respondents were back working six months after the typhoon, 27.3% one year and 16.3% after one month, 9.9% were still looking for livelihood alternatives at the time of the survey (question 36). This tardiness in bringing back people's income sources was later pointed as a flaw in the humanitarian operations, as explained ahead.

The post-disaster assistance (from the government and other humanitarian organizations) provided was classified by 53.5% of respondents as insufficient to cover to their household's basic needs (question 35). Figure 4.11 summarizes the most common types of humanitarian relief received (question 34), in which food and water stood out, followed by medicine and others (mostly monetary assistance). The relatively small importance given to the restoring of livelihoods confirmed the opinions collected during this dissertation's fieldtrips and was indicative of a short-sighted humanitarian action, consisting of overlapped efforts in terms of some basic needs (food and water), but lacking support in other sectors, such as livelihood and psychological monitoring – a most glaring need, considering the depression and trauma reports abovementioned.

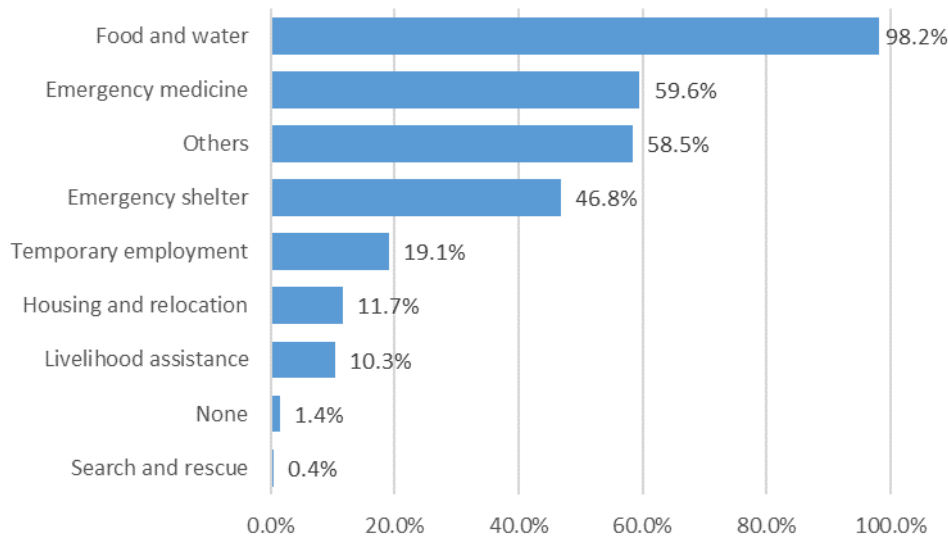


Figure 4.11 - Post-disaster assistance given to the households in the aftermath of Haiyan

For some of the appointed reasons, 57.4% of households considered themselves to be fully recovered (50.6% of which having recovered in less than two years), whilst the remaining 38.7% did not and estimated that that process would yet take more than a year (question 38). Regardless of all the destruction and the suffering brought along by Haiyan, 69.1% of the interviewed Taclobanons agreed that this event had helped them to increase awareness towards tropical cyclones and 19.1% that it had motivated them to reinforce their houses (question 39). In fact, when inquired about what motivated them to take some preventive measures towards natural hazards (as presented in the following section, question 45), 94.3% of them pointed their experience from Typhoon Haiyan as the main driver behind these behavioral changes.

Resilience and preparedness

Despite this increased awareness, preparing for impending hazards is yet an effort for most Taclobanon households, whose low incomes does not allow for allocating much for protective measures. Overall, as inquired in question 50 of the OML survey, 22.7% affirmed that they felt very highly prepared for any weather and

climate-related event, 34.4% highly prepared, 35.8% moderately prepared and 5.3% not prepared.

However, as seen on Figure 4.12 (question 44), 83.0% of the respondents could store food, water and medicine. Moreover, 46.8% claimed to monitor typhoon warnings and 48.2% were aware of the importance of evacuating their residences and moving to a safer place or shelter. This perception of the importance of evacuation, confirmed in the fieldtrip contacts, represented a major change since typhoon Haiyan and is a strongly positive indicator of resilience. In fact, the effectiveness of the evacuation protocols in Tacloban has been tested in posterior storms, such as Typhoon Ruby, in December of 2014, for which the local government has identified 21 evacuation centers and moved thousands of people.

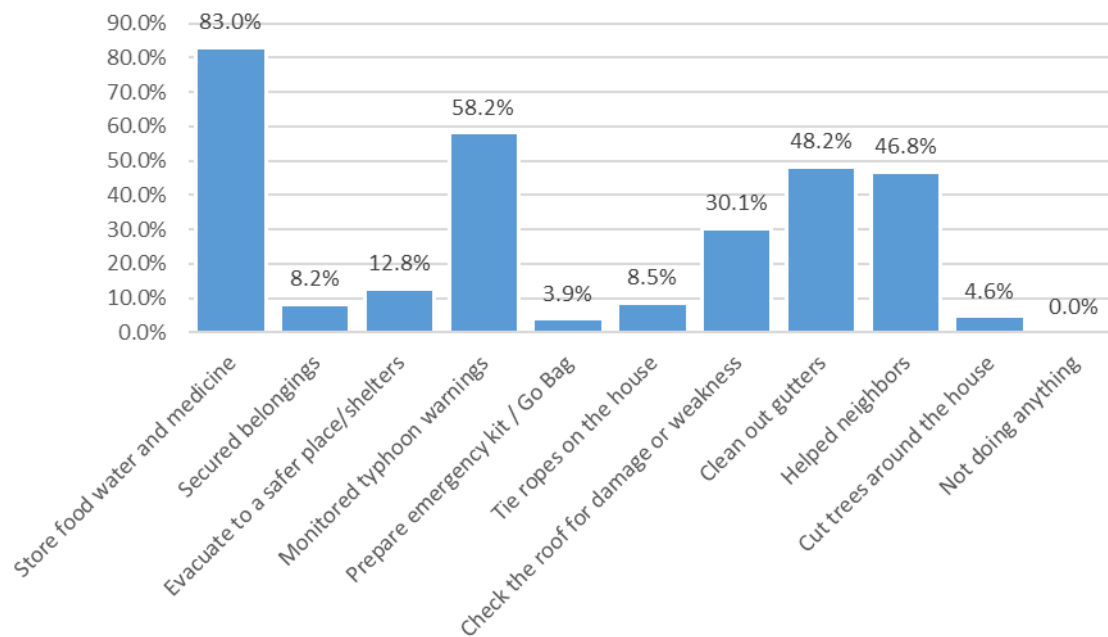


Figure 4.12 - Strategies to prepare for impending hazards (Q41)

As for the measures taken during and after the hazard (question 42), a majority of 53.9% respondents reported that they would probably just repair their houses using local available materials, whilst only 7.4% would consider moving

somewhere else. This type of response has been also identified by Santos (2018): considering the precarity of their houses architecture, most residents were willing to rebuild them after the storm, in detriment of reinforcing them beforehand (although 21.3% would rebuild them using more durable materials). Worryingly, in 26.2% of the interviewed households people pointed the reduction of food intake as a probable strategy to undergo when affected by a natural hazard – this may be indicative of a lack of confidence in their own resilience and/or the humanitarian organizations capability to provide them enough food in a relief situation. Actually, 50.7% of respondents declared that their household would not be able to sustain itself without help from the outside, should it be affected by a natural hazard.

Moreover, a curiously significant percentage of 14.5% of respondents affirmed that, during and after a catastrophe, they would pray. This type of response is a consequence of the high influence that the catholic church has on the Filipino culture and could again be interpreted as an evidence that people do not believe to be sufficiently resilient themselves, and that divine intervention is needed to keep them safe.

Figure 4.13 (concerning question 44) below, scrutinizes the capacity of the households of sustaining themselves up to three days when cut off from various services. In the context of this dissertation, it was interesting to enhance that 64.9% of the households considered themselves to have up to 3 days of water in the case of an interruption of the supply, which was a positive indicator of water-related resilience.

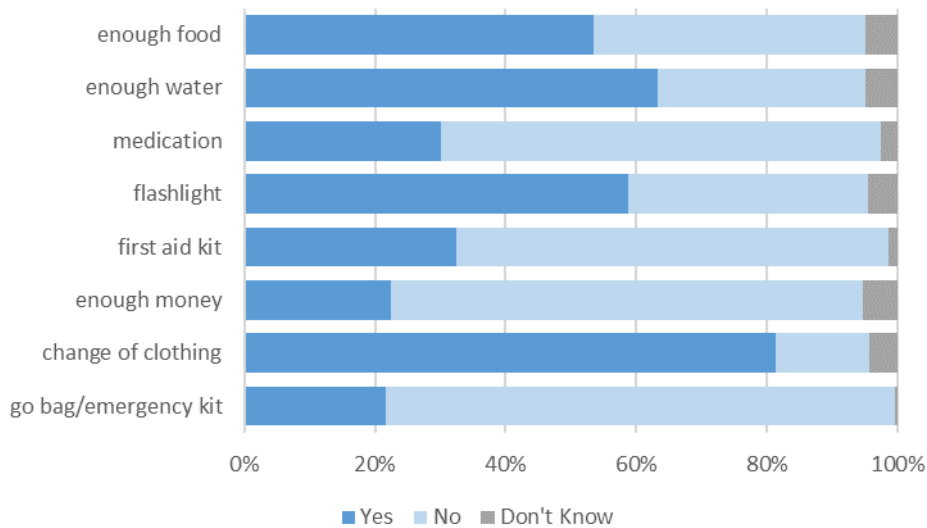


Figure 4.13- Independence from services (3 days)

From the same figure, it becomes apparent that saving money to prepare for natural hazards, as seen before, is not a priority for Taclobanons. Indeed, 68.4% of the respondents claimed that money was the main reason that prevented them to embrace more of these precautionary actions (question 47).

The majority of Taclobanons (85.5% for question 55) relied on television announcements of impending catastrophes to prepare. The radio was the second most frequent communication channel (62.1%), followed by the community word-of-mouth (56.0%), including relatives and neighbors, and the LGU releases (37.2%). In fact, 79.4% received the city’s LGU warnings before, during and after disasters, with 52.1% considering those to be timely, 59.9% to be sufficient and 57.1% to be reliable (questions 60 and 60.1). Additionally - as summarized on Figure 4.14, referent to question 84, further ahead of the survey, although most respondents understood that the household resilience and preparedness towards disasters was their own responsibility, 77.7% still believed that responsibility to be shared with the LGU (with 40.1% strongly agreeing and 37.6% agreeing to that affirmation).

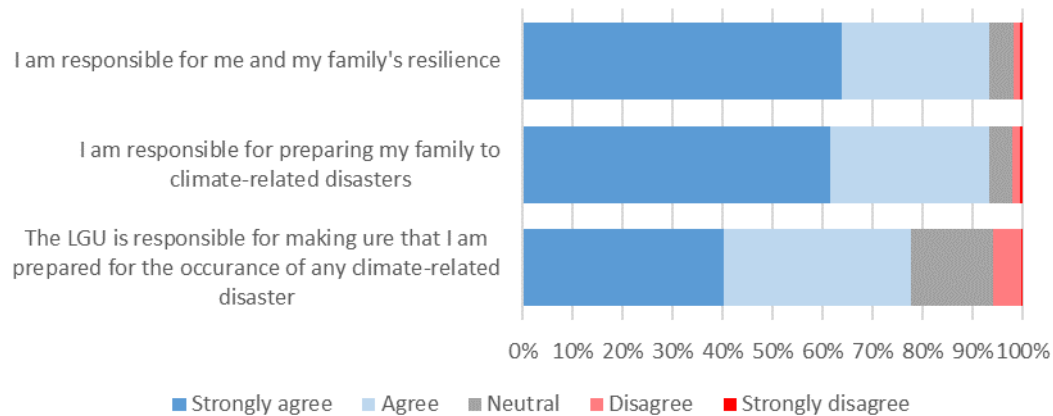


Figure 4.14 - Perception of responsibility (Q84)

These results are of the utmost importance to Tacloban’s LGU, so as to improve and reinforce their DRRM and CCA actions, hence the majority of the city’s residents claimed to rely on them¹⁹.

The respondents revealed to be educated towards hazards (questions 61 and 62), as 40.1% had already participated in flood drills and 35.1% on trainings on disaster preparedness (most of them conducted by NGOs and the LGU) – principally focusing on warnings and alert signals, first aid and evacuation routes and sites. Curiously, however, a significant share of respondents still identified a few indigenous ways of predicting a disaster – for example, by the observation of clouds or abnormal animal behavior (anxious dogs, silent chickens or moving cockroaches).

An overwhelming majority of respondents (98.9%, for question 63) affirmed to be able to make use of the learnt information and decide what to do if the household was affected by any of the weather and climate-related hazards, events and disasters. Hence, their confidence in their own skills (despite perceiving

¹⁹ Along with the main results of the survey, particularly these results comprising the city’s DRRM and CCA actions were presented to the Tacloban City LGU, on a presentation conducted by the OML Center researchers, in Tacloban, in August 29th, 2017

themselves to be totally dependent on external relief) establishes a strong asset for resilience.

A small percentage of respondents practiced agricultural activities (including livestock, fishing and forestry) as their main source of income, which was thought to be the reason why only 9.6% claimed to rely on the terrestrial ecosystem for their livelihood, and 5.7% in marine ecosystems for fishing purposes. This apparent disconnection from the surrounding ecosystems is often presented in specific literature as one of the reasons for disregarding their protection, leading to a decrease in resilience towards natural hazards – as published by Klein (2003) in his abovementioned research, maintaining a healthy ecosystem is equivalent to reinforcing local resilience, considering their buffer potential in the event of typhoons or flooding, and resourcefulness for the extraction of goods. However, as evidenced by question 24, the majority of respondents had the perception that the ecosystems played a significant role in the protection of the community in any weather and climate-related hazard, event or disaster (with 36.9% strongly agreeing to that and 29.4% agreeing, regardless of 17.4% disagreeing). This growing perception of the importance of ecosystems despite the low dependence of livelihoods, could be, in the context of this dissertation, interpreted as a positive resilience indicator. It constituted an evidence of a satisfying environmental/climate change awareness and information, coherent with the levels of education of the surveyed population.

In fact, looking into this perception with further detail, 75.9% of respondents strongly agreed (and 23.8% agreed) that the maintenance of a healthy environment was important (Figure 4.15). Over 70% have also enhanced the relevance of planting trees to protect the community – probably a result of the several mangrove reforestation projects that were undergoing in Tacloban, post-Haiyan, so as to prevent the damage of future storm surges. However, despite the

devastation provoked by Haiyan in the city, and the consequent necessity of reclassification of risk areas, a smaller percentage (of 50.7%) of respondents classified as very important the prohibition of new developments in the hazard prone areas. Finally, perhaps the most important option in the context of this dissertation, the idea of building protective structures such as dams, dikes and a seawall were the third classified in terms of importance. These results confirmed that the surveyed communities were considering the immediate impacts of climate change (such as the storm surges) towards which they need protection, but not the long-term impacts such as floods and droughts²⁰ – for which, as demonstrated in this dissertation, a dam would be crucial to enhance water security and, therefore, resilience towards CC impacts.

²⁰ However, one has to bear in mind that the available option mixed water retention structures (dams and dikes) with coastal protection constructions; this fact diffculted the analysis of the perception of rainfall related structures only, which would be most interesting for this study.

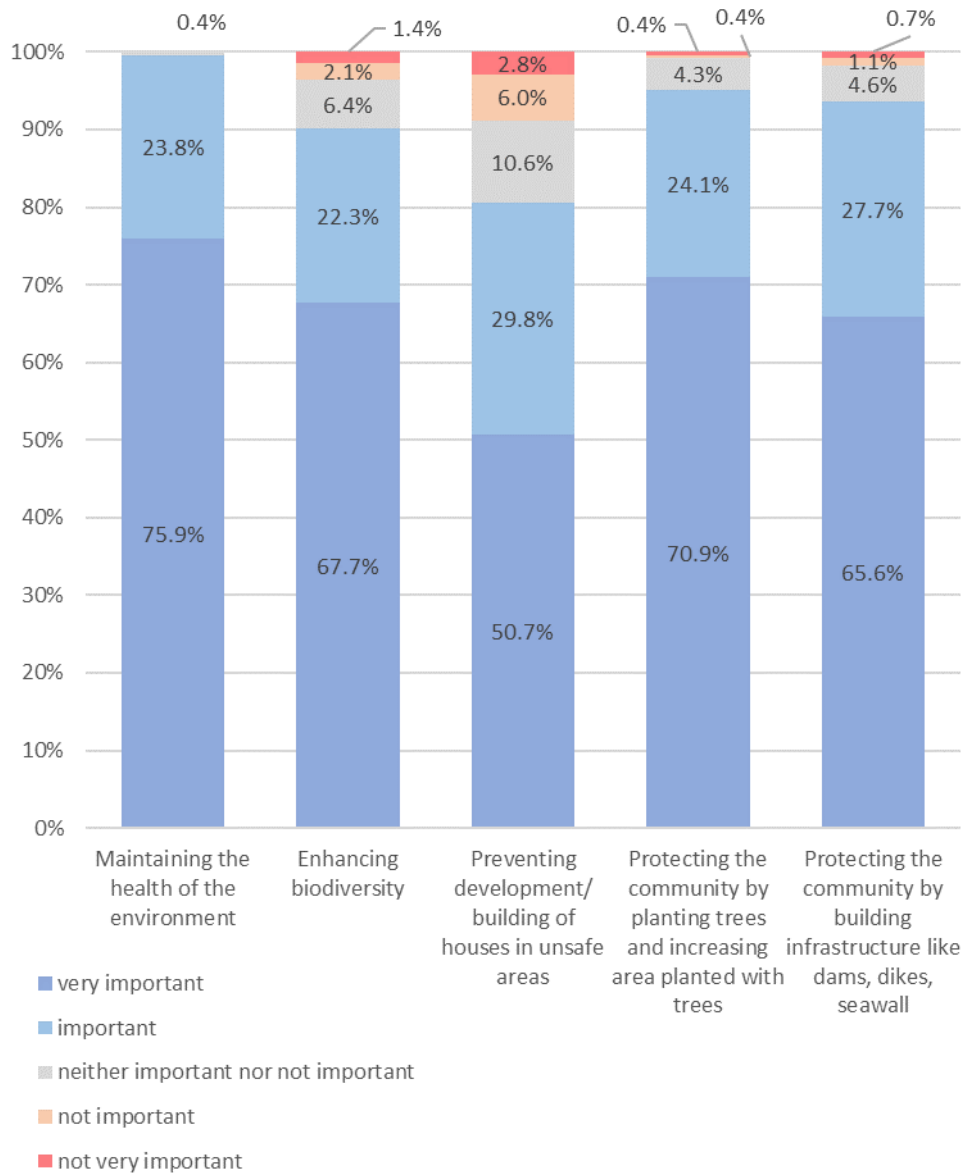


Figure 4.15 – Importance of environmental protection measures

Perception

The OML survey included a group of questions with the aim of analyzing the perception on matters of resilience (questions 85 and 86). From question 85, as summarized on Figure 4.16, it became evident the confusion between the concepts of preparedness and resilience, hence most respondents defined resilience only as being prepared to face a disaster, or to be able to cope with it

during the event. Most alarming, however, is the fact that 36% of respondents claimed not to know what resilience was about.

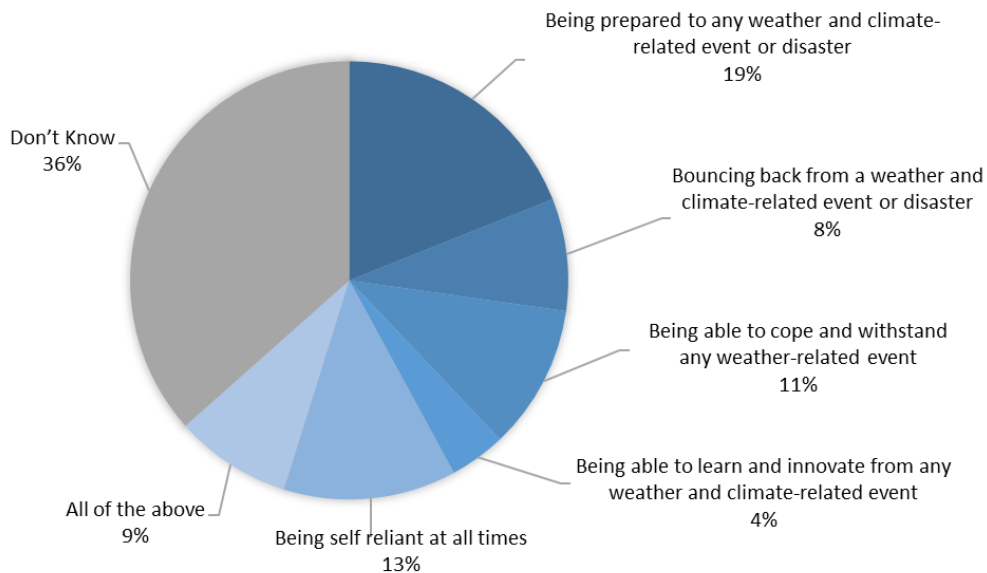


Figure 4.16 - Meaning of resilience (Q87)

On the final questions of the OML survey (Q85 and Q86), the respondents were inquired about their perception of their household resilience. A total of 54.6% (question 86) rated positively their household resilience (37.9% classifying it as high and 16.7% as very high). On the other hand, 38.7% affirmed that their resilience was only moderate, and 6.7% that it was low or very low. Overall, it became apparent that Taclobanons had a good perception of their resilience status, considering the social resilience indicators hereby analyzed. Figure 4.17 below summarizes these perceptions, in which can be observed that respondents classified their household resilience to be mostly 'high' or 'very high' on the listed aspects.

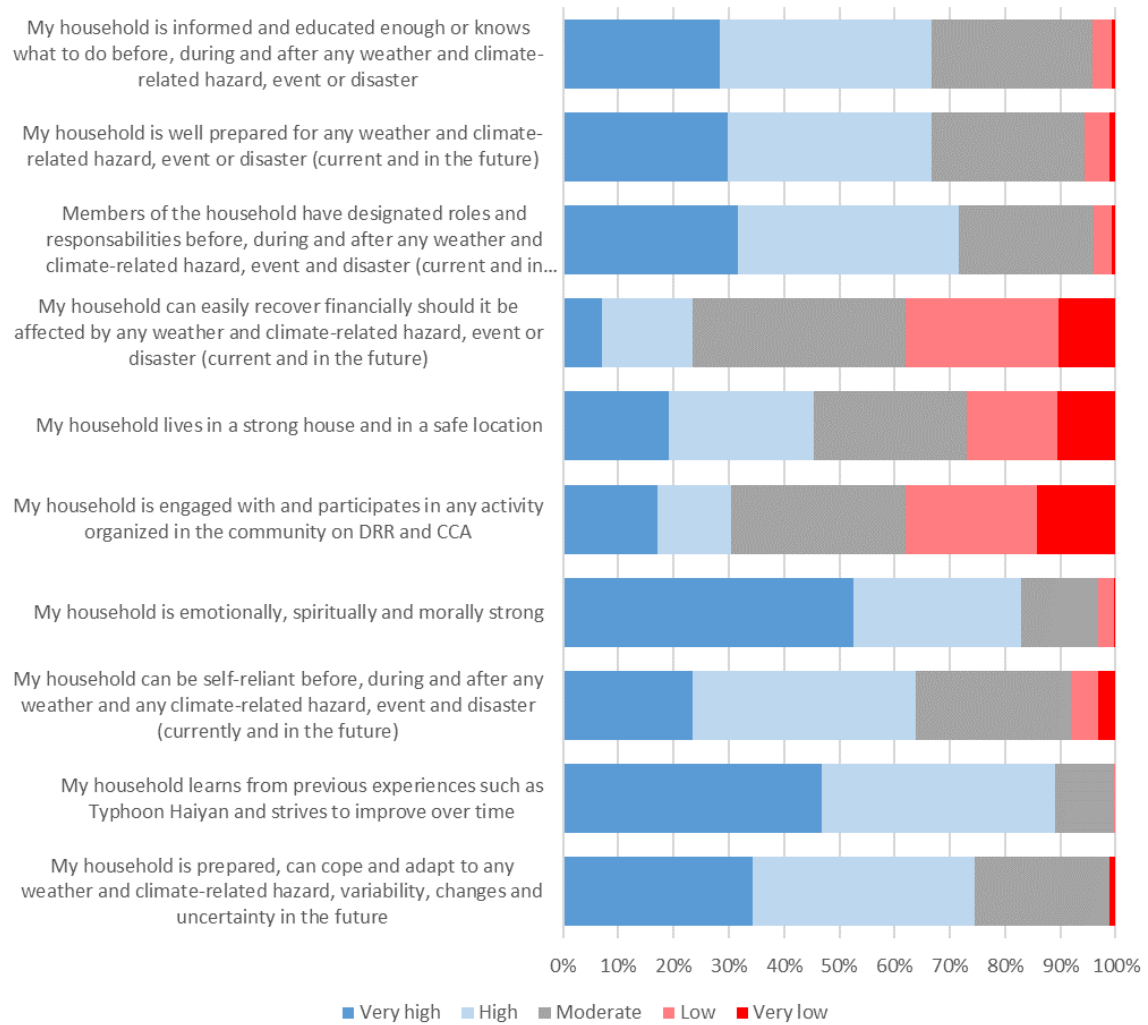


Figure 4.17 - Perception of household resilience (Q85)

Water supply constraints perception

From the results of the HH survey, special emphasis was given to question 19 where the respondents were inquired about the basic social services that needed improvement on their household. Amongst the possible answers – water supply, water quality, electricity, sewage/sanitation and others – water supply was pointed as a top priority by most respondents (corresponding to 54.6% of households). As is plotted on Figure 4.18, it is most relevant to enhance that almost the totality of respondents in the relocation areas in Tacloban North highlighted water supply as a top priority issue to be developed.

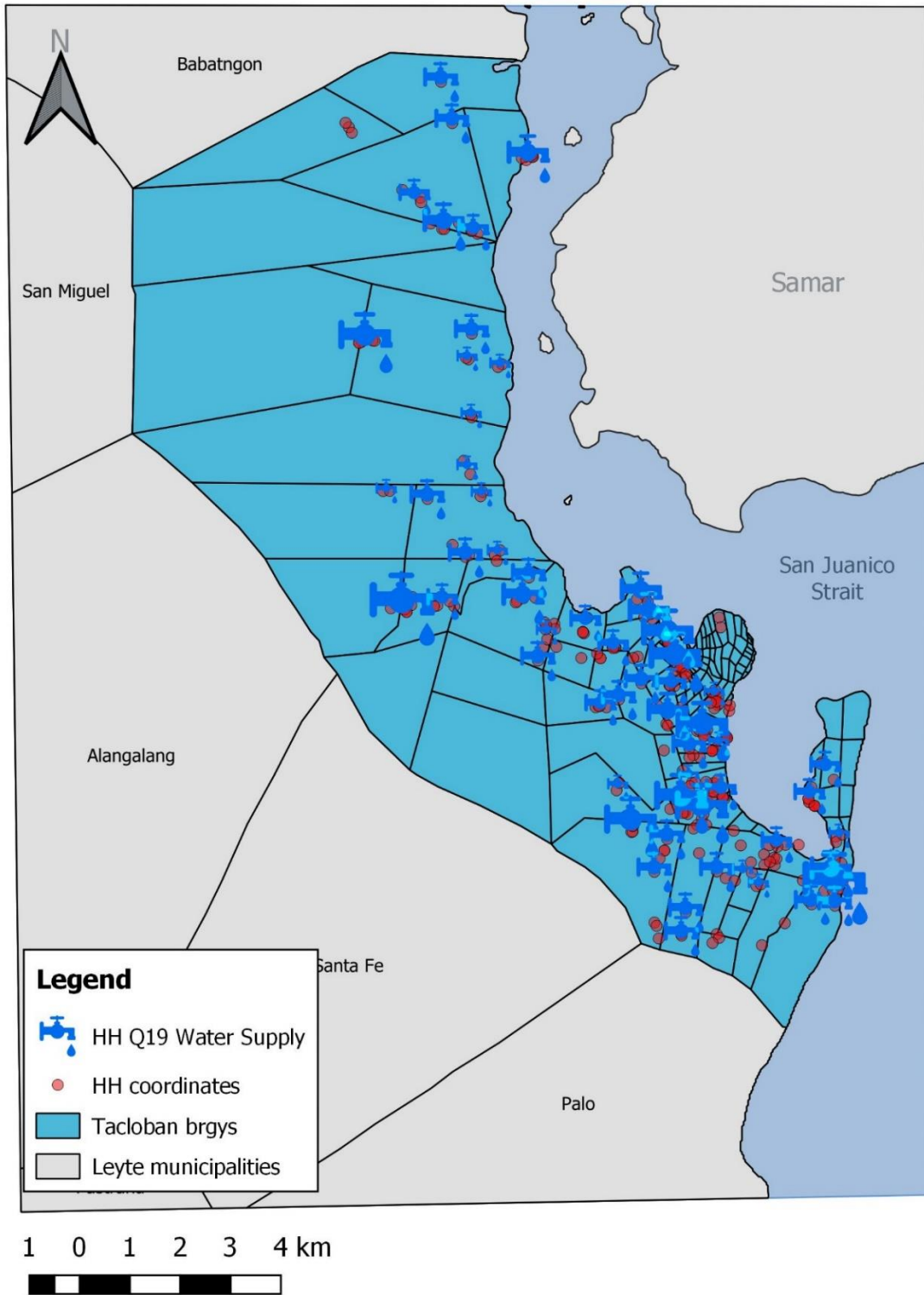


Figure 4.18 - Location of households and of respondents that highlighted water supply as a priority asset (Q19)

These results confirmed the opinions collected during the fieldtrips to Tacloban, either from the community in general, either from the local government. Moreover, it should be stressed that, after the water supply urgency, the improvement of water quality and sewage/sanitation aspects were the most representative, with 40.4% and 36.5% of respondents, respectively. Electricity was only chosen by 9.9% of HH, whilst 15.6% chose other issues that needed further development (such as garbage collection, for example) to increase their household resilience.

4.4. Conclusions

The demographic characterization of respondents returned that 54% of HH had at least one person in need of special assistance, which can be significant for evacuation and recovery actions. Regardless of the education of Taclobanons, their income dependence on self-employed small businesses (with no alternative income) could be of concern if these businesses are affected by a new storm. Moreover, the majority of HH stated that their income was insufficient to cover all their basic needs and still be able to save for emergencies. In sum, the respondents evidenced a fragile financial stability and robustness, which conferred them a low resilience.

A significant percentage of respondents (over 75%) were aware of CC and its impacts. However, they highlighted the increasing temperatures and the shift of seasons as the most predominant impacts, in detriment of the increase of the intensity of tropical cyclones. Incoherently, 95.7% pointed tropical cyclones as the climate-related hazard that they were most vulnerable to. With regard to CC impacts on the hydrological cycle, whilst 27.0% expected heavier rains, only 11.0% considered a delay of the rainy season – which is foreseen on PAGASA's reports. In return, only 11.3% of the interviewed HH claimed to be saving water to face those CC impacts. This result was indicative of a low perception of the real impacts of CC

in the local water availability, which conferred them with a low resilience score on those matters. However, flooding was pointed as a major concern than drought (44.3% versus 14.5%, respectively). The difference could be perhaps related to the experiences lived by the respondents, as flooding was, to date, a more common phenomenon in the city than drought. This was of great relevance for this dissertation, evidencing that Taclobanons were not aware of the real impacts of CC, namely the increasing prevalence of droughts.

In the aftermath of the suffering and destruction brought along by Haiyan, the majority of surveyed Taclobanons (69.1%) agreed that this event had helped them to increase their awareness towards tropical cyclones, and 19.1% claimed that it had even motivated them to reinforce their houses. Moreover, Haiyan was the cause behind an increased perception of the importance of evacuating in the event of a new typhoon, a positive indicator of resilience. Nonetheless, 50.7% still feared that their household would not be able to sustain itself after such a big storm, and that they depended on external help. This response could be interpreted as indicative of a lack of confidence on their own resilience.

Overall, the survey results confirmed that Taclobanons were considering the immediate impacts of CC (such as storm surges), towards which they needed immediate protection, but not the long-term impacts (such as floods or droughts). Alarmingly, 36.0% did not have a clear perception of what the term resilience meant, and it was still largely confused with simple preparedness.

In the context of this dissertation, an important conclusion to be highlighted was the preference that respondents gave to water network improvements as a mean to increase their HH resilience. This was most evident in Tacloban North relocation areas, as could be expected. Another interesting aspect was the fact that 64.9% claiming to have enough water for three days of consumption, if a hazard forced the interruption of the supply.

5. FINAL REMARKS

In order to address the water shortage issues in Tacloban, namely on the northern relocation areas, the need for a complete hydrological analysis of the local water catchment alternatives became compelling. The QSWAT modeling results have supported the initial premise that Binahaan River solely did not have enough flow to meet the yearly demand of this city, thus not being a resilient water source. This was particularly true to the period of March to August, when up to 20.3% of days revealed an insufficient flow. The seasonality of Binahaan is expected to aggravate due to climate change, given the increased variability of the rainfall patterns throughout the year (despite the total annual increase of precipitation).

The proposed idea of recurring to the two northern rivers, Pongso and Cabayugan, to supply the Tacloban North resettlement has evidenced a similar outcome. Thus, regardless of the supply solution chosen (i.e., either keeping the system based solely on Binahaan River or exploring other options), the implementation of flow regulation infrastructures is advised to minimize the described seasonality.

In an endeavor to bring this analysis closer to an integrated view of resilience, the perception of the local community on these water constraints was addressed. These results, achieved through a survey conducted in Tacloban, have underlined the generalized misconception about the meaning of resilience, which was simplified to simple preparedness. Furthermore, the responses of the survey have evidenced that Taclobanons seemed to be more aware of the impacts of extreme events enhanced by climate change (such as the tropical cyclones and associated storm surges), than they were conscious of the long-term impacts. Two examples of the latter can be the floods and especially the droughts caused by the aggravated seasonality of the local rain patterns – which are likely to worsen the water supply constraints, as hereby depicted. However, when asked about what features of their household should be improved to confer them more resilience,

for the majority of the respondents, the water supply service came as a first choice.

As for most academic projects, the results of this dissertation should not be interpreted excluding their inherent limitations. Those derived from the inexistence of some of the required data and the necessity of recurring to nearby stations, in the case of the hydrological modeling. Plus, the lack of real flow measurements for calibration purposes and the rough approximation with a forth river of Leyte, may have incurred uncertainty to his study. What is more, as for every modeling outputs (either climatological or hydrological, both present on this dissertation), a careful interpretation should be handled.

In parallel, the conclusions resulting from the household survey conducted may entail biases. In its turn, these originate from the misunderstanding of the questions by the respondents, or the influence of the opinion of their peers. The fact that the survey was conducted during working hours may have implicated that the respondents were unemployed, older and/or less educated people, which may have influenced their perception of the surveyed aspects.

Overall, one can consider that this dissertation has successfully accomplished its proposed objectives, bringing a positive contribute to the present discussion on resilience enhancement in CCA and DRR contexts. It represents also a valuable contribution for the local government of Tacloban as it generated knowledge on the local water resources – fulfilling the proposed applied research goals.

It should not, however, be treated as a finalized endeavor. Possible future developments of this work include conducting real flow measurements on the three studied rivers, in order to refine and improve the modeling results. Other pertinent analysis would be the follow up of the water supply scheme choice, and the detailed study and sizing of the flow regulation infrastructures, hereby proven necessary. The study and implementation of a wastewater drainage and treatment

system is of the most importance, as San Juanico strait is becoming heavily polluted. Finally, the lessons learned from the household survey regarding the perception of the population on resilience should be deepened. In an era when climate change dominates worldwide discussions and extreme phenomena as Haiyan are thought to become more frequent, it is urgent to educate the habitants of such hazard prone areas and involve them in the adaptation strategies that will allow them to become truly resilient.

REFERENCES

- Abarquez, M., 2016. *Be Secure - Understanding Community Practice*, Tacloban, Philippines: LMWD for USAID Be Secure Project - Water Security for Resilient Economic Growth and Stability.
- ADB, 2010. *Water District Development Sector Project. Final Report. Volume 6: Subproject Appraisal Report: Leyte Metro Water District*, Manila: POYRY IDP Consult, INC., Philippines.
- Arnold, J. G. et al., 2012. *Input/Output Documentation, Version 2012*, Texas, USA: Texas Water Resources Institute.
- Boase, J., 2014. *Learning from Tacloban*, Tacloban, Philippines: unknown editor.
- Chen, J., Brissette, F. P. & Leconte, R., 2011. Uncertainty of downscaling method in quantifying the impact of climate change on hydrology. *Journal of Hydrology*, Volume 401, pp. 190-202.
- CIA, 2015. *The World Fact Book, Philippines*. [Online]
Available at: <https://www.cia.gov/library/publications/the-world-factbook/geos/rp.html>
[Accessed 2 November 2015].
- City Government of Tacloban, 2014. *TRRP- Tacloban Recovery and Rehabilitation Plan*, Tacloban, Philippines: City Government of Tacloban.
- City Government of Tacloban, 2016. *Tacloban North Integrated Development Plan*, Tacloban, Philippines: City Government of Tacloban.
- City Government of Tacloban, 2018. *Comprehensive Land Use Plan*, Tacloban, Philippines: City Planning and Development Office.
- Climate Change Commission, 2012. *National Climate Change Action Plan 2011-2028*, Manila, Philippines: Climate Change Commission.
- Coelho, P. S., 2009. *Modelação Matemática da Qualidade da Água em Sistemas Albufeira-Rio*, Lisbon, Portugal: New University of Lisbon, Faculty of Sciences and Technology.
- Cutter, S. L. et al., 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, Volume 18, pp. 598-606.
- Dams, J. et al., 2015. Multi-model approach to assess the impact of climate change on runoff. *Journal of Hydrology*, Volume 529, pp. 1601-1616.
- de Wit, M. J. M. et al., 2007. Impact of climate change on low-flows in the river Meuse. *Climatic Change*, Volume 82, pp. 351-372.
- Diaz-Nieto, J. & Wilby, R. L., 2005. A comparison of statistical downscaling and climate change factor methods: impacts on low flows in the River Thames, United Kingdom. *Climatic Change*, Volume 69, pp. 245-268.

Dibike, Y. B. & Coulibaly, P., 2005. Hydrological impact of climate change in the Saguenay watershed: comparison of downscaling methods and hydrologic models. *Journal of Hydrology*, Volume 307, pp. 145-163.

Dile, Y., Srinivasan, R. & George, C., 2016. *QGIS Interface for SWAT (QSWAT). Version 1.3. Step by Step Setup for the Robit Watershed, Lake Tana basin Ethiopia*. [Online] Available at: <http://swat.tamu.edu/software/qswat/> [Accessed 17 April 2016].

DIVA-GIS, 2015. *Free Spatial Data*, Montpellier, France: DIVA-GIS.

DLIFLC, 2011. *Philippines in Perspective: an Orientation Guide*, Manila, Phillipines: Defense Language Institute Foreign Language Center.

Duijnhoven, H. & Neef, M., 2014. Framing Resilience. From a model-based approach to a management process. *Procedia Economics and Finance*, Volume 18, pp. 425-430.

Eadie, P., 2017. *Post-disaster resilience: problems and challenges. Project "Poverty Alleviation in the Wake of Typhoon Yolanda". Working paper V*, Nottingham, UK: University of Nottingham.

Ellis, J., 2014. *Climate Resilience Indicator Literature Review*, Nakusp, Canada: Columbia Basin Trust.

Engle, N., Bremond, A., Malone, E. L. & Hoss, R. H., 2014. Towards a resilience indicator framework for making climate-change adaptation decisions. *Mitigation and Adaptation Strategies for Global Change*, Volume 19, pp. 1295-1312.

EUMETSAT, 2013. *Typhoon Haiyan approaching the Philippines (November 7th, 2013)*, Darmstadt, Germany: EUMETSAT.

FIES, 2015. *2015 Family Income and Expenditure Survey*, Manila, Philippines: National Statistics Office.

Flato, G. et al., 2013. Evaluation of Climate Models. In: T. F. Stocker, et al. eds. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, pp. 741 - 866.

Folke, C., 2006. Resilience: The emergence of a perspective for socio-ecological systems analyses. *Global Environmental Change*, Volume 16, pp. 253-267.

Fowler, H. J., Blenkinsop, S. & Tebaldi, C., 2007. Linking Climate Change modelling to impact studies: recent advances in downscaling techniques for hydrological modelling. *International Journal of Climatology*, Volume 27, pp. 1547-1578.

Fowler, H. J. & Kilsby, C. G., 2007. Using regional climate model data to simulate historical and future river flows in northwest England. *Climatic Change*, Volume 80, pp. 337-367.

FSIN, 2014. *Resilience Measurement Principles - toward an agenda for measurement design*, Rome, Italy: World Food Programme.

- Gao, B., Yang, D., Zhao, T. & Yang, H., 2012. Changes in the eco-flow metrics of the Upper Yangtze River from 1961 to 2008. *Journal of Hydrology*, Volume 448-449, pp. 30-38.
- GENI, 2000. *Global Energy Institute Network, Hydropower in the Philippines*, San Diego, California, USA: US Department of Energy.
- GIZ, 2014. *Assessment of early warning efforts in Leyte for Typhoon Haiyan/Yolanda*, Bonn and Eschborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.
- Global Weather, 2016. *Global Weather Data for SWAT*, Texas, USA: Texas A&M University.
- Gultiano, S., Balbarino, E. & Saz, E., 2003. Chapter 3: Geography of the Philippines. In: P. Urich, ed. *Population Dynamics, Land Availability and Adapting Land Tenure Systems: Philippines, a case study*. Paris: CICRED, FAO, pp. 29-57.
- Hay, L. E., Wilby, R. L. & Leavesley, G. H., 2000. A comparison of delta change and downscaled GCM scenarios for three mountainous basins in the united states. *Journal of the American Water Resources Association*, 36(2), pp. 387-397.
- HDN, 2013. *Philippine Human Development Report 2012/2013*, Manila, Philippines: Human Development Network.
- Homeris, P. A., 2016. *Final Results of the Vulnerability and Risk Assessment. Critical vulnerabilities, projected trends, potential impacts, proposed adaptation options*, Tacloban, Philippines: LMWD for USAID Be Secure Project - Water Security for Resilient Economic Growth and Stability.
- IPCC, 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge, UK, and New York, USA: Cambridge University Press.
- IPCC, 2013. *Climate Change 2013: The Physical Science Basis. Contribution of the Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. ed. Cambridge, UK and New York, USA: Cambridge University Press.
- ISRIC, 2016. *Soil Grids - a global gridded soil information*, Wageningen, Netherlands: ISRIC.
- Jones, L. & Tanner, T., 2015. *Measuring 'subjective' resilience. Using people's perceptions to quantify household resilience (Working Paper 423)*, London, UK: Overseas Development Institute.
- JTWC, 2013. *Annual Tropical Cyclone Report 2013*, Hawaii, USA: Joint Typhoon Warning Center .
- Klein, R., Nicholls, R. & Thomalla, F., 2003. Resilience to natural hazards: How useful is this concept?. *Environmental Hazards*, Volume 5, pp. 35-45.
- Lander, M., Guard, C. & Camargo, J. S., 2014. [The Tropics] Sidebar 4.2.: Super Typhoon Haiyan (in State of the Climate, 2013). *Bull. Amer. Meteor. Soc.* , 95(7), pp. 112 - 114.
- Laprise, R., 2008. Regional Climate Modeling. *Journal of Computational Physics*, Volume 227, pp. 3641-3666.

- Lencastre, A. & Franco, F. M., 2006. *Lições de Hidrologia*. 3rd ed. Caparica, Lisbon: Fundação da Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa.
- Li, Z. et al., 2016. Impacts of future climate change on river discharge based on hydrological inference: A case study of the Grand River Watershed in Ontario, Canada. *Science of the Total Environment*, Volume 548-549, pp. 198-210.
- LMWD, 2014. *LMWD Fact Sheet*, Tacloban, Philippines: Leyte Metropolitan Water District.
- LMWD, 2015. *Leyte Metropolitan Water District (About)*. [Online] Available at: <http://www.lmwd.gov.ph/about.html> [Accessed 20th December 2017].
- LMWD, 2016. *Fact Sheet (2016)*, Tacloban, Philippines: Leyte Metropolitan Water District.
- Maharaj, S. S. & New, M., 2013. Modelling individual and collective species responses to climate change within Small Island States. *Biological Conservation*, Volume 163, pp. 283-291.
- Minville, M., Brissette, F. & Leconte, R., 2008. Uncertainty of the impact of climate change on the hydrology of a nordic watershed. *Journal of Hydrology*, Volume 358, pp. 70-83.
- NDRRMC, 2014a. *Post Disaster Needs Assessment (PDNA) in Typhoon Yolanda Affected Areas*, Quezon City, Manila, Philippines: NDRRMC - National Disaster Risk Reduction and Management Council.
- NDRRMC, 2014b. *Update Sit Rep No. 104 Effects of Typhoon "Yolanda" (Haiyan), 29 January 2014*, Quezon City, Philippines: NDRRMC Proactive.
- NEDA, 2013a. *Reconstruction Assistance on Yolanda - Implementation for results*, Manila, Philippines: National Economic and Development Authority.
- NEDA, 2013b. *Reconstruction Assistance on Yolanda (RAY) - Build Back Better*, Pasig City, Philippines: National Economic and Development Authority (NEDA).
- Neitsch, S. L., Arnold, J. G., Kiniry, J. R. & Williams, J. R., 2011. *Soil and Water Assessment Tool - Theoretical Documentation - Version 2009*, Texas, USA: Texas Water Resources Institute.
- NOAA, 2018. *About the Saffir-Simpson Hurricane Wind Scale*. [Online] Available at: <https://www.nhc.noaa.gov/aboutsshws.php?> [Accessed 19th June 2018].
- Norris, F. H. et al., 2008. Community Resilience as a Metaphor, Theory, Set of Capacities and Strategy for Disaster Readiness. *American Journal of Community Psychology*, Volume 41, pp. 127-150.
- Olden, J. D. & Poff, N. L., 2003. Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. *River Research and Applications*, 19(2), pp. 101-121.
- OXFAM, 2013. *Typhoon Haiyan - the response so far and vital lessons for the Philippines recovery (briefing note)*, Oxford, UK: Oxfam GB.

- OXFAM, 2014a. *In the shadow of the storm: Getting recovery right one year after typhoon Haiyan*, Oxford, UK: Oxfam GB.
- OXFAM, 2014b. *Philippines typhoon - six months on (May 2014)*, Ottawa, Canada: Oxfam Canada.
- OXFAM, 2014c. *The right move? Ensuring durable relocation after Typhoon Yolanda*, Oxford, UK: Oxfam GB.
- OXFAM, 2016. *Humanitarian Quality Assurance: Philippines: Evaluation of Oxfam's humanitarian response to typhoon Haiyan*, Oxford, UK: Oxfam GB.
- PAGASA, 2011. *Climate Change in the Philippines*, Manila, PH: PAGASA.
- PAGASA, 2016. *Climatic Normal of the Philippines (1981-2010)*, Manila: PAGASA.
- POPCEN, 2010. *2010 Census of Population and Housing*, Manila, Philippines: Philippines Statistics Authority.
- POPCEN, 2015. *2015 Census of Population and Housing*, Manila, Philippines: Philippines Statistics Authority.
- Proag, V., 2014. Assessing and Measuring Resilience. *Procedia Economics and Finance*, Volume 18, pp. 222-229.
- PROVIA, 2013. *PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change*, Nairobi, Kenya: UNEP.
- PSA, 2013. *Population of Tacloban City Rose to More than 200 Thousand (Results from the 2010 Census of Population and Housing)*. [Online]
Available at: <https://psa.gov.ph/content/population-tacloban-city-rose-more-200-thousand-results-2010-census-population-and-housing>
[Accessed 16th December 2015].
- PSA, 2017a. *Highlights of the 2015 Census Results for Tacloban City*, Manila, Philippines: Philippines Statistics Authority, Leyte Provincial Statistical Office.
- PSA, 2017b. *Philippines In Figures 2017*, Manila, Philippines: Philippines Statistics Authority.
- QGIS Project, 2016. *QGIS User Guide. Release 2.14*. [Online]
Available at: http://docs.qgis.org/2.14/en/docs/user_manual/preamble/foreword.html
[Accessed 20 August 2016].
- Ranjan, E. S. & Abenayake, C. C., 2014. A study on community's perception on disaster resilience concept. *Procedia Economics and Finance*, Volume 18, pp. 88-94.
- Rummukainen, M., 2010. State-of-the-art with regional climate models. *Wiley Interdisciplinary Reviews: Climate Change*, Volume 1(1), pp. 82-96.
- Santos, C. T., 2018. *The impact of tropical cyclone Haiyan in the Philippines: Contribution of spatial planning to enhance adaptation in the city of Tacloban*, Lisbon, Portugal: Universidade de Lisboa, Faculdade de Ciências.

- Santos, C. T. et al., 2016. The Impacts of Typhoon Haiyan in the Philippines: Implications to land use planning. *Climate, Disaster and Development Journal*, 1(1), pp. 57-66.
- Schmidli, J. et al., 2007. Statistical and dynamical downscaling of precipitation: an evaluation and comparison of scenarios for the European Alps. *Journal of Geophysical Research*, Volume 112.
- Sellami, H., Benabdallah, S., La Jeunesse, I. & Vanclooster, M., 2016. Quantifying hydrological responses of small Mediterranean catchments. *Science of the Total Environment*, Volume 543, pp. 924-936.
- Serpa, D. et al., 2015. Impacts of climate and land use changes on the hydrological and erosion processes of two contrasting Mediterranean catchments. *Science of the Total Environment*, pp. 64-77.
- Teutsschbein, C., 2013. *Hydrological modeling for Climate Change Impact Assessment - Transferring Large-Scale Information from Global Climate Models to the Catchment Scale*. Doctoral Dissertation ed. Stockholm: Stockholm University, Department of Physical Geography and Quaternary College.
- Tierney, K. & Bruneau, M., 2007. Conceptualizing and Measuring Resilience. A Key to Disaster Loss Reduction. *TR News*, Volume 250, pp. 14-17.
- Tolentino, P. L. M., Geronia, M. C. M., Clutario, M. V. A. & David, C. P. C., 2016. Potential long-term impact of Typhoon Haiyan on the water sources of Tacloban and its vicinity. *Climate, Disaster and Development Journal*, 1(1), pp. 9-14.
- Turnbull, M., Sterret, C. L. & Hilleboe, A., 2013. *Toward Resilience. A guide to Disaster Risk Reduction and Climate Change Adaptation*. Warwickshire, UK: Practical Action Publishing Ltd.
- UNISDR, 2015. *Sendai Framework for Disaster Risk Reduction 2015-2030*, Geneva, Switzerland: UNISDR.
- UNU-INWEH, 2016. *Waterbase*. [Online] Available at: <http://www.waterbase.org/index.html> [Accessed March 2016].
- USAID, 2015. *Tacloban City North Bulk Water Supply Project, Rapid Feasibility Study, Final Report*, Manila, Philippines: USAID.
- USAID, 2017a. *Climate-resilient water infrastructure: guidelines and lessons from the USAID Be Secure project*, Manila, Philippines: AECOM.
- USAID, 2017b. *Real Impact: Be Secure*, Manila, Philippines: USAID Bureau for Economic Growth, Education and Environment (E3).
- USEPA, 2015. *Climate Ready Utilities. Adaptation Strategies Guide for Water Utilities*, Washington D. C., USA: USEPA.
- USGS, 2015. *Earth Explorer Platform*, USA: USGS.

Weather and Climate, 2015. *Average Weather in Tacloban, Philippines*. [Online]
Available at: <https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Tacloban,Philippines>
[Accessed 11 November 2015].

Wernstedt, F. L. & Spencer, J. L., 1967. *The Phillipine Island World: a physical, cultural and regional geography*. California: University of California Press.

Winderl, T., 2014. *Disaster Resilience Measurements. Stocktaking of ongoing efforts in developing systems for measuring resilience*, New York, USA: United Nations Development Programme.

Xu, C., Widén, E. & Halldin, S., 2005. Modelling Hydrological Consequences of Climate Change - Progress and Challenges. *Advances in Atmospheric Sciences*, 22(6), pp. 789-797.

Yevjevich, V., 1982. Chapter 7 - Probability distribution functions in Hydrology. In: *Probability and Statistics in Hydrology*. Colorado, USA: Water Resources Publication, pp. 118-164.

ANNEXES

ANNEX I – Resilience Definitions

ANNEX II – Rainfall data analysis and validation

ANNEX III – WGEN input files

ANNEX IV – Household Survey

ANNEX V – Copyright Permission OML Center

ANNEX VI – Declarations of originality and conformity

ANNEX VII – List of Publications

ANNEX I – Resilience definitions

Table I.1 – Consulted resilience definitions

Worldwide	Per continent/region	National/local
<p>UN/UNISDR, FAO The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.</p> <p>Comment: “Resilience” means the ability to “resile from” or “spring back from” a shock. The resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need.</p>	<p>African Ministers’ Council on Water (AMCOW) The capacity of a social or ecological system to resist, absorb, accommodate and recover from the effects of a (climate) risk on a timely and efficient manner, maintaining its structure and functions. It reflects the amount of change a system is able to support, until what point it is able of reorganizing itself and to what extent it can learn and adapt</p>	<p>Los Angeles County Community Disaster Resilience (USA) Resilience, in the context of disasters, is the ability to mitigate and rebound quickly. Community resilience is the ability of communities to withstand and recover from past disasters and to learn from past disasters to strengthen future response and recovery efforts.</p>
<p>DRI International a) Resilience is the ability of an organization to resist being affected by an event or the ability to return to an acceptable level of performance in an acceptable period of time after being affected by an event b) Resilience is the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must</p>	<p>EEA (EU) (Ecological) resilience can be defined in two ways. The first is a measure of the magnitude of disturbance that can be absorbed before the (eco) system changes its structure by changing the processes and variables that control behavior. The second, a more traditional meaning, is a measure of resistance to disturbance and the speed of return to the equilibrium state of an ecosystem</p>	<p>UK Cabinet Office (UK) Ability of the community, services, area and infrastructure to detect, prevent, and if necessary to withstand, handle and recover from disruptive challenges.</p>
<p>Resilience Alliance Resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks.</p>	<p>Climate-ADAPT (EU) The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization and the capacity to adapt to stress and change <i>(same definition as IPCC AR4)</i></p>	<p>US Department of Energy (USA) Resilience, or the ability of a region to respond to climate variations and natural events that result from climate change, is given by its adaptation and coping capacity and its sensitivity</p>

Worldwide	Per continent/region	National/local
<p>IPCC (AR4, WGII) The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change</p> <p>IPCC (2012) The ability of a system and its components to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.</p>	<p>African Climate Amount of change a system can support without altering its natural state</p>	<p>OXFAM (UK) Resilience: The ability of women, men, and children to realize their rights and improve their well-being despite shocks, stresses, and uncertainty. Oxfam considers resilience at the individual, household, and community level, because this is where impact is ultimately felt. However, clearly many causes of vulnerability cannot be resolved at this level, so the roles and responsibilities of states and other relevant institutions, including private companies and investors, must also be addressed.</p>
<p>OECD Resilience refers to the capacity of a natural system to recover from disturbance</p>	<p>Asian Development Bank (ADB) The ability of a system and its components to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions. <i>(same definition as IPCC AR4)</i></p>	<p>USEPA (USA) and Global Change (USA) A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy and the environment.</p>
<p>World Food Programme Resilience is the capacity that ensures that adverse stressors or shocks do not have long-lasting adverse development consequences.</p>		<p>USAID (USA) the ability of people, households, communities, countries and systems (social, economic, ecological) to mitigate, to adapt to, recover from shocks and stresses (eg. Climate change) in a manner that reduces chronic vulnerability and facilitates inclusive growth</p>

References:

ADB, 2013. *Investing in Resilience. Ensuring a Disaster-Resistant Future*. Manila, Philippines:

Asian Development Bank

Available at: <http://www.adb.org/sites/default/files/publication/30119/investing-resilience.pdf>

[Accessed 9th October 2014]

African Climate, 2014. *Glossary*. Cape Town, South Africa: African Climate

Available at: <http://africanclimate.net/pt-pt/node/6471>

[Accessed 9th October 2014]

AMCOW, 2014. African Ministers Council on Water Webpage. Abuja, Nigeria: AMCOW
Available at: http://www.amcow-online.org/index.PHP?searchword=resilience&ordering=&searchphrase=all&Itemid=140&option=com_search&lang=en
[Accessed 9th October 2014]

Civil Contingencies Act Enhancement Programme, 2012. *Glossary: Revision to Emergency Preparedness*. London, UK: UK Government, Cabinet Office
Available at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61046/EP_Glossary_amends_18042012_0.pdf
[Accessed 9th October 2014]

DRI International, 2012. New York, USA: DRI International
Available at: <https://www.drii.org/index.PHP>
[Accessed 9th October 2014]

EEA, 2014. *Glossary*. Copenhagen, Denmark: European Environmental Agency
Available at: https://climate-adapt.eea.europa.eu/help/glossary/index_html/#linkResilience
[Accessed 9th October 2014]

EPA, 2014. *Glossary of Climate Change Terms*. Washington DC, USA: United States Environmental Protection Agency
Available at: <http://www3.epa.gov/climatechange/glossary.html#R>
[Accessed 9th October 2014]

FAO, 2012. *Building resilience for adaptation to climate change in the agriculture sector. Proceedings of a Joint FAO/OECD workshop 23-24 April 2012*. Rome, Italy: Food and Agriculture Organization of the United Nations
Available at: <http://www.fao.org/docrep/017/i3084e/i3084e.pdf>
[Accessed 9th October 2014]

USGCRP, 2014. Glossary. Washington DC, United States: United States Global Change Research Program
Available at: <http://www.globalchange.gov/climate-change/glossary>
[Accessed 9th October 2014]

GWP, 2013. *Segurança da Água e Desenvolvimento Resiliente às Alterações Climáticas. Documento Técnico de Referência*. Stockholm, Sweden: Global Water Partnership
Available at: https://www.gwp.org/globalassets/global/wcdp-files/wacdep-publications/tdb_portuguese_final.pdf
[Accessed 9th October 2014]

IPCC, 2012. *Glossary of terms*. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press, Cambridge, UK, and New York, NY, USA

Available at: https://www.ipcc.ch/pdf/special-reports/srex/SREX-Annex_Glossary.pdf
[Accessed 9th October 2014]

Los Angeles County Community Disaster Resilience. *Glossary*. Los Angeles, USA: LA County
Available at: <http://www.laresilience.org/resources/glossary.PhP>
[Accessed 9th October 2014]

OECD, 2014. *Glossary of Statistical Terms*.
Available at: <https://stats.oecd.org/glossary/detail.asp?ID=2330>
[Accessed 9th October 2014]

OXFAM, 2013. *No Accident: resilience and the inequality of risk*. 172 Oxfam Briefing Paper.
Oxford, UK: OXFAM GB
Available at: https://www.oxfam.org/sites/www.oxfam.org/files/file_attachments/bp172-no-accident-resilience-inequality-of-risk-210513-en_1_0.pdf
[Accessed 9th October 2014]

PNNL, 2008. *Climate Change Vulnerability and Resilience: Current Status and Trends for Mexico*. Springfield, USA: Pacific Northwest National Laboratory
Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18136.pdf
[Accessed 9th October 2014]

Resilience Alliance, 2014. *Glossary*. Georgia, USA: Resilience Alliance
Available at: <http://www.resalliance.org/glossary>
[Accessed 9th October 2014]

UNISDR, 2009. *2009 UNISDR Terminology on Disaster Risk Reduction*. Genève, Switzerland: United Nations.
Available at: http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf
[Accessed 9th October 2014]

USAID, 2017. *Climate-resilient water infrastructure: guidelines and lessons from the USAID Be Secure project*. Manila, Philippines: USAID/AECOM

ANNEX II – Rainfall data analysis and validation

Introduction

The Probability Theory is a branch of mathematics that investigates random phenomena and is commonly applied to hydrologic data – considering that rainfall data series can be seen as a collection of phenomena, related to distributions in time and space of random variables. Thus, the annual, monthly and daily rainfall data collected from a synoptic station are random variables (assuming that rainfall events are independent from each other) which should be validated through a statistical analysis. However, the real probability distribution functions of basic hydrological variables cannot be derived theoretically and the adjustment of fitted probability distributions functions is the most feasible method for the condensation of complex statistical information on the frequency distribution of the hydrological data. This is true considering that nearly all distributions in hydrology have an empirical nature, obtained from limited and observed data (Yevjevich, 1982). According to Lencastre and Franco (2006), the most frequent method to adjust distribution models to empiric samples is the Moments Method, due to its simplicity, as it assumes that the statistical parameters from the distribution function and the ones from the available sample are equal – e.g. the mean, μ , is equaled to the sample mean and the standard deviation, σ , is equaled to the sample standard deviation. One of the main advantages of adjusting such a function is that it further allows extrapolating values with a return period greater than the period of the analyzed sample (with a comfortable confidence degree, usually around $1-\alpha= 0.95$) (Lencastre & Franco, 2006).

Methods

The **Normal Distribution Function**, or Gaussian, is the continuous distribution function most commonly adjusted to hydrological parameters such as the annual rainfall values or the average annual water flow, which result from the sum of many daily random variables (Lencastre & Franco, 2006). However, this fit is not as good for monthly

rainfall and monthly runoff, and not recommended at all for daily data series (Yevjevich, 1982). For a variable to fit a normal distribution, four conditions should be met: 1) a very large number of causative factors affect the values; 2) each factor has a small influence on the outcome; 3) the effect of each factor is independent of the effects of other factors and 4) their effect on the outcome is cumulative. The density probabilistic function is, therefore, defined for any real value of x , with a unique maximum at $x=\mu$ and inflection points at $\mu\pm\sigma$ (with μ representing the mean and σ the standard deviation of the sample), assuming a bell-shaped curve. The x axis is an asymptote and the function is symmetrical at $x=\mu$, meaning that the mean is the location (central value) and σ is the scale (dispersion) parameter. Within the framework of this dissertation, the Normal Distribution Function was adjusted to the total annual rainfall records to assess their statistical representativity, recurring to the following expressions (adopted from Lencastre & Franco, 2006):

$$F(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^z e^{-\frac{z^2}{2}} dz \quad (\text{Equation I})$$

where

$$z = \frac{x-\mu}{\sigma}, \text{ with } (-\infty < z < \infty) \quad (\text{Equation II})$$

On a spreadsheet, the total annual rainfall data was placed in ascending order (n), and z and $F(z)$ were estimated for each corresponding rainfall record. Moreover, the obtained $F(z)$ was graphically compared to the empirical distribution parameters ($F(x)_{emp}$), determined through the following equation:

$$F(x)_{emp} = \frac{n}{N+1} \quad (\text{Equation III})$$

where N corresponds to the length of the sample ($N=40$ for the total annual and maximum daily rainfall).

The quality of fit of the adjustment of distribution functions to empirical data may be analyzed either analytically or graphically (although a certain degree of subjectivity

cannot be avoided to any visual fit). In fact, before the application of numerical tests to assess the goodness of the fit, it is often useful to check graphically whether the adjusted function is close to, or far from, a good fit. If a good graphical fit is verified (meaning that $F(x)_{emp}$ and $F(z)$ lines have a similar behavior), there is a positive chance that the distribution function fit may also be accepted by the following numerical tests:

- To apply the **Chi-Squared Test**, the division of the sample into M intervals is required (generally $M \geq 5$ is recommended). Thus, this test statistic follows the described equation:

$$X^2 = \sum_{j=1}^M \frac{(O_j - E_j)^2}{E_j} \quad (\text{Equation IV})$$

where for each of the M intervals, O_j represents the number of elements of the sample contained in it, E_j is the corresponding expected value according with the tested distribution model ($E_j = N \cdot P_j$, where N is the number of records of the sample and P_j is the probability of each interval). This expression is defined for $\nu = M - 1 - l$ degrees of freedom, with l representing the number of statistical parameters estimated from the sample itself (as the mean and standard deviation). To assess the quality of the fit, the determined X^2 is further compared with tabled values of X^2 , hereby consulted in Lencastre & Franco's publication (pp.431). If the determined X^2 is higher than the tabled correspondent, one should reject the fit of the distribution function and assume that it does not describe the behavior of the empirical data. But if the determined X^2 is lower (or equal) to the tabled correspondent, the fit is considered adequate and one can proceed to extrapolate values from the adjusted distribution function.

- Whilst the Chi-Squared test is a parametric test - hence the distribution function is known (or assumed), its parameters are estimated from the sample data and the tests are made by recurring to the statistic measuring of the goodness of fit to an empirical distribution - the **Kolmogorov-Smirnov Test** is described as a non-parametric test. The latter, also often called distribution-free test, does not require the estimation of parameters, nor assumes

distribution function of any given type. Moreover, because the parameters of a distribution function fitted to an empirical distribution must be estimated from the sample data itself, the Kolmogorov-Smirnov is for many authors not an exact test, but only an approximation (Yevjevich, 1982). To apply the Kolmogorov-Smirnov test, two new statistics must be determined for each rainfall record (Equations V and VI), and the highest value obtained for these two new columns is noted:

$$\left| \frac{n}{N} - F(z) \right| \quad \text{(Equation V)}$$

$$\left| F(z) - \frac{n-1}{N} \right| \quad \text{(Equation VI)}$$

Similarly to the Chi-Squared test, this maximum determined value is compared to its tabled correspondent (hereby consulted again in Lencastre & Franco, pp.434): if the determined value is lower (or equal) to the tabled one, the adjustment is considered a good fit but, if otherwise, one should not rely on it for subsequent hydrological studies.

Once statistically proven the robustness of the given rainfall series, one useful analysis is the determination of **average, wet and dry years**, parting from the adjusted distribution function – applicable only to the analysis of total annual rainfall data and the fitted Gaussian distribution. It is commonly accepted that very dry years correspond to $F(z) \leq 0.5$, dry years $F(z) \leq 0.20$, average years to $0.20 \leq F(z) \leq 0.80$, wet years to $F(z) \geq 0.8$ and very wet years to $F(z) > 0.95$. Based on this assumption, inverting Equation I one can determine corresponding z values and subsequently, using an inverted Equation II, the corresponding rainfall thresholds. Each total annual rainfall record can thus be classified as average, dry, very dry, wet or very wet year – considering its placement within the referred intervals.

Results

Concerning the data series validation, Tacloban's daily rainfall records (for the baseline scenario only), were grouped per year to obtain 40 total annual values. To this shorter series corresponded an average rainfall of 2563.1 mm (coherent with the Climatological Normal annual average for 1987-2006 of 2565.3 mm) and a standard deviation of 576.2 mm, with the maximum total annual rainfall being registered for the year of 2008 (4108.8 mm) and the minimum for 1992 (1431.2 mm). The difference between these extremes, evidenced the great year-on-year variability of rainfall in Tacloban, was corroborated by their significant standard deviation.

The adjustment of a Gaussian Distribution Function to the total annual rainfall data series, is shown in detail on Table II.1, and the graphical fit between the empirical and theoretical distributions is represented on Figure II.1.

Table II.1 - Annual rainfall data adjustment of the normal distribution function

R_ord (mm)	n	F(x) emp	z	F(z)
1431.2	1	0.0244	-1.9643	0.0247
1778.3	2	0.0488	-1.3619	0.0866
1787.3	3	0.0732	-1.3463	0.0891
1851.6	4	0.0976	-1.2347	0.1085
1996.7	5	0.1220	-0.9829	0.1628
2094.7	6	0.1463	-0.8128	0.2082
2096.3	7	0.1707	-0.8101	0.2090
2119.6	8	0.1951	-0.7696	0.2208
2137.7	9	0.2195	-0.7382	0.2302
2174.8	10	0.2439	-0.6738	0.2502
2197.6	11	0.2683	-0.6343	0.2630
2252.3	12	0.2927	-0.5393	0.2948
2267.5	13	0.3171	-0.5130	0.3040
2302.4	14	0.3415	-0.4524	0.3255
2336.1	15	0.3659	-0.3939	0.3468
2346.9	16	0.3902	-0.3752	0.3538
2392.5	17	0.4146	-0.2960	0.3836
2399.4	18	0.4390	-0.2840	0.3882
2405.2	19	0.4634	-0.2740	0.3921
2408.1	20	0.4878	-0.2689	0.3940
2414.7	21	0.5122	-0.2575	0.3984

R_ord (mm)	n	F(x) emp	z	F(z)
1431.2	1	0.0244	-1.9643	0.0247
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2119.6	8	0.1951	-0.7696	0.2208
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2174.8	10	0.2439	-0.6738	0.2502
2197.6	11	0.2683	-0.6343	0.2630
2252.3	12	0.2927	-0.5393	0.2948
2267.5	13	0.3171	-0.5130	0.3040
2302.4	14	0.3415	-0.4524	0.3255
2336.1	15	0.3659	-0.3939	0.3468
2346.9	16	0.3902	-0.3752	0.3538
2495.7	22	0.5366	-0.1169	0.4535
2531.4	23	0.5610	-0.0550	0.4781
2560.3	24	0.5854	-0.0048	0.4981
2595.6	25	0.6098	0.0565	0.5225
2599.0	26	0.6341	0.0624	0.5249
2684.7	27	0.6585	0.2111	0.5836
2790.4	28	0.6829	0.3945	0.6534
2829.5	29	0.7073	0.4624	0.6781
2846.9	30	0.7317	0.4926	0.6888
2871.9	31	0.7561	0.5360	0.7040
2900.2	32	0.7805	0.5851	0.7207
2919.8	33	0.8049	0.6191	0.7321
2995.6	34	0.8293	0.7506	0.7736
3096.8	35	0.8537	0.9263	0.8228
3455.5	36	0.8780	1.5488	0.9393
3508.4	37	0.9024	1.6406	0.9496
3678.4	38	0.9268	1.9356	0.9735
3863	39	0.951	2.2560	0.9880
4108.8	40	0.976	2.6825	0.9963

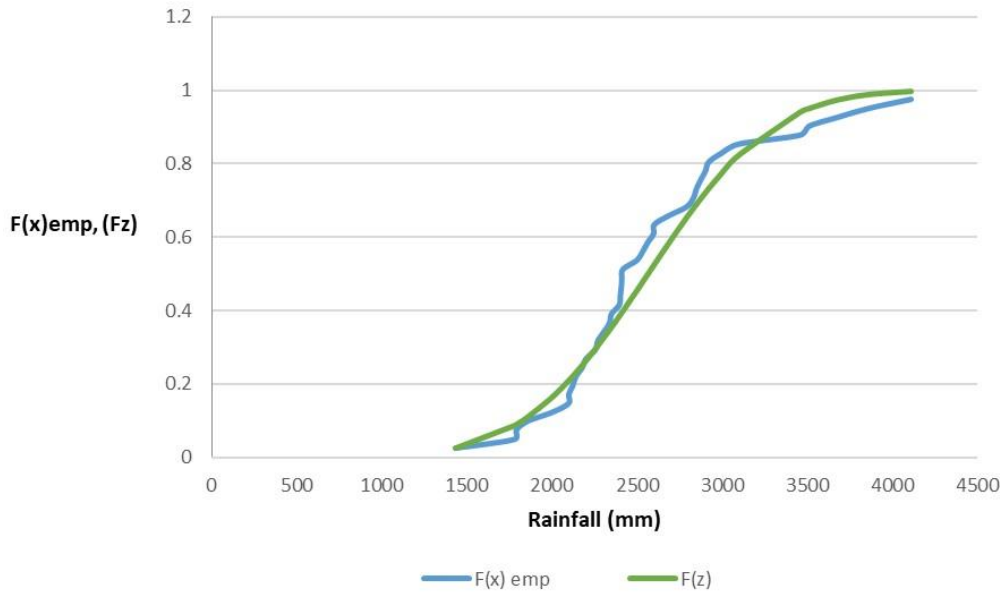


Figure II.1 - $F(x)_{emp}$ and $F(z)$ comparison for total annual rainfall data

The quality of the Gaussian distribution adjustment was further tested by the Chi-Squared and Kolmogorov-Smirnov tests (Tables II.2 and II.3, respectively).

Table II.2 - Chi-Squared test application for total annual rainfall data With $M = 8$ (for $N=40$), $E_j = 5$ and $P_j = 0.125$

j	P_j	O_j	$(O_j - E_j)^2$
1	0.125	4	1
2	0.250	5	0
3	0.375	7	4
4	0.500	8	9
5	0.625	3	4
6	0.750	7	4
7	0.875	1	16
8	1.000	5	0

Table II.3 - Kolmogorov-Smirnov test for total annual rainfall series (Dmax calc highlighted)

n	F(x) emp	z	F(z)	n/N-F(z)	F(z)-(n-1)/N
1	0.0244	-1.9643	0.0248	0.0003	0.0247
2	0.0488	-1.3619	0.0867	0.0366	0.0616
3	0.0732	-1.3463	0.0891	0.0141	0.0391
4	0.0976	-1.2347	0.1085	0.0085	0.0335
5	0.1220	-0.9829	0.1628	0.0378	0.0628
6	0.1463	-0.8128	0.2082	0.0581	0.0832
7	0.1707	-0.8101	0.2090	0.0340	0.0590
8	0.1951	-0.7696	0.2208	0.0208	0.0458
9	0.2195	-0.7382	0.2302	0.0052	0.0302
10	0.2439	-0.6738	0.2502	0.0002	0.0252
11	0.2683	-0.6343	0.2630	0.0120	0.0130
12	0.2927	-0.5393	0.2948	0.0052	0.0199
13	0.3171	-0.5130	0.3040	0.0210	0.0040
14	0.3415	-0.4524	0.3255	0.0245	0.0005
15	0.3659	-0.3939	0.3468	0.0282	0.0032
16	0.3902	-0.3752	0.3538	0.0462	0.0212
17	0.4146	-0.2960	0.3836	0.0414	0.0164
18	0.4390	-0.2840	0.3882	0.0618	0.0368
19	0.4634	-0.2740	0.3921	0.0829	0.0579
20	0.4878	-0.2689	0.3940	0.1060	0.0810
21	0.5122	-0.2575	0.3984	0.1266	0.1016
22	0.5366	-0.1169	0.4535	0.0965	0.0715
23	0.5610	-0.0550	0.4781	0.0969	0.0719
24	0.5854	-0.0048	0.4981	0.1019	0.0769
25	0.6098	0.0565	0.5225	0.1025	0.0775
26	0.6341	0.0624	0.5249	0.1251	0.1001
27	0.6585	0.2111	0.5836	0.0914	0.0664
28	0.6829	0.3945	0.6534	0.0466	0.0216
29	0.7073	0.4624	0.6781	0.0469	0.0219
30	0.7317	0.4926	0.6888	0.0612	0.0362
31	0.7561	0.5360	0.7040	0.0710	0.0461
32	0.7805	0.5851	0.7207	0.0793	0.0543
33	0.8049	0.6191	0.7321	0.0929	0.0679
34	0.8293	0.7506	0.7736	0.0764	0.0514
35	0.8537	0.9263	0.8228	0.0522	0.0272
36	0.8781	1.5488	0.9393	0.0393	0.0643
37	0.9024	1.6406	0.9496	0.0246	0.0496
38	0.9268	1.9356	0.9735	0.0235	0.0485
39	0.9512	2.2560	0.9880	0.0130	0.0380
40	0.9756	2.6825	0.9963	0.0037	0.0213

In conclusion:

- The Chi-Squared statistical test result suggested not to reject this data series, with the estimated χ^2_{calc} (of 7.60) being lower than the reference value of χ^2_{tab} (of 11.07, for $v=5$).
- Accordingly, the Kolmogorov-Smirnov test confirmed the quality of this adjustment, also recommending the non-rejection of the total annual rainfall series, hence the calculated D_{max} (0.1266 for $n=21$) resulted lower than the tabulated D_{max} (0.1696).

As observed, the empirical data distribution accompanies the theoretical Gaussian distribution curve, wherefore it can be concluded that the total annual rainfall data is well described by this statistical law. This allowed the classification of average, wet and dry years for this data series. This analysis returned a majority of average years and only a few annual records for the extreme values of $F(z)$, as observed on Table II.4 from the 40 years of the analyzed period, only 1992 was a very dry year, 4 years were classified as dry (1973, 1977, 1998 and 2004), 3 years as wet (1996, 2000 and 2006) and 3 years as very wet (1999, 2001 and 2008).

Table II.4 - Average, wet and dry years estimation

	F(z)	z	Rainfall (mm)
very dry year	0.05	-1.6449	1615.3
dry year	0.20	-0.8416	2078.1
average year	0.50	0.0000	2563.1
wet year	0.80	0.8416	3048.0
very wet year	0.95	1.6449	3510.9

It can be observed that this series is very regular, with few very wet or very dry years – although, on a year-to-year analysis, rainfall appears to be significantly variable, as confirmed by its strong standard deviation. Figure II.2 shows the location of these extremes within the data series, evidencing that both wet and very wet years are

placed on the second half of the analysis period. This corroborates the existing literature on climate change impacts in the Philippines, which claims that (as previously referred) rainfall is intensifying for Leyte region.

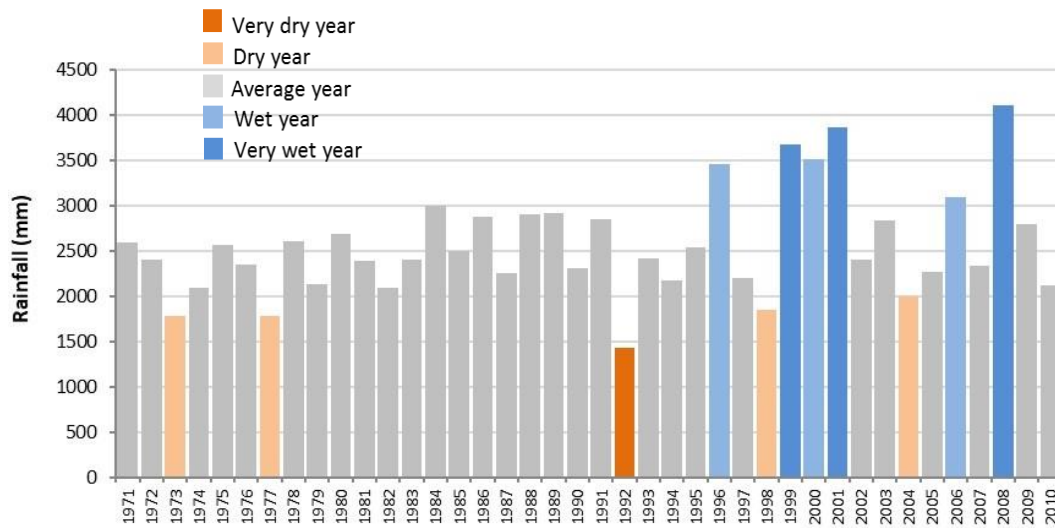


Figure II.2 - Total annual rainfall series for Tacloban (1971-2010)

ANNEX III - WGEN input files

Table III.1 - Climatic variables used on the creation of Tacloban's WGEN input file (Arnold, et al., 2012)

Variable name	Description and formulas	Units	Source
OBJECTID	Identification of the station	-	-
STATE	Operating status of the station (optional)	-	-
STATION	Station name	-	-
LSTATION	Station name (optional)	-	-
ID	Station ID	-	-
WLATITUDE	Latitude of weather station used to create statistical parameters	Degrees	PAGASA
WLONGITUDE	Longitude of weather station used to create statistical parameters	Degrees	PAGASA
WELEV	Elevation of the weather station	Meters	PAGASA
RAIN_YRS	Number of years of maximum monthly 0.5h rainfall data used to define RAIN_HHMX1(...) ₁₂	-	Global Weather
TMPMX1(...) ₁₂	<p>Mean daily maximum air temperature for month 1 to 12:</p> $\mu mx_{mon} = \frac{\sum_{d=1}^N Tmx_{mon}}{N}$ <p>where μmx_{mon} is the mean daily maximum temperature for each month (°C), Tmx_{mon} is the daily maximum temperature on record d (°C) and N is the total number of daily maximum temperature records for month mon</p>	°C	PAGASA
TMPMN1(...) ₁₂	<p>Mean daily minimum air temperature for month 1 to 12:</p> $\mu mn_{mon} = \frac{\sum_{d=1}^N Tmn_{mon}}{N}$ <p>where μmn_{mon} is the mean daily minimum temperature for each month (°C), Tmn_{mon} is the daily minimum temperature on record d (°C) and N is the total number of daily maximum temperature records for month</p>	°C	PAGASA
TMPSTDMX1(...) ₁₂	<p>Standard deviation for daily maximum air temperature for month 1 to 12:</p> $\sigma mx_{mon} = \sqrt{\frac{\sum_{d=1}^N (Tmx_{mon} - \mu mx_{mon})^2}{N - 1}}$	°C	PAGASA

Variable name	Description and formulas	Units	Source
	where σ_{mxmon} is the standard deviation for daily maximum temperature in month mon ($^{\circ}\text{C}$), T_{mxmon} is the daily maximum temperature on record d in month mon ($^{\circ}\text{C}$), μ_{mxmon} is the average daily maximum temperature for the month mon ($^{\circ}\text{C}$) and N is the total number of daily maximum temperature records for month mon		
TMPSTDMN1(...)12	Standard deviation for daily minimum air temperature for month 1 to 12: $\sigma_{mn_{mon}} = \sqrt{\frac{\sum_{d=1}^N (T_{mn_{mon}} - \mu_{mn_{mon}})^2}{N - 1}}$ where σ_{mnmon} is the standard deviation for daily minimum temperature in month mon ($^{\circ}\text{C}$), T_{mnmon} is the daily minimum temperature on record d in month mon ($^{\circ}\text{C}$), μ_{mxmon} is the average daily minimum temperature for the month mon ($^{\circ}\text{C}$) and N is the total number of daily minimum temperature records for month mon	$^{\circ}\text{C}$	PAGASA
PCPMM1(...)12	Mean total monthly precipitation for month 1 to 12: $\bar{R}_{mon} = \frac{\sum_{d=1}^N R_{day,mon}}{yrs}$ where \bar{R}_{mon} is the mean monthly precipitation (mm H2O), $R_{day,mon}$ is the daily precipitation for record d in month mon (mm H2O), N is the total number of records in month mon used to calculate the average, and yrs is the number of years of daily precipitation records used in calculation	mm H2O	PAGASA
PCPSTD1(...)12	Standard deviation for daily precipitation for month 1 to 12 (quantifies the variability in precipitation for each month): $\sigma_{mon} = \sqrt{\frac{\sum_{d=1}^N (R_{day,mon} - \bar{R}_{mon})^2}{N - 1}}$ where σ_{mon} is the standard deviation for daily precipitation in month mon (mm H2O), $R_{day,mon}$ is the amount of precipitation for record d in month mon (mm H2O), \bar{R}_{mon} is the average precipitation for the month (mm H2O), and N is the total number of daily precipitation records for month mon (including 0 values)	mm H2O /day	PAGASA

Variable name	Description and formulas	Units	Source
PCPSKW1(...).12	<p>Skew coefficient for daily precipitation in month (quantifies the symmetry of the precipitation distribution about the monthly mean):</p> $g_{mon} = \frac{N \cdot \sum_{d=1}^N (R_{day,mon} - \bar{R}_{mon})^3}{(N - 1) \cdot (N - 2) \cdot (\sigma_{mon})^3}$ <p>where g_{mon} is the skew coefficient for precipitation in the month, N is the total number of daily precipitation records for month mon, $R_{day,mon}$ is the amount of precipitation for record d in month mon (mm H₂O), \bar{R}_{mon} is the average precipitation for the month (mm H₂O), N is the total number of daily precipitation records for month mon (including 0 values), and σ_{mon} is the standard deviation for daily precipitation in month mon (mm H₂O)</p>	-	PAGASA
PR_W1_1(...).12	<p>Probability of a wet day (> 0mm precipitation) following a dry day (0 mm precipitation) in the month:</p> $P_i(W/D) = \frac{days_{W/D_i}}{days_{dry_i}}$ <p>where $P_i(W/D)$ is the probability of a wet day following dry day in month i, $days_{W/D_i}$ is the number of times a wet day followed a dry day in month i for the entire period of record, and $days_{dry_i}$ is the number of dry days in month i during the entire period of record</p>	-	PAGASA
PR_W2_1(...).12	<p>Probability of a wet day following a wet day in the month:</p> $P_i(W/W) = \frac{days_{W/W_i}}{days_{wet_i}}$ <p>where $P_i(W/W)$ is the probability of a wet day following wet day in month i, $days_{W/W_i}$ is the number of times a wet day followed a wet day in month i for the entire period of record, and $days_{wet_i}$ is the number of wet days in month i during the entire period of record</p>	-	PAGASA
PCPD1(...).12	<p>Average number of days of precipitation in a month:</p> $\bar{d}_{wet,i} = \frac{days_{wet,i}}{yrs}$ <p>where $\bar{d}_{wet,i}$ is the average number of days of precipitation in month i, $days_{wet,i}$ is the number of wet days in month i during the entire period of record, and yrs is the number of years</p>	-	PAGASA

Variable name	Description and formulas	Units	Source
	of record		
RAINHHMX1(...) ₁₂	Maximum 0.5 hour rainfall in entire period of record for month (representing the most extreme 30 minute rainfall intensity recorded in the entire period)	mm H ₂ O	Global Weather
SOLARAV1(...) ₁₂	Average daily solar radiation for month: $\mu rad_{mon} = \frac{\sum_{d=1}^N H_{day,mon}}{N}$ <p>where μrad_{mon} is the mean daily solar radiation for the month (MJ/m²/day), $H_{day,mon}$ is the total solar radiation reaching the earth's surface for day d in month mon (MJ/m²/day), and N is the total number of daily solar radiation records for month mon</p>	MJ/m ² /day	Global Weather
DEWPPT1(...) ₁₂	Relative humidity (fraction), defined as the amount of water vapor in the air as a fraction of saturation humidity, for each month: $\mu rhum_{mon} = \frac{\sum_{d=1}^N rhum_{day,mon}}{N}$ <p>Where $\mu rhum_{mon}$ is the mean relative humidity for the month, $rhum_{day,mon}$ is the relative humidity for day d in month mon and N is the total number of records for month mon</p>	-	PAGASA
WINDAV1(...) ₁₂	Average daily wind speed in month: $\mu wnd_{mon} = \frac{\sum_{d=1}^N wnd_{day,mon}}{N}$ <p>Where μwnd_{mon} is the mean daily wind speed for the month (m/s), $wnd_{day,mon}$ is the average wind speed for day d in month mon (m/s), and N is the number of wind speed records for month mon</p>	m/s	PAGASA

ANNEX IV - Household Survey



Weather, Climate and Ecosystems (WaCE Project)
Measuring Resilience After Typhoon Haiyan

HOUSEHOLD SURVEY QUESTIONNAIRE

== 0 ==

Preliminary information [to be accomplished by the Enumerator before the start of the interview]

1. City/Municipality
 - 1 Tacloban City
 - 2 Palo
 - 3 Ormoc City
2. Barangay
3. Strata
 - 1 Upland
 - 2 Inland
 - 3 Coastal
4. Date [dd/mm/yy]
5. Enumerator's Name
6. Enumerator's Code

7. Enumerator's Contact No.
8. Household No / Code
9. Household GPS Point: (update)
10. Photo of respondent / house (if respondent agrees)
11. Time stamp:
12. Housing structure

Roofing	1. Shingles	2. G.I. Sheets	3. Concrete	4. Mixed
Wall	1. Wood	2. Concrete	3. Mixed	
Flooring	1. Soil	2. Wood	3. Concrete	4. Mixed

== 0 =

Short Introduction

Hello, my name is _____. I am an enumerator for a study by the Oscar M. Lopez Center a privately funded non-profit research organization focused generating science-based solutions in the area of climate change adaptation and disaster risk management.

This Survey is one tool by which we will be able to help build climate and disaster resilience. We also believe that your active participation is key in building your community's resilience. The results of this survey will hopefully be used to point toward needed action - action catered specifically to your city/municipality.

At the Center, we define resilience as: the capacity of individuals, households, communities, institutions and systems to withstand, respond to, cope with, adapt and grow from climate-related challenges.

Your responses are strictly confidential and will only be used for research purposes.

This will take 45 minutes to an hour. Please receive this small gift as a token of our appreciation.

Thank you very much for your participation!

== = Start of Survey = = =

Information about the Respondent

The following questions will tell us more about you.

- 1 First Name
Last Name
2. Gender [Select 1]
 - 1 Male
 - 2 Female

3. Age Bracket
 - 1 18-24
 - 2 25-34
 - 3 35-44
 - 4 45-54
 - 5 55- 59
 - 6 60 and above
4. What is your highest educational attainment? [Select 1] -
 - 1 None / Elementary undergraduate
 - 2 Elementary graduate / High school undergraduate
 - 3 High school graduate / Vocational course graduate / College undergraduate
 - 4 College graduate / Post-college graduate
5. What is your major source of income? [Select all applicable]
Hired Worker
 - 1 Professional/technical (teachers, engineers, architects, etc.)
 - 2 Managers
 - 3 Community workers
 - 4 Clerical/administrative/sales
 - 5 Non-agricultural skilled (welders, drivers, machine operators, etc.)
 - 6 Non-agricultural unskilled (laborers, messengers, janitors, etc.)
 - 7 Agricultural (includes livestock, fishing and forestry)
Employers and Self-employed
 - 8 Agricultural operators (owners, [what other choices?])
 - 9 Non-agricultural entrepreneurs (vendors, sari-sari stores, business owners, etc.)
Others
 - 10 Property owners (income mainly from rentals)
 - 11 Unpaid family worker
 - 12 Retired
 - 13 Unemployed
 - 14 Student

6. What are your other/alternative sources of income?
(same options as above)

7. How much do you get per month? [Select 1]
- 1 PHP 7500 and below
 - 2 PHP 7501 - 10550
 - 3 PHP 10551 and above

Information about the household

The following information will tell us more about your household.

1. How would you best describe this household? **[Select 1]**
 - 1 Single – living alone
 - 2 Nuclear – living with own family only
 - 3 Extended – living with extended family (uncle/aunt, cousins, etc.)
 - 4 Others, please specify: ____If response is #1, skip 3 and 4.
2. How many are you in this household? **[enter answer]** _____
3. How many people aged 18 and over lives in your household? **[enter answer]** _____
4. Would you describe anyone in your household as a person requiring assistance or supervision? **[select all applicable]**
 - 1 Disability
 - 2 Chronic Illness
 - 3 Short-term illness (less than six months)
 - 4 Old
 - 5 Young/Child
 - 6 Pregnant
 - 7 Others, please specify:
 - 8 None

5. Do you, or any member of the household, own or rent the house you live in? **[Select 1]**

- 1 Owned
- 2 Rented
- 3 Used for free with consent (from owner, formal)
- 4 Used for free without consent (informal settler)
- 5 Don't Know
- 6 Others, please specify:

6. Do you, or any member of the household, own or rent the land where your house is currently built? **[Select 1]**

- 1 Yes
- 2 No
- 3 Don't Know

7. Do you think that your current house is strong enough?

- 1 Yes
- 2 No, but taking measures to reinforce it
- 3 No, not taking any measure to reinforce it
- 4 Don't Know

8. How stable is your income in your household? **[Select 1]**

- 1 Insufficient for food
- 2 Just enough to provide food
- 3 Just enough for food and utilities (water, electricity, etc.)
- 4 Just enough for food, utilities and education of children
- 5 Just enough for basic needs (food, utilities, education) and for emergencies and home necessities
- 6 More than enough for emergencies and home reinforcements

9. Does your household income cover the household's basic needs? **[Select 1]**

- 1 Yes
- 2 Partially
- 3 No

10. Do you have other sources of income/financial resources?

Other income sources	How often	How much
Money transfer from other relatives living in other cities/provinces		
Remittances from family/relatives abroad		
Retirement pension		
Support from Government		
Support from NGOs (regular)		
Others: _____		

Drop down options

How often do you receive? **[Select 1]**

- 1 once a month
- 2 twice in every four months
- 3 twice a year
- 4 once a year
- 5 others, specify
- 6 Not Applicable

How much do you usually receive? **[Select 1]**

- 1 Below PhP 4,999
- 2 PhP 5,000 – 7,999
- 3 PhP 8,000 – 11,999
- 4 PhP 12,000 – 14,999
- 5 PhP 15,000 or higher
- 6 0 (Not applicable)

xxiv

11. Do you have savings? **[Select 1]**

- 1 Yes
- 2 No

If none, proceed to # 13

12. Where do your savings go? **[Select all applicable]**

- 1 Education
- 2 Purchase of properties/assets
- 3 Investment/business
- 4 Preparation for impending disasters
- 5 Health-related emergencies
- 6 Natural hazard related emergencies
- 7 Travel
- 8 Others, specify

12.1 Which of the above is your priority? (indicate the code as listed above) **[drop down]**

13. Do you (or any of your household members) have any of the following insurances? **[Select all applicable]**

- 1 Life insurance
- 2 Health/medical insurance
- 3 Car insurance
- 4 Home insurance
- 5 Crop insurance (if a farming household)
- 6 None

14. How often does your family take their meals? **[Select 1]**

- 1 Less than once a day
- 2 Once a day
- 3 Twice a day
- 4 Three times a day
- 5 More than three times a day

15. In the last twelve (12) months, did you ran out of food (to the point that you cannot afford to buy)? **[Select 1]**

- 1 Yes
- 2 No
- 3

Information about the social services available to your household

16. Do you or anyone in your household have physical disability, chronic illness or any sickness? **[Select 1]**

- 1 Yes
- 2 No
- 3 Don't Know

17. Do you or anyone in your household find it difficult to access health / medical facilities/services for any of the following reasons? **[Select 1]**

- 1 No health / medical facilities near the house
- 2 Inadequate health/medical facilities in the community
- 3 Distance/Transport/Accessibility
- 4 Cost
- 5 Limited accessibility for people with disability
- 6 No problems accessing health/medical facilities/services
- 7 Others, please specify:

18. Considering all the places you or members of your household need to go to everyday, which of the following statements best describe the road network and transportation system in your area? **[Select 1]**

- 1 No difficulty / can easily get to the places we need to go to
- 2 Sometimes have difficulty getting to places
- 3 Often have difficulty
- 4 Can't get to the places we need to go to

18a. What do you think are the causes of this difficulty? **[Select all applicable]**

- 1 Poor road network
- 2 Inadequate public transportation
- 3 Inefficient public transportation
- 4 Don't Know

19. Which among the following basic social services you think needs further improvement in your household? **[Select all applicable]**

- 1 Water supply
- 2 Water quality
- 3 Electricity
- 4 Sewage / sanitation
- 5 Others, please specify:

Information about the ecosystem and the built/physical environment

The following questions will revolve around how you feel about the natural environment and built infrastructure.

20. Is your livelihood dependent on the following? **[Select all applicable]**

- 1 Forestry
- 2 Fishing
- 3 Aquaculture
- 4 Agriculture
- 5 Hunting
- 6 Ecotourism
- 7 Others
- 8 None [Skip to question 55]

21. How long have you been involved in such livelihood? **[Select 1]**

- 1 1 yr
- 2 3 yrs
- 3 5 yrs
- 4 10 yrs
- 5 20 yrs and above

22. How much are you earning from such livelihood per month? [Select 1]

- 1 Less than 500
- 2 501-1000
- 3 1001-2000
- 4 2001-5000
- 5 5001 and above

23. Do you think ecosystems will protect the community in any weather and climate-related hazard, event or disaster?

- 1 Strongly disagree
- 2 Disagree
- 3 Neither agree or disagree
- 4 Agree
- 5 Strongly Agree

24. Please indicate the degree of importance of the following:

	Very Important	Important	Neither important or not important	Not Important	Very Important
24.1 Maintaining the health of the environment					
24.2 Enhancing biodiversity					
24.3 Preventing development / building of house in unsafe areas					
24.4 Protecting the community by planting trees and increasing area					

planted with trees					
24.5 Protecting the community by building infrastructure like dams, dikes, seawall					

Information about weather and climate-related hazards, events or disasters

The following questions are about you and your household's awareness of, and preparedness to weather and climate-related hazards, events or disasters.

25. Due to its location, is your home at risk from being affected by any of the following weather and climate-related hazard? **[Select all applicable]**

- 1 Tropical Cyclones (super typhoon, typhoon, tropical storm, tropical depression)
- 2 Heavy Rainfall / Thunderstorms
- 3 Floods
- 4 Landslides
- 5 Storm Surge
- 6 Drought
- 7 Sea Level Rise
- 8 Others, please specify:
- 9 No
- 10 Don't know

26. Which among the weather and climate-related hazard do you think will have the highest impact to your home? **[Select one]**

- 1 Tropical Cyclones (super typhoon, typhoon, tropical storm, tropical depression)
- 2 Heavy Rainfall / Thunderstorms
- 3 Floods
- 4 Landslides
- 5 Storm Surge
- 6 Drought
- 7 Sea Level Rise
- 8 Others, please specify:
- 9 None
- 10 Don't Know

27. Which among the weather and climate-related hazard, event or disaster do you think will affect your home and household in the future? **[Select all applicable]**

- 1 Tropical Cyclones (super typhoon, typhoon, tropical storm, tropical depression)
- 2 Heavy Rainfall / Thunderstorms
- 3 Floods
- 4 Landslides
- 5 Storm Surge
- 6 Drought
- 7 Sea Level Rise
- 8 Others, please specify:
- 9 None
- 10 Don't Know

28. Did your or any member of your household experience any serious harm during Typhoon Haiyan? [Select one]

- 1 Yes
- 2 No

29. Which among hazards associated with Typhoon Haiyan do you think was the major cause of these harm from Haiyan? [Select all applicable]

- 1 Strong wind
- 2 Storm surge

- 3 Flooding
- 4 Landslide
- 5 Others, please specify:

30. Due to Typhoon Haiyan, did you or any member of your household experience any of the following? [select all applicable]

- 1 Injury
- 2 Illness
- 3 Casualty
- 4 Depression, trauma, psychological
- 5 Others, please specify:

31. Aside from having experienced any serious harm, what were the impacts of Typhoon Haiyan to your household?

- 1 House totally Destroyed/Damaged – collapsed roof/collapsed/twisted housing frame / missing or collapsed walls / missing or incomplete foundation
- 2 House Partially Damaged – minor to moderate damages
- 3 House not damaged
- 4 Disrupted livelihood
- 5 Lost job or source of income
- 6 Monetary losses, please provide an estimate: ----
- 7 Others, please specify:

32. Was your household displaced for more than 3 months after Typhoon Haiyan as a consequence of your house being destroyed or rendered uninhabitable, or the area in which it is located is now rendered uninhabitable?

- 1 Moved to and still staying at a temporary shelter
- 2 Moved to a temporary shelter and now back to original location
- 3 Relocated to a permanent shelter
- 4 To be relocated to a permanent shelter
- 5 Others, please specify:
- 6 No

33. How much was the cost of damage in your households' assets?
(estimated cost of damage, source of fund)

34. Did you/your household receive any post-disaster assistance extended by the government and other humanitarian organizations?

- 1 Food and water
- 2 Emergency shelter
- 3 Emergency medicine
- 4 Search and rescue
- 5 Temporary employment
- 6 Housing and relocation
- 7 Livelihood assistance
- 8 Others, please specify:
- 9 No

35. Were the services / assistance you received after the disaster adequate or enough to cover your household's basic needs?

- 1 Yes
- 2 No

36. How long did it take you to get back to work or livelihood (or schooling) after Haiyan? [Select 1]

- 1 In a few days
- 2 1 month
- 3 6 months
- 4 1 year
- 5 2 years
- 6 Still looking for livelihood after Haiyan

37. How long did it take you to get back to your normal life after Haiyan? [Select 1]

- 1 Less than a month
- 2 Less than half a year
- 3 Less than a year
- 4 Less than 2 years

5 Still not back to normalcy

38. How long did it take you to fully recover from Haiyan? If not yet fully recovered, how much more time will it take you to recover? [Select 1]

- 1 Less than a month
- 2 Less than half a year
- 3 Less than a year
- 4 Less than 2 years
- 5 Still not yet fully recovered, it will take less than a month more
- 6 Still not yet fully recovered, it will take less than half a year more
- 7 Still not yet fully recovered, it will take less than a year more
- 8 Still not yet fully recovered, it will take more than a year more

39. Are there any positive effects / gains / benefits that you gained from your experience in Haiyan? [Select all applicable]

- 1 Increased awareness
- 2 Better livelihood
- 3 Better house
- 4 More food
- 5 Better services
- 6 Others, please specify:
- 7 None
- 8 Don't Know

40. Aside from Typhoon Haiyan (Yolanda), name any other past disaster event/s that you can recall. Please rank according to level of impact to your community, household/family and self; (From 1 being the lowest, 5 being the highest)

Disaster Event	When (month/year)	Level of Impact (1-5)

41. What are the strategies that you do to prepare for any impending hazard, event or disturbance? [Select all applicable]

- 1 Store food, water and medicine
- 2 Clean out gutters, drains and/or canals
- 3 Tie ropes on the house
- 4 Secured belongings (household items, appliances, boats, farm implements)
- 5 Cut trees around the house to prevent damage from falling branches / trees
- 6 Check the roof for damage or weakness
- 7 Prepare emergency kit / Go Bag
- 8 Evacuate to a safer place / shelters
- 9 Monitored typhoon warnings
- 10 Helped neighbors
- 11 Others, please specify: -----
- 12 Not doing anything

42. What are the strategies that you do to cope during and after a weather and climate-related hazard, event or disaster? [Select all applicable]

- 1 Stay in evacuation area
- 2 Wait for relief goods and other aid from government and NGOs
- 3 **Repairing, reconstructing houses using locally available materials**
- 4 **Repairing, reconstructing houses using more durable materials---**
- 5 Moving properties to other places
- 6 Look for alternative livelihood
- 7 Borrowing money from friends, neighbors, family
- 8 Borrowing money from informal lending institutions (e.g. 5-6, pawnshop, sari-sari store)

- 9 Reduce food consumption
- 10 Reduce medical expenses
- 11 Sale of valuable items / assets
- 12 Received remittances from relative abroad
- 13 Received cash relief or assistance from DSWD, government, NGOs/INGOs
- 14 Others, please specify: ---
- 15 Not doing anything

If (15) not doing anything, proceed to #44

43. Do you think your household can sustain itself without the help from outside should your home be affected by any of these hazards? [Select one]

- 1 Yes
- 2 No
- 3 Don't know

44. If you were cut off from services without warning and had no water or electricity and had to sustain yourself/your household for up to three days, would you have....?

	1 Yes 2 No 3 Don't Know	Was this the case before Typhoon Haiyan (Yolanda)? 1 Yes 2 No
Enough food		
Enough drinking water		
Adequate supplies of regularly taken medications		

Flashlight with batteries		
First Aid Kit		
Enough money		
Adequate change of clothing		
Do you have all items mentioned above in a "Go Bag" or an "Emergency Kit"?		

45. What prompted you/your household to take steps towards preparing for a disaster? [Select all applicable]
- 1 Experience from Typhoon Haiyan (Yolanda)
 - 2 Other recent local disasters aside from Haiyan (eg storms, flooding, landslides, etc)
 - 3 Recent disasters not affecting you/your household (eg in other communities/provinces/regions of the Philippines)
 - 4 Have moved to new house / community
 - 5 Conversations with friends and/or family
 - 6 Government provided information on TV, radio, advertisements, radio interviews or brochures
 - 7 Other organization provided information on TV, radio, advertisements, radio interviews or brochures
 - 8 Social media
 - 9 Local community events promoting preparation for disasters
 - 10 Other (specify)
 - 11 Don't know

46. Are you spending to prepare for or reduce the impact of natural disasters? [Select one]

- 1 Yes
- 2 No

46.1 If yes, how much do you spend per year? [Select one]

- 1 less than PhP500
- 2 PhP500 - 1000
- 3 PhP1000-1500
- 4 PhP1500-2000
- 5 above PhP 2000

46.2 If no, how much are you willing to spend per year? [Select one]

- 1 less than PhP500
- 2 PhP500 - 1000
- 3 PhP1000-1500
- 4 PhP1500-2000
- 5 above PhP 2000

47. What has stopped or prevented you/your household from taking steps to prepare for disasters? [Select all applicable]

- 1 Don't have enough information, knowledge or skill on what to do
- 2 Time
- 3 Money
- 4 Physical disability
- 5 Unlikely to happen again in our lifetime
- 6 Because we do not own the house
- 7 Because we are living in a temporary shelter
- 8 Others, please specify:
- 9 Have not thought about it
- 10 Don't Know

48. Do you think you have enough household insurance if your home will be affected by any of these hazards? [Select one]

- 1 Yes
- 2 No
- 3 Don't Know

49. Do you think you can get help or support from any of the following sources if your household will be affected by any of these hazards?

Source of support	1 Yes 2 No 3 Maybe
Friend	
Neighbor	
Relatives	
Colleagues at work	
Community, charity or religious organization	
Local Government Unit (LGU)	
National Government	
Non Government Organizations (NGO)	
Media	
Others, please specify:	

50. Using a scale of 1 to 5 (5 being Very Prepared and 1 Not at all Prepared) how prepared are you / is your household for any weather and climate-related hazard, event or disaster?

- 1 Very low (Not at all prepared)
- 2 Low (Unprepared)
- 3 Moderate (Slightly prepared)
- 4 High (Prepared)
- 5 Very High (Very Prepared)

Knowledge and Awareness on weather and climate-related hazards, events or disasters

The following questions will revolve around your communication needs and media sources

51. What are the types of communication channels/media available to your household? [select all applicable]

- 1 TV
- 2 Radio
- 3 Internet
- 4 Newspaper
- 5 Poster/Leaflets
- 6 Smart/mobile phones
- 7 Others, please specify:
- 8 None
- 9 Don't Know

52. How do you usually get internet connection? [select all applicable]

- 1 Own internet connection
- 2 Internet shops
- 3 Others, please specify:
- 4 None
- 5 Don't Know

53. How often do you use the internet? [select one]

- 1 Several times a day
- 2 Once a day
- 3 Once a week
- 4 Once a month
- 5 Do not use

54. What types of social media do you use?

	Always	Sometimes	Never
--	--------	-----------	-------

Facebook			
Twitter			
Government Agency Websites			
You Tube			
Email			
Skype			
Instant messaging			
Others			

55. Where do you usually get information about weather and climate-related hazards, events or disasters? [select all applicable]

- 1 TV
- 2 Radio
- 3 Internet
- 4 Print (Newspaper/Poster/Leaflet/Brochure/Magazine)
- 5 National Government
- 6 LGU
- 7 Government Agencies (PAGASA, etc.)
- 8 NGO
- 9 Family/Relatives/Neighbors
- 10 Others, please specify: __

56. How often do you usually go to / use these sources to get information about weather and climate-related hazards, events or disasters?

	Always	Sometimes	If needed (impending disturbance)	Never
TV				
Radio				
Internet				
Print				
National Government				
LGU				
Government Agencies				
NGO				
Family/Relatives/Neighbors				
Others, specify				

57. Do you access any government agency website to get information about these hazards? [select one]

- 1 Yes
 - 2 No
- If (2) No, proceed to # 59

58. What are these websites? List three (3) and indicate how often you use these websites.

Websites	Frequency of Use

Drop down menu

- 1 Always
- 2 Sometimes
- 3 If needed
- 4 Never

59. What is (are) your preferred source(s) of information about the hazards that affect your community or if there's an impending event or disturbance? [Select all applicable]

- 1 TV
- 2 Radio
- 3 Internet
- 4 Newspaper
- 5 SMS
- 6 LGU / Barangay Official
- 7 LGU / City/Municipal DRRM
- 8 Others, please specify:

60. Do you receive warnings from LGUs before, during and after disasters? [Select 1]

- 1 Yes
- 2 No

60.1 If yes, please indicate how strongly you agree or disagree with the following statements [Select 1]:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I find the information provided by the LGU to arrive in a timely manner					
I find the information provided by the LGU sufficient for us to prepare for and safeguard our belongings before a disaster					
I find the information provided by the LGU reliable					

61. Did you participate in any (flood, typhoon, earthquake, etc.) drills organized in your community? [Select 1]

- 1 Yes
- 2 No
- 3 There are no emergency drills in the brgy/community

62. Did you receive any training on disaster preparedness, risk reduction and management? [Select 1]

- 1 Yes
- 2 No
- 3 There are no training on disaster preparedness in the brgy/community
If (2) or (3), proceed to # 63

62.1 Who provided the training? [Select all applicable]

- 1 LGU
- 2 NGO
- 3 Church
- 4 Community organizations
- 5 Others, please specify:

62.2 What are the information provided in the training? [Select all applicable]

- 1 On warning/alert signal
- 2 First Aid
- 3 Rescue operations
- 4 Evacuation routes and sites
- 5 Identification of hazards in the community
- 6 Others, please specify:

62.3 Was the information provided useful? [Select 1]

- 1 Yes
- 2 No

63. In your own capacity, do you think you will be able to make use of the information you get from any of the sources for you to be able to decide what to do should your household be affected by any of weather and climate-related hazards, events and disasters?

- 1 Yes
- 2 No
- 3 Don't Know

63.1 If no/don't know, how would you like to be informed further? And how often would you want it to be?

	<ul style="list-style-type: none"> 1 Once 2 Once a month 3 Once every 3 months 4 Once a year 5 Don't want to be informed
Basic Orientation on Weather and Climate-related hazards, events, or disasters	
Hazard-specific drills (flood, storm surge, etc.)	
Training on first aid / response	
Trainings	
Others, specify:	

64. Do you know or use any indigenous / local way in knowing that a hazard will affect you (e.g. abnormal animal behavior, appearance and movement of clouds)? If yes, please specify: _____

65. Is there any early warning system(s) in place in your community (e.g. Bandilyo, Use of Drums, Church Bells, etc.)? If yes, please specify: _____

Knowledge and Awareness on climate and climate change

The following questions will tell us more about your awareness and attitude on climate change

66. Are you aware of climate change? [select one]

- 1 Yes
- 2 No

If (2) No, proceed to # 69

67. How did you know about climate change? [select all applicable]

- 1 TV
- 2 Radio
- 3 Internet
- 4 Newspaper
- 5 School
- 6 Government
- 7 NGO
- 8 Others, please specify

68. What do you think are the causes of climate change? [select one]

- 1 Natural processes (volcanic eruption, solar activity, etc.>)
- 2 Human activities
- 3 Both natural and human
- 4 Others, please specify
- 5 Don't Know
- 6 Climate change is not real

69. Are you doing anything to help address the causes of climate change?
[Select all applicable]

- 1 Planting trees
- 2 Conserving electricity (switching off lights, plugging out appliances)
- 3 Conserving water
- 4 Using alternative transportation (walking, bike, mass/public transport)
- 5 Using reusable / eco-bags when shopping
- 6 Reduce, reuse, recycle
- 7 Harvesting rainwater
- 8 Others, please specify:
- 9 Not doing anything

70. What do you think are the manifestations of climate change? [select all applicable]

- 1 Increasing temperature
- 2 Heavier rains
- 3 Shifting of seasons

- 4 More intense tropical cyclones
- 5 More frequent tropical cyclones
- 6 Delayed onset of rainy season
- 7 More variability in weather patterns
- 8 All of the above
- 9 Others, please specify:
- 10 None of the above
- 11 Don't Know

71. What do you think are (or will be) the impacts of climate change to you and your household? [select all applicable]

- 1 Disruption of livelihood
- 2 Damage to house and property
- 3 May cause harm, injury or illness
- 4 Damage to crops
- 5 Loss of income
- 6 Decrease in income
- 7 Others, please specify:
- 8 None
- 9 Don't Know

72. What are the adaptation measures/strategies being implemented by your household to minimize the current and potential impacts of climate change? [select all applicable]

- 1 Relocate residence to a safer place permanently
- 2 Transfer to an evacuation area or a safe place temporarily
- 3 Restructure / retrofit / reinforce house
- 4 Change livelihood and sources of income
- 5 Diversify livelihood and sources of income
- 6 Prepare household needs and safety precautions
- 7 Plant trees around the house
- 8 Others, please specify:
- 9 Not doing anything
- 10 Don't Know

73. How would you like to know more about climate change and what you can do to reduce its impacts to your household? [select all applicable]

- 1 Receive information materials (brochure, posters, briefs)
- 2 Visit websites or portals
- 3 Hear about it in the radio
- 4 Watch a television series or news
- 5 Attend trainings /seminars
- 6 Consult with local authorities (LGUs)
- 7 Others, please specify:
- 8 Don't want to know anything about climate change

74. Do you think Typhoon Haiyan (Yolanda) was due to climate change?
[select one]

- 1 Yes
- 2 No
- 3 Don't Know

75. Thinking about weather and climate-related hazards/disasters and climate change issues, would you be willing to? [Select one]

	Yes	No	Maybe
75.1 Participate regularly, on an on-going basis (e.g. belong to a group; attend monthly meetings)			
75.2 Participate for specific reasons or events (e.g. attend a community meeting; be involved in a preparedness activity)			
75.3 Pass on information to other community members			
75.4 Encourage other people in your community to get prepared			

76. How do you think communities can be involved in addressing climate-related hazards/disasters and climate change issues? [enter answer]

Social Cohesion and Community Connectedness

The following questions will help us understand the networks you have in your community.

77. How long have you lived in this community? [Select 1]

- 1 less than one year
- 2 1-5 years
- 3 6-10 years
- 4 More than 10 years

78. Are you a member of any of the following organizations in your community? [Select all applicable]

- 1 Fisher folks association
- 2 Farmers association
- 3 Women
- 4 Elderly
- 5 Youth
- 6 Service Organizations (Rotary Club, Knights, etc.)
- 7 Other, please specify: ----
- 8 Not a member of any group

79. Please rate from 1-5 (1 being the lowest, 5 being the highest) how often do you undertake each of the following: [Select 1]

	Always [5]	Sometimes [4]	Not so often [3]	Once [2]	Never [1]
79.1 I have worked with others on something to improve community life					
79.2 I participate in local activities or events (e.g., festivals, fairs)					
79.3 I have contributed money, food or clothing to local causes, charities, or to others in my community					
79.4 I have attended a public meeting on a community issue					
79.5 I have been involved in volunteer activities intended to benefit my community (e.g., fundraising, clean-up drives, tree planting, etc.)					

80. Please indicate how strongly you agree or disagree with the following statements:

	Strongly Agree [5]	Agree [4]	Neutral [3]	Disagree [2]	Strongly Disagree [1]
80.1 There are enough opportunities in the community to participate in activities where I can interact with other members					
80.2 There are barangay officials I can trust					
80.3 I feel safe living in the community					
80.4 Most of my neighbors can be trusted					

Personal well-being, beliefs and values

The following questions are about your own personal well-being, beliefs and values.

81. Which of the following statements best describes your understanding of faith or spirituality? [Select 1]

- 1 A sense of connection to something outside myself;

- 2 Something that sustains me through times of hardship;
- 3 A system of morality and values;
- 4 Maintaining a sense of hope;
- 5 A formal religious belief (e.g. Christianity, Islam etc);
- 6 I don't think about issues of faith or spirituality;
- 7 None of the above;
- 8 Other (please specify)

82. Please rank in order of importance the TOP 5 values that you think are most important to pass on to your children or any younger member(s) of your household (with 1 being the most important)

- 1 Understanding
- 2 Respect
- 3 Hard work
- 4 Discipline
- 5 Faith/Religion
- 6 Resilience
- 7 Saving money
- 8 Determination
- 9 Sense of responsibility
- 10 Others, please specify

83. With regards to what happens in the wider community, in general, to what extent do you see yourself: [Select 1]

	Always	A great deal	Sometimes	Not very	Not at all
83.1 I feel that I can influence what happens in my community					
83.2 I feel that I see positive results from					

participating in community activities					
83.4 I feel that I have an active part in keeping this community going					

84. Please indicate how strongly you agree or disagree with the statements below [Select 1]

	Strongly Agree	Agree	Neither agree nor Disagree	Disagree	Strongly Disagree
84.1 I am responsible for me and my families' resilience					
84.2 I am responsible for preparing my family to climate-related disasters					
84.3 The LGU is responsible for making sure that I am prepared for the occurrence of any climate-related disaster					

Household resilience

The following questions are about your household's resilience.

85. On a scale of 1 to 5 (5 being the highest), how would you rate the level of resilience of your household?

	Question	Levels (low-high)					Score
		1	2	3	4	5	
1	My household is informed and educated enough OR knows what to do before, during and after any weather and climate-related hazard, event or disaster	Very Low	Low	Moderate	High	Very High	
2	My household is well prepared for any weather and climate-related	Very Low	Low	Moderate	High	Very High	

	hazard, event and disaster (current and in the future)						
3	Members of the household have designated roles and responsibilities before, during and after any weather and climate-related hazard, event and disaster (current and in the future)	Very Low	Low	Moderate	High	Very High	
4	My household can easily recover financially should it be affected by any weather and climate-related hazard, event and disaster	Very Low	Low	Moderate	High	Very High	

	(current and in the future)						
5	My household lives in a strong house and in a safe location	Very Low	Low	Moderate	High	Very High	
6	My household is engaged with and participates in any activity organized in the community on DRR and CCA	Very Low	Low	Moderate	High	Very High	
7	My household is emotionally, spiritually and morally strong	Very Low	Low	Moderate	High	Very High	
8	My household can be self-reliant before, during, and after any weather and any climate-related	Very Low	Low	Moderate	High	Very High	

	hazard, event and disaster (current and in the future)						
9	My household learns from previous experiences such as Typhoon Haiyan and strives to improve over time	Very Low	Low	Moderate	High	Very High	
10	My household is prepared, can cope and adapt to any weather and climate-hazard, variability, changes and uncertainty in the future	Very Low	Low	Moderate	High	Very High	

86. Considering your past experiences, existing weather and climate-related hazard/s that your household is/are exposed to, and future climate changes, how would you rate the level of your household's resilience on a scale of 1 to 5 (5 being the highest)?

- 1 Very Low (not at all resilient)
- 2 Low (not resilient)
- 3 Moderate (slightly resilient now, but not sure in the future)
- 4 High (resilient to known / experience hazards now and in the future)
- 5 Very High (resilient to all kinds of current and future hazards)

90. Are you willing to be contacted later for follow up interview?

- 1 Yes
- 2 No

Can you provide your mobile number?

Community Resilience

The following questions are about community resilience

==== End of survey ====

87. What does resilience means to you? [select one]

- 1 Being prepared to any weather and climate-related event or disaster
- 2 Bouncing back from a weather and climate-related event or disaster
- 3 Being able to cope and withstand any weather-related event
- 4 Being able to learn and innovate from any weather and climate-related event
- 5 Being self reliant at all times
- 6 All of the above
- 7 Don't Know

Your responses are strictly confidential. No personal information will be published or released. Your responses will be combined with those of other respondents to compile aggregate and analyzed information.

Thank you very much for your assistance.

88. What do you think makes your community resilient? Identify at most least three.

- 1
- 2
- 3

89. What can you or your household do to make your community more resilient?

COPYRIGHT PERMISSION DECLARATION

Dear Dr. Rodel Lasco,

In the context of my PhD dissertation with the provisional title “Improving the resilience of water supply towards climate change impacts in Tacloban, Philippines”, I hereby seek the OML Center permission to reproduce part of the survey data collected during project WaCE, conducted in Leyte in 2016. The referred data, in which collection and treatment I have participated as a OML Center Research Fellow, supports my dissertation’s chapter on community resilience analysis.

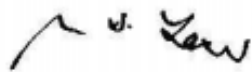
Moreover, the OML Center scientific paper named “Hydrological modeling to assess water resources resilience towards climate change impacts in Tacloban, Philippines”, published on CDD Journal on February of 2018, exposes the hydrological modeling analysis of my case study. This material will be used to strengthen and sustain my thesis and will only be used for the academic purposes of my dissertation. The remaining OML copyrighted material will too be duly referenced and a copy of my final PhD version will be provided to OML Center.

Please indicate your approval of this request by signing this letter where indicated below.

With my best regards,

Rita Marteleira
(PhD student and OML Center Research Fellow)

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Dr. Rodel Lasco
(Scientific Director OML Center)

ANNEX VI – Declarations of originality and conformity

DECLARAÇÃO

Declaro que esta dissertação é o resultado da minha investigação pessoal e independente. O seu conteúdo é original e todas as fontes consultadas estão devidamente mencionadas no texto, nas notas e na bibliografia.

A candidata,

Rita G. S. Marteleira

A handwritten signature in black ink that reads "Rita G.S. Marteleira". The signature is written in a cursive style and is positioned above the printed name.

Lisboa, 27 de Novembro de 2018

DECLARAÇÃO

Declaro que esta Dissertação se encontra em condições de ser apreciado pelo júri a designar.

O(A) orientador(a),

Professora Doutora Maria José Roxo



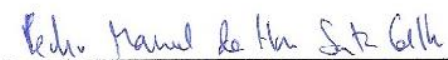
Lisboa, 27 de Novembro de 2018

DECLARAÇÃO

Declaro que esta Dissertação se encontra em condições de ser apreciado pelo júri a designar.

O orientador,

Professor Doutor Pedro Santos Coelho



Lisboa, 22 de Novembro de 2018

ANNEX VII - List of Publications

Marteleira, R., Roxo, M. J., Lasco, R., Coelho, P. S., 2018, *Hydrological modeling to assess water resources resilience towards climate change in Tacloban, Philippines*, *Climate, Disaster and Development Journal*, Volume 3 (1), pp. 3-22
(DOI10.18783/cddj.v003.i01.a02)

Marteleira, R., Coelho, P. S., Delfino, R. J., Santos, C. T., Roxo, M. J., 2019?, *Social perception of resilience and water scarcity in Tacloban, Philippines*, (submitted)

Marteleira, R., Coelho P.S., Roxo, M.J., 2019?, *Towards a holistic approach of resilience: integrating natural resources analysis and social perception*, (submitted)

Presence in national and international conferences

Marteleira, R., Coelho, P. S., Roxo, M. J., 2017, *Water resources resilience and social perception of water scarcity in Tacloban, Philippines*, International Conference on Sustainable Development, September 18-19th of 2017, Columbia University, New York, USA

Marteleira, R., Coelho, P. S., Roxo, M. J., 2017, *O impacto do super tufão Haiyan em Tacloban, Filipinas*, Congresso da Geografia Portuguesa - As dimensões e a responsabilidade social da geografia, November 9-11th of 2017, Faculdade de Letras da Universidade do Porto, Porto, Portugal

Marteleira, R., Coelho P.S., Roxo, M.J., 2018, *Water resources resilience analysis in the typhoon-devastated city of Tacloban, Philippines*, International Conference of Water Science for Impact, October 16-19th of 2018, Wageningen University and Research, Wageningen, Netherlands

