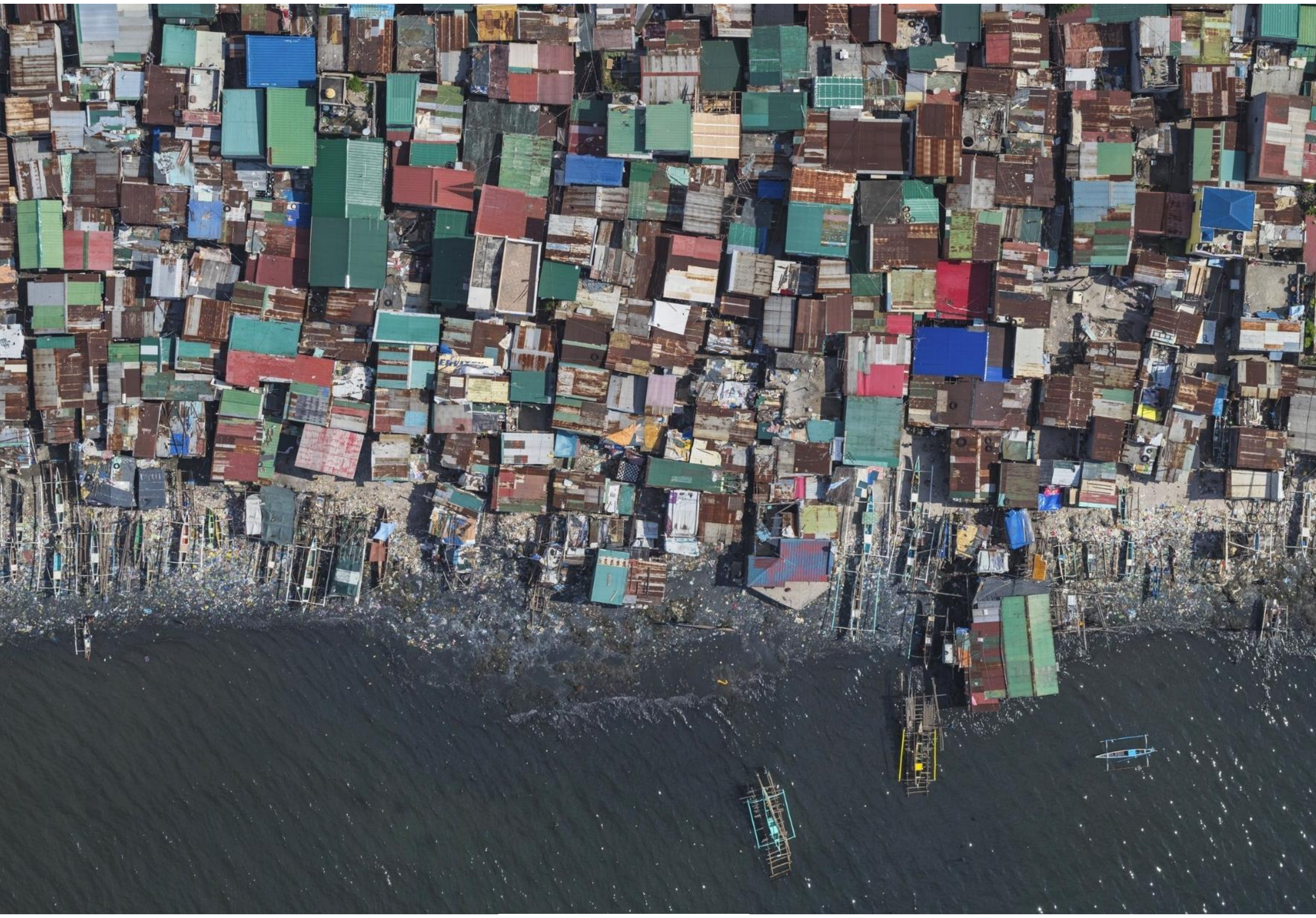
Fair Impact-based Forecasting in Manila Bay, Philippines

Integration of the information needs of disaster managers into fair impact-based forecasting to improve emergency management

Irene Benito Lazaro



TU Delft Delft University of Technology
Deltares Enabling Delta Life
510 AN INITIATIVE OF THE NETHERLANDS RED CROSS

On the cover, aerial image of Barangay Tangos, in Manila Bay, Philippines. Image taken by Bernhard Lang, 2017.

Fair impact-based forecasting in Manila Bay, Philippines

Integration of the information needs of disaster managers into fair impact-based forecasting, to improve emergency management

By

Irene Benito Lazaro

in partial fulfilment of the requirements for the degree of

Master of Science

in Civil Engineering

at the Delft University of Technology,

to be defended publicly on Monday October 14, 2019 at 10:00 AM.

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Preface

This thesis represents the final result of becoming a Master of Science in Water Management at Delft University of Technology, at the Faculty of Civil Engineering and Geosciences. I would like to acknowledge all the people that has contributed to my graduation. I would first like to thank my committee for assessing my thesis.

Secondly, I would like to thank Deltares and 510 for giving me the change of doing a thesis in such a fascinating topic and providing me the opportunity of working in these two fantastic working environments. I am grateful to Roman Schotten for the daily supervision during my work, which has allowed me to learn and improve my research, and to Aklilu Teklesadik for his guidance and help on the field work to the Philippines.

Besides, I would like to thank all the disaster managers and emergency people I have had the honour to talk to during my thesis and the amazing people I met during my visit in the Philippines.

Finally, I want to thank my family, for helping to reach my dreams, and my friends for their endless support.

Irene Benito Lazaro

Delft, September 2019

Abstract

The Philippines is a country located in the typhoon belt of the Pacific. Its location makes it typhoon prone and on average around 20 typhoons enter the country every year (Asian Disaster Reduction Center, 2008). This natural phenomenon can have disastrous effects and therefore, good preparedness is of special importance. Traditionally weather forecasts have been used in order to predict the physical characteristics of typhoons to organise early actions that can dampen their damage. However, regardless the good meteorological forecasts, typhoons kept having large effects in coastal areas, due to the gap of knowledge between a hazard and its impact. For this reason, nowadays disaster managers are increasingly more interested in the knowing the repercussion of natural hazards, which can help to prepare and mitigate their consequences (Tozier de la Poterie et al., 2018).

Although forecasts that predict the impact of hazards, the so-called impact-based forecasts, are rising, there are not many of these systems operationalised yet. To make these forecasts more functional it is essential to understand what their users' needs are. Because disaster managers work under stressful conditions, it is crucial to have the right information in order to take effective actions.

This research has developed an impact-based forecasting prototype for Manila Bay, Philippines, considering the information needs of disaster managers. In order to do so, an iterative process has been followed in the creation of the system, in which disaster managers provided their inputs and feedbacks on the prototype. The impacts on the assets of relevance for the disaster managers have been forecasted with the use of Delft-FEWS and Delft-FIAT. Furthermore, this forecasting system has been novel in predicting the impact of typhoons considering not only the hazard and exposure but also implementing the vulnerabilities of the affected area.

The findings of this study suggest that an impact-based forecasting system for Manila Bay should provide information on the affected population, livelihoods, hospitals, roads and schools. Those assets have been pointed out as most important for disaster managers at local scale. The output of the forecasting system should provide actionable results that allow disaster managers to make quick and relevant decisions. Furthermore, the data displayed in the system should be simple, clear and with colour codes that allow for a fast interpretation of the results and provide maps with information of the impacts on all the assets per municipality or province. Besides, it has been observed that vulnerability plays an important role when prioritising the action areas of disaster managers.

The aim of this research was to develop an impact-based forecasting system that considers the information and display needs of disaster managers, while integrating the vulnerabilities of the affected area. Therefore, the objective of this thesis was not to develop an accurate mathematical model that provides the exact impact. Instead, it is a guide of what a disaster managers-based forecast should provide. Hence, in order to make this forecasting system operational, validation of the prototype and consideration of other hazards, such as wind speeds, are recommended.

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List of Acronyms

510	510 an initiative of the Netherlands Red Cross
CCC	Climate Change Commission
DMS	Disaster Management Service
DRRMCs	National Disaster Risk Reduction and Management Councils (
EAP	Early Action Protocol
FbF	Forecast-based Financing
FIAT	Flood Impact Assessment Tool
HCI	Human-computer interaction
IBF	Impact-based Forecasting
INFORM	Index for Risk Management
LGUs	Local Government Units
NGOs	Non-governmental organisations
NDRP	National Disaster Response Plan
NDRRMC	National Disaster Risk Reduction and Management Council
NMHSs	National Meteorological and Hydrological Services
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PDRA	Pre-Disaster Risk Assessment
PRC	Philippine Red Cross
RDANA	Rapid Damage Assessment and Needs Analysis
UN	United Nations
WES	Wind Enhance Scheme

1 Introduction

1.1 Problem statement

The geographical location of the Philippines makes it extremely vulnerable to all kinds of natural disasters. The Philippines is situated along the typhoon belt of the Pacific and receives every year on average 20 typhoons, five of which can be very destructive (Asian Disaster Reduction Center, 2008). Because of the large effects of these typhoons, there is an increasing need to reduce their impact by supplying actionable forecasts. Therefore, this thesis will focus on the impact of typhoons in Manila Bay (Philippines), and their forecast.

Humanitarian organisations are increasingly more interested in the impacts of typhoons rather than in forecasting the hazard itself. Knowing the repercussion of natural hazards can help to prepare and mitigate their consequences (Tozier de la Poterie et al., 2018). Therefore, there is a change on user needs from a meteorological forecast towards impact-based forecasting (World Meteorological Organization, 2015). Nowadays there are already impact-based forecasts that predict the effects of cyclones. However, there are not many examples of operationalised impact-based forecasting systems. Few of those examples are the forecast-based financing (FbF) systems of the Red Cross and the example of Dumfries, Scotland of Deltares. To make impact-based forecasts more functional it is essential to know what the decision-makers' information needs are and how these should be delivered. Because emergency responders usually must make decisions under pressure, a forecasting design with humanitarian aid organisations that considers the vulnerabilities of the affected people can lead to an improvement in the decision making and the response when a cyclone occurs (van den Homberg, Visser, & van der Veen, 2017).

1.2 Purpose of this thesis

Emergency managers coordinate the required actions during natural disasters. To carry out a successful coordination, relevant data as well as its good presentation are necessary (Van Den Homberg, Meesters, & Van De Walle, 2014). Therefore, this thesis aims to create a prototype that resembles forecast-based emergency management systems for crisis managers, while implementing the vulnerabilities of the affected people, in order to develop a fairer impact-based forecast.

The creation of this prototype taking into account the vulnerabilities of people in that area of the Philippines does not only imply an improvement in impact-based forecasting, but it might also have an effect in the Philippine society. The information provided by this forecast is adapted to its user needs and therefore, it can help to improve emergency management, which can result in less personal and economic damages (Tozier de la Poterie et al., 2018). This output is expected to help the humanitarian organisations to make decisions regarding typhoons in the Manila Bay during the disaster management cycle of the cyclone: mitigation, preparedness, response and recovery.

1.3 Research questions

The main purpose of this thesis is to study the information needs of emergency managers and how those should be delivered, while implementing into the prototype vulnerabilities of the affected population. In order to fulfil these objectives, the following research questions should be answered.

Main research question:

- How can the information needs of crisis managers be integrated into fair impact-based forecasting in order to improve forecast based-emergency management?

Sub questions:

- Which information do disaster responders find more relevant for emergency management regarding cyclones in Manila Bay, Philippines?
- How do disaster managers find more suitable the display of that information?
- How can the relevant information needed by the stakeholders be calculated and implemented into the prototype?
- Which vulnerability data is available and can be used to fulfil the needs of the stakeholders?
- How can that vulnerability data be implemented into the prototype in order to provide a fair impact-based forecast?
- How can the prototype be designed in order to provide the needs of disaster managers?

1.4 Thesis structure

To answer the research questions mentioned in the previous section, this thesis is structured as follows. Chapter 2 sets a theoretical framework that defines the basic concepts necessary to understand this thesis. Afterwards, Chapter 3 provides deeper information related to impact-based forecasting and disaster management. The programs used for the development of the forecasting system are presented in Chapter 4. Chapter 5 first delivers basic understanding on social science methodologies used in this thesis. Later on, the specific research approach followed in this research is explained. It is important to understand the starting point of this thesis. Therefore, Chapter 6 presents the initial conditions of the forecasting system used in this research. Chapters 7, 8, 9, 10, 11, 12 form the core of this thesis. Chapter 7 presents the methodology and results of the interviews to disaster managers carried out to understand their information and display needs. Once those needs are understood, Chapter 8 provides the methodology and results of the new impact models created in for the forecasting system. The implementation of vulnerability and its results is described in Chapter 9. In order to make the forecasting system easily and quickly understood, an interactive dashboard has been created and its methodology as well as the results out of it are provided in Chapter 10. Moreover, to improve the forecasting system designed, feedback rounds have been performed. Chapters 11 and 12 describe the methodology and results from the visits to the 3rd Asia Pacific Dialogue Platform on Forecast-based Financing and the interviews to disaster managers from the Philippine Red Cross. Finally, Chapter 13 presents a summary of the final forecasting system created as an outcome from this thesis. To end, Chapters 14 and 15 provide, respectively, the limitations and conclusions of this research.

2 Theoretical framework

This chapter presents an introduction to the basic concepts that should be well understood before starting to read this thesis. First, risk and its components are explained. Afterwards, weather forecasting as well as impact-based and fair impact-based forecasting are described.

2.1 Risk

Risk is a wide term in which there is not yet a consensus about its interpretation among different fields. However, in spite of the different views towards risk, there is a general acceptance on the fact that risk has two dimensions: the impact and its likelihood of occurrence. Hence, in mathematical terms, the general definition of risk can be defined as the product of impact and its associated probability (Dumbravă & Vladut-Severian, 2013; Schotten, 2017):

$$\text{Risk} = \text{Impact} \cdot \text{Probability} \tag{2.1}$$

In the specific field of disaster management, the World Meteorological Organization (2015) defines the risk of impact as the probability of potential harm on human beings and damage or destruction of their livelihoods or assets due to their exposure and vulnerability (United Nations Office for Disaster Risk Reduction (UNISDR), 2017; World Meteorological Organization, 2015):

$$\text{Risk of impact} = \text{Hazard} \cdot \text{Exposure} \cdot \text{Vulnerability} \tag{2.2}$$

Therefore, the risk of impact of a natural hazard can be reduced by taking actions to diminish the exposure and/or the vulnerability of the affected people and assets. Although nowadays disaster management actions have focussed mainly on exposure reduction, vulnerability has proven to play an important role, especially in recurrent events of low intensity (Cardona et al., 2012).

For the specific case study of this thesis, the hazard, exposure and vulnerability can be defined more precisely:

- Hazard: Storm surge
- Exposure: Manila Bay, Philippines
- Vulnerability: %Vulnerable population

2.2 Hazard: Storm surge

Definition

Hazard is defined by the World Meteorological Organization (2015) as a “hydrometeorological - based, geophysical or human-induced element that poses a level of threat to life, property or the environment”. In this thesis, the hazard studied is the storm surge produced by cyclones. A tropical cyclone is the generic term for low pressure systems that form over tropical or sub-tropical warm waters. Tropical cyclones have organised convection (i.e. thunderstorm activity) and strong winds near the centre. Low level winds circulate anti-clockwise in the northern hemisphere and clockwise in the southern hemisphere (Australian Government Bureau of Meteorology, 2019; Met Office United Kingdom, 2018; NOAA, 2017).Tropical cyclones are named different depending on their wind speeds as well as their geographical location. When their maximum wind speeds are less than 17m/s, they are usually called "tropical depressions". When tropical cyclones reach wind speeds of at least 17m/s, they are usually called "tropical storms". Once speeds reach 33m/s or more, the tropical storm is called “Hurricane” in the Atlantic and eastern North Pacific, “Typhoon” in the western North Pacific and “Cyclone” or “Tropical Cyclone” in other places of the world, such as in the Indian Ocean and the South Pacific (Met Office United Kingdom, 2018; NOAA, 2017).

Formation

Tropical cyclones derive their energy from warm tropical oceans, and form when the sea-surface temperature is above 26.5°C. In the tropics there are large areas of low-pressure air, that rise when they get heated, and create showers that can cluster and build thunderstorms. This phenomenon produces a flow of very warm, moist, rapidly rising air, leading to the development of a centre of low pressure at the surface (Australian Government Bureau of Meteorology, 2019; Met Office United Kingdom, 2018).

Impact

Tropical cyclones have dangerous consequences, due to their destructive winds, heavy rainfall producing flooding and storm surge. The Saffir-Simpson Hurricane Wind Scale is used to rank tropical cyclones based on wind strength in many parts of the world (Met Office United Kingdom, 2018). These winds can cause large property damages, turn airborne debris potentially dangerous and produce phenomenal seas. However, storm surge is the phenomena of tropical cyclones that poses the greatest threat to life and assets along coastal areas (Australian Government Bureau of Meteorology, 2019; NOAA National Hurricane Center, n.d.).

A storm surge is an abnormal raise of water generated by a storm, typically of about 2 to 5m higher than the normal (astronomical) tide level. If the surge occurs at the same time as a high tide (i.e. storm tide), the area inundated can be extensive, particularly along low-lying coastlines (Australian

Government Bureau of Meteorology, 2019). Equation (2.3) describes the increase in water level during a storm tide in a tropical cyclone event (Schotten, 2017):

$$\text{Total Water Level} = \text{Storm Surge} + \text{Tides} + \text{Waves} + \text{Freshwater Input} \qquad (2.3)$$

Figure 2.1 depicts a schematic representation of a cyclone storm surge.

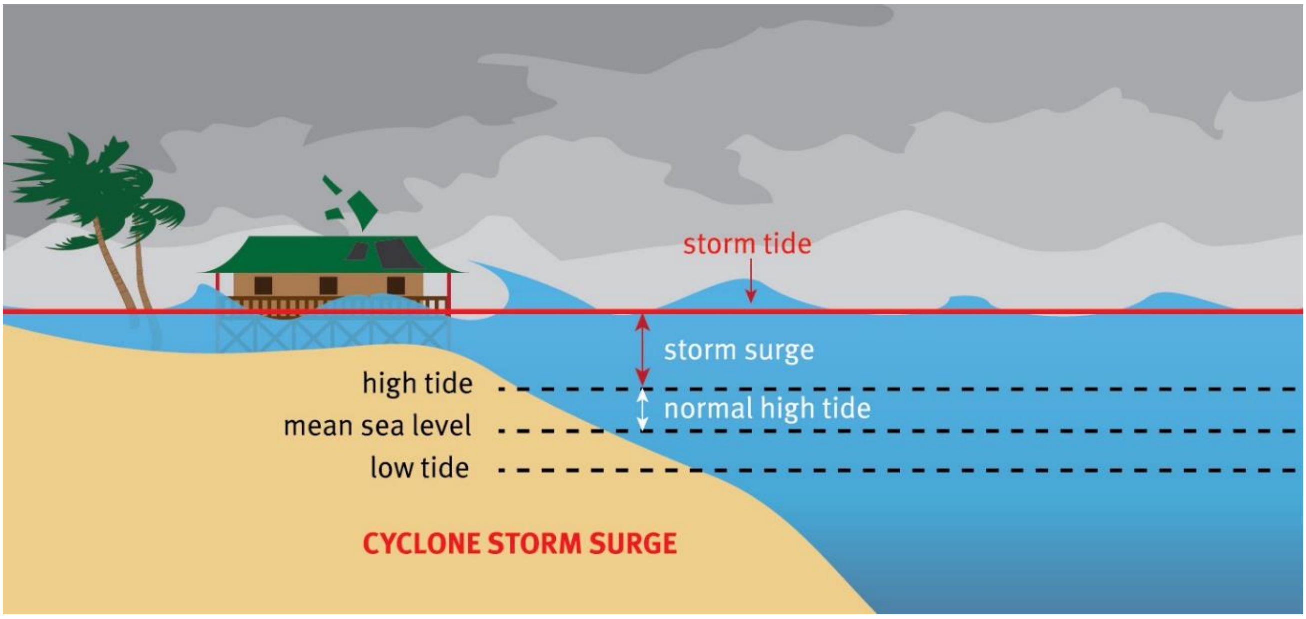


Figure 2.1. Cyclone storm surge (Australian Government Bureau of Meteorology, 2019)

Typhoons in the Philippines

The geographical location of the Philippines makes it extremely vulnerable to all kinds of natural disasters. According to Kreft, Eckstein, Junghans, Kerestan, & Hagen (2014), the Philippines are one of the most affected countries in the world due to weather events.

The Philippines are situated along the typhoon belt of the Pacific and receive every year on average 20 typhoons, of which five can be very destructive (Asian Disaster Reduction Center, 2008; Bautista et al., 2014). Typhoon Haiyan struck the country in November 2013. This typhoon was the strongest recorded tropical cyclone to make landfall, and caused 6000 causalities and over US$ 13 billion losses (Kreft et al., 2014).

2.3 Exposure: Manila Bay

Exposure due to a natural hazard relates to who and what may be affected in an area at risk. Exposure is related to the location of population and resources. If those were not located in potentially dangerous settings, no disaster risk would exist (Bautista et al., 2014; Cardona et al., 2012; ISDR, 2004; World Meteorological Organization, 2015). The elements at risk that are usually of most interest in a risk analysis are those that are critical for the functioning of society, such as buildings, structures, facilities, network infrastructure and utilities, people and communities, primary sources of food and potable water, and natural resources (Bautista et al., 2014).

Being exposed to a hazard, however, does not strictly imply being at risk. Vulnerability must also be taken into account. It is possible to be in a location where a cyclone will occur, but if there are enough resources to mitigate its potential effects, there is no risk. On the other hand, it is necessary to be exposed to a hazard in order to be vulnerable (World Meteorological Organization, 2015).

Philippines

The Republic of the Philippines is located in the Southeast Asia, and is an archipelago formed by 7.641 islands that are extended along 300.000 km^2. These islands are, however, divided into three groups: Luzon, Visayas and Mindanao (Republic of the Philippines, n.d.). The census of population on August 2015 was of 100.981.437 inhabitants, being Luzon the most populated island (Republic of the Philippines - Philippine Statistics Authority, 2016). Figure 2.2 depicts the population density map of the Philippines per province.

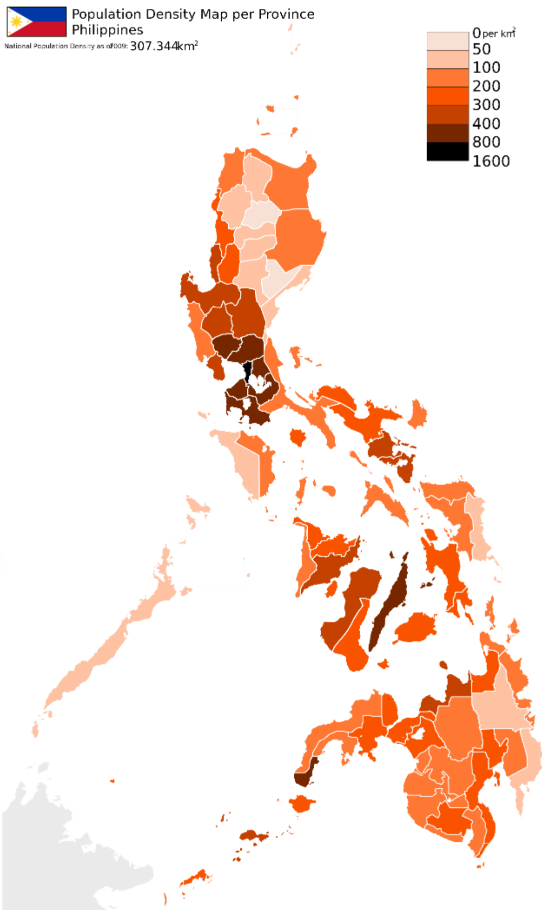


Figure 2.2. Population density map per province of the Philippines (Wikimedia Commons, n.d.)

The Philippines is politically divided in 18 administrative regions. Within those regions there are 81 provinces and 1.489 municipalities. The smallest administrative division in the Philippines is called barangay, and in total there are 42.036 barangays in the country (Republic of the Philippines - Philippine Statistics Authority, 2016).

Furthermore, the Philippine economy has become one of the most buoyant economies in the East Asia and the Pacific region. In 2018 the Philippines experimented an economic growth of 6.2% and is expected to improve from a lower-middle income country to an upper-middle income country in the short future. This economic development of the country is supported by the good moment of businesses such as real estate, finance and insurance industries. The increase of businesses has been accompanied by a migration of the population from the rural areas towards the cities. However, this transition has produced a rise in the creation of bad working conditions (The World Bank, 2019).

Manila Bay

Manila Bay is a semi-enclosed bay located in the southwestern part of Luzon island. The provinces of Cavite and Metro Manila on the east, Bulacan and Pampanga on the north and Bataan on the west and northwest are at the boundaries of Manila Bay. The bay has a coastline of 190 km, and a surface area of 1.700 km^2 and drains a basin area of around 17.000 km^2, formed by 26 catchments (Jacinto, Velasquez, Diego-Mcglone, Villanoy, & Siringan, 2006).

The historical, cultural and economic values of the bay make it one of the most important water bodies in the Philippines, where since Hispanic times has been a relevant area of economic growth and where nowadays counts with local and international harbours (Jacinto et al., 2006).

Figure 2.3 below depicts the Manila Bay area considered for this thesis, as well as its density population. Notice that in the locations with larger population, the exposure will be large in case a hazard occurs in the area. However, the most populated area might not be the most vulnerable and hence, it might not be the most affected by a cyclone.

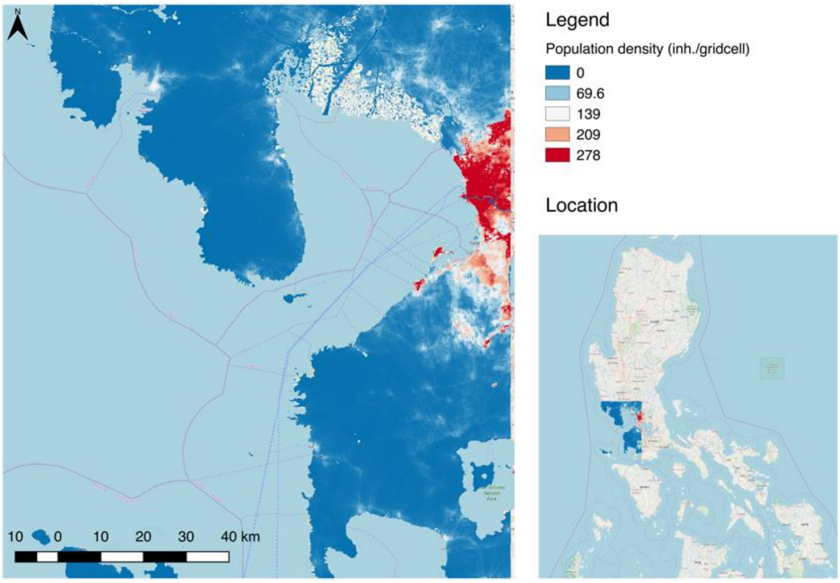


Figure 2.3. Map of the Manila Bay area population density and its location in the Luzon island

2.4 Vulnerability

Definition

Vulnerability describes the characteristics of people due to historical, cultural, social, environmental, political and economic circumstances. Therefore, a vulnerable population is not only at risk due to their exposure to a specific hazard but also due to their daily social integration in the society (Cardona et al., 2012). However, when considering the vulnerability related to disaster risk, vulnerability refers to the susceptibility of the exposed elements, such as human beings and their livelihoods, to suffer adverse effects due to a disaster event. Vulnerability is hence, linked to the predisposition, sensitivities, fragilities, weaknesses, deficiencies or lack of capacities that affect the adverse consequences of natural hazards (World Meteorological Organization, 2015).

Relation exposure and vulnerability

The impact degree of natural disasters is directly related to the exposure and vulnerability of those events. This can be observed from Equation (2.1) mentioned above. Vulnerability and exposure are dynamic and change throughout time and space. Human beings are differently exposed and vulnerable due to economic, gender, education, health, class factors (Cardona et al., 2012).

During extreme events, with low probability but high intensity, exposure plays a dominant role on the severity degree of the event. On the other hand, on less extreme events, which occur more often and are less intense, vulnerability has larger importance. Furthermore, the occurrence of repetitive disasters of low intensity can, in the longer time, increase the vulnerability of the population, because of their impact on the coping capacities of the population, which reduces the well preparedness and response towards new events (Cardona et al., 2012).

Vulnerability factors

There are a number of aspects that are related to vulnerability. Physical, social, economic and environmental factors can influence the susceptibility of human beings, infrastructures and other elements to the impacts of hazards (Australian Government-Geoscience Australia, 2017; PreventionWeb, n.d.; United Nations Office for Disaster Risk Reduction (UNISDR), 2017).

Physical factors

Physical vulnerability is associated to the physical conditions of population, environment or infrastructures. The poor design and construction of buildings, the lack of building standards or the inadequate materials as well as an unregulated land use planning can increase the vulnerability of infrastructures. Furthermore, the physical condition of individuals (injuries, sicknesses or disabilities) make them more vulnerable as well when disasters occur (Australian Government-Geoscience Australia, 2017; PreventionWeb, n.d.).

Social factors

Social vulnerability is associated to the capacity of a human being or a community to anticipate, cope with, resist and recover from the impact of a natural disaster (Wisner, Blaikie, Blaikie, Cannon, & Davis, 2004). Poverty and inequality, social exclusion as well as discrimination by gender, race, age and social status are factors that can rise the vulnerability of human beings and communities, increasing their susceptibility towards the effects of a hazard event (PreventionWeb, n.d.).

Economic factors

Economic vulnerability is an important determinant of the disaster damages and losses of an event. This kind of vulnerability can be divided into the damages to stocks, such as property damage, and the damages on the production of goods and services, that are related to the uninsured informal sector, vulnerable rural livelihoods, dependence on single industries, globalisation of business and supply chains among others (Noy & Yonson, 2018; PreventionWeb, n.d.).

Environmental factors

Environmental vulnerability can influence the susceptibility of the population when a disaster occurs, due to poor management of the environment and the natural resources, and due to climate change (PreventionWeb, n.d.).

Coping capacity

Coping capacity is the combination of the skills and resources of a human being or community to manage and reduce the adverse consequences of a natural disaster (PreventionWeb, n.d.; United Nations Office for Disaster Risk Reduction (UNISDR), 2017).

Different literature shows different relations between vulnerability and coping capacity. On the one hand, some authors such as White et al. (2005) propose that coping capacity is part of vulnerability, meaning that coping capacity is inversely proportional to vulnerability. On the other hand, authors such as Hahn (2003) propose that coping capacity is an element more of risk (Villagrán De León, 2006).

Early warning systems reduce vulnerability

In the previous section it has been mentioned that coping capacity is the counter side of vulnerability and hence, the more coping capacity the less vulnerable a community or person is. However, there are other measures that can reduce vulnerability. The Paris Agreement established that early warning systems are one of the main pathways in order to reduce vulnerability, as well as to enhance adaptive capacity, increase resilience and reduce damages related to weather hazards (République Française, 2015; World Meteorological Organization (WMO), 2018).

Early warning systems can allow the population to have enough time for emergency preparedness and design response plans that reduce their susceptibility to the impact of a natural hazard (République Française, 2015). Therefore, the improvement of these early warning systems can imply a significant disaster risk reduction.

2.5 Weather forecasting

Traditional forecasts provide information related to atmospheric variables such as wind, temperature, humidity and precipitation and their evolution throughout time and space (World Meteorological Organization, 2015).

These forecasts can be predicted following a deterministic or probabilistic approach. However, nowadays probabilistic approaches are rising due to the possibility of covering more scenarios through ensemble prediction mechanisms (World Meteorological Organization, 2015).

National meteorological services usually release warnings to inform the population about a potential upcoming natural event that might be harmful for human beings or assets. These warnings are generally based on weather-based factors and are often expressed as the probability of a threshold being exceeded. Weather warnings are generally provided in the shape of messages, colour-codes or number-codes. Nowadays, meteorological forecasts and warnings have evolved towards a more dynamic provision of information, in which forecasts are updated almost continuously (World Meteorological Organization, 2015).

Cyclone forecasting

The prediction of weather parameters can provide information that helps during the preparation of a cyclone event. Usual parameters forecasted on cyclone events include, among others, the position of the cyclone, its intensity, the wind distribution, rainfall and storm surge (World Meteorological Organization, 2017).

Furthermore, several national meteorological services provide warnings based on the weather categorisation of cyclones. However, few of them combine the intensity rates of the cyclones with the estimates of their expected damage. One of the most well-known categorisations that does take into account these estimates is the US Saffir-Simpson Hurricane Scale, in which the severity of the cyclones is based on their sustained wind speeds. The categorisation of the US Saffir-Simpson Hurricane Scale can be seen in Figure 2.4 (World Meteorological Organization, 2015, 2017):

Category	Sustained winds
1	74–95 mph 64–82 kt 119–153 km/h
2	96–110 mph 83–95 kt 154–177 km/h
3 (major)	111–129 mph 96–112 kt 178–208 km/h
4 (major)	130–156 mph 113–136 kt 209–251km/h
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher

Figure 2.4. US Saffir-Simpson Hurricane Scale (World Meteorological Organization, 2015)

2.6 Impact-based forecasting

Despite the good meteorological forecasts and warnings, every year disastrous weather events cause losses of lives and large damages to infrastructures. The reason for these negative effects in spite of the good predictions might lie on the difference between the weather estimates and the actual impacts those events cause. Nowadays there is a large knowledge on the physical characteristics of the weather, but few understandings on the effects this weather has on the communities and assets.

Impact-based forecasts provide a solution to this problem, contributing to a better understanding on the effects of natural hazards by predicting the possible impacts of an event. These impacts are measured from the results of the weather forecast. Therefore, impact-based forecasting can be relevant to increase the response preparation on the early warning face of a disaster, reducing this way the weather effects on vulnerable people that live in areas prone to natural disasters (510.Global An Initiative of the Netherlands Red Cross, 2018; World Meteorological Organization, 2015).

An example of an impact-based warning released by National Meteorological and Hydrological Service would be the following:
"Rainfall accumulations of 20 mm to 30 mm expected tomorrow between 1400 and midnight, resulting in possible road closures due to flooding across the south-east" (World Meteorological Organization, 2015).

In this thesis, impact-based forecasting is considered to combine data on the hazard and exposure of an event. The result of impact-based forecasting is hence, the affected population or infrastructure, without considering its vulnerabilities. Equation (2.4) and Figure 2.5 show the definition and interpretation of impact-based forecasting for this thesis.

$$\text{Impact-based forecasting} = \text{Hazard} \cdot \text{Exposure} \qquad (2.4)$$

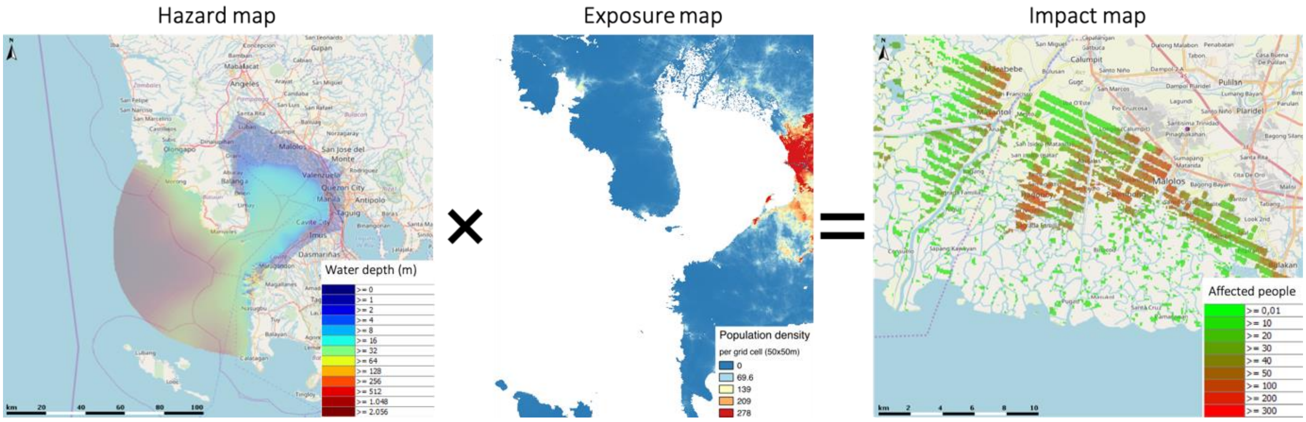


Figure 2.5. Schematic example of the creation of an impact map

Risk-based forecasting

Although impact-based forecasting has improved the way in which disaster managers take decisions, it is also important to know the likelihood of occurrence of these forecasts. For this reason, risk-based forecasting includes the probability dimension, in order to predict risk. Equation (2.5) provides the definition of risk-based forecasting for this thesis.

$$\text{Risk-based forecasting} = \text{Hazard} \cdot \text{Exposure} \cdot \text{Probability} \qquad (2.5)$$

The World Meteorological Organization recommends the National Meteorological and Hydrological Services (NMHSs) to identify the likelihood of a hazard and its potential severity, in order to make use of a risk matrix that helps on the decision making during an event. Figure 2.6 depicts a risk matrix, in which the relation of likelihood of the hazard and its impact define a colour coded warning system.

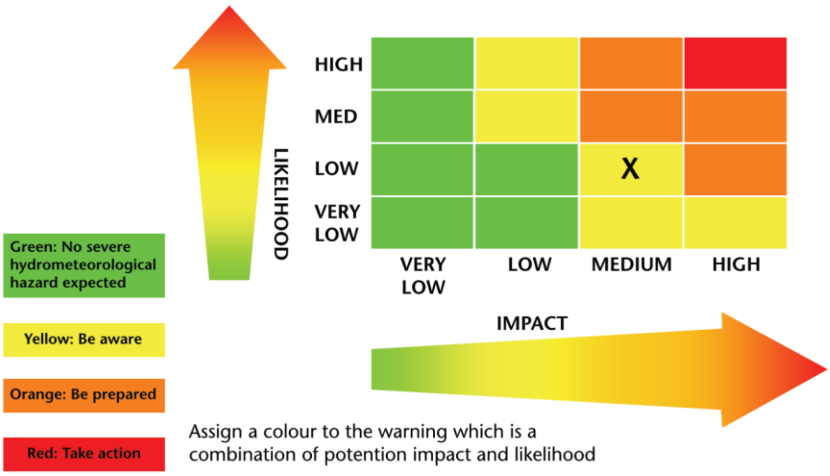


Figure 2.6. Risk matrix with a colour code warning indication the actions to be taken depending on the impact and the likelihood of the hazard (World Meteorological Organization, 2015)

Fair impact-based forecasting

Nowadays, impact-based forecasting focusses mainly on the overlap of hazard and exposure (Budiyono, Aerts, Brinkman, Marfai, & Ward, 2015). However, as it has been mentioned above, vulnerability plays an important role on the severity of the natural disasters. Therefore, in this thesis it is aimed to introduce the vulnerability dimension into impact- and risk-based forecasting, in order to provide a more realistic and fair assessment of the impact. Equation (2.6) and Figure 2.7 show the definition and interpretation of impact-based forecasting for this thesis.

$$\text{Fair impact-based forecasting} = \text{Hazard} \cdot \text{Exposure} \cdot \text{Vulnerability} \qquad (2.6)$$

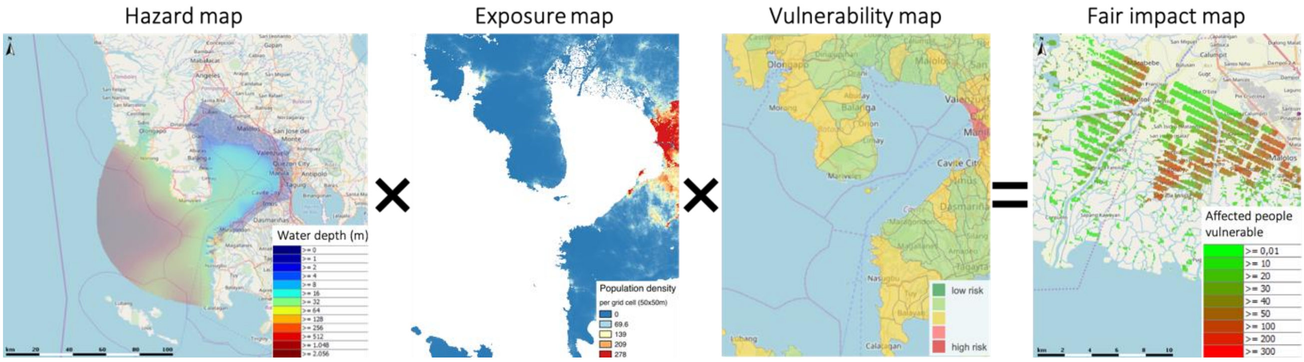


Figure 2.7. Schematic example of the creation of a fair impact map

2.7 Impact forecasting

The World Meteorological Organization considers a third kind of forecast, called impact forecast. Impact forecasts provide the prediction of impacts in detail, at individual or community level. Therefore, the availability of local and specific exposure and vulnerability data is of large importance. The warning delivered with impact forecasting provides precise information on who or what will be affected by a hazard. In order to make this kind of forecast viable, the National Meteorological and Hydrological Services must have a strong relationship with other relevant agencies and communities (World Meteorological Organization, 2015).

An example of an impact warning released by National Meteorological and Hydrological Service would be the following:

“Expect journey times on the A111 likely to be lengthened by an hour because of significant traffic disruption in the south-east tomorrow afternoon due to localised flooding which is expected to follow a heavy rain event” (World Meteorological Organization, 2015).

It can be observed that in this warning example, compared to the impact-based warning example, the exposure information is much more detailed and location specific.

3 Literature review

This chapter provides further knowledge related to impact-based forecasting and disaster management that can improve the understanding of the thesis later on.

3.1 Expressions for risk of impact

Several studies have described the risk of impact towards natural events. However, the definition of risk of impact, also called disaster risk, is not consistent and varies among authors due to their differences in the perception of risk and vulnerability. Table 3.1 presents some expressions of disaster risk described by different authors.

Table 3.1.Disaster risk formulas defined by different authors (Alexander, 2000; Dilley, Chen, Deichmann, Lerner-Lam, & Arnold, 2005; Hahn, 2003; ISDR, 2004; Villagrán De León, 2006; World Meteorological Organization, 2015)

Disaster risk formula	**Author**
Risk = Hazard · Vulnerability	ISDR (2004)
$\text{Total Risk} = \left(\sum \text{Elements at risk}\right) \cdot \text{Hazard} \cdot \text{Vulnerability}$	Alexander, D. (2000:10)
$\text{Risk} = \frac{\text{Hazard} \cdot \text{Vulnerability}}{\text{Coping Capacity}}$	UNISDR (2002:41)
Risk = Hazard · Vulnerability · Deficiencies in Preparedness	Villagrán (2001)
Risk = Hazard · Exposure · Vulnerability	Dilley et al. (2005) and WMO (2015)
$\text{Risk} = (\text{Hazard \& Exposure})^{1/3} \cdot \text{Vulnerability}^{1/3} \cdot \text{Lack coping capacity}^{1/3}$	Joint Research Centre (2017)
Risk = Hazard + Exposure + Vulnerability - Coping Capacities	Hahn (2003)

The definition of disaster risk used by Dilley et al. (2005) and the World Meteorological Organization (2015) is the most appropriate for the IBF prototype designed in this thesis (see Table 3.1). The reason to choose this expression is because it has been considered necessary to make a distinction between the hazard, the exposure and the vulnerability, and because it has been assumed that the risk of impact is the union of those three dimensions and not their sum.

INFORM index

When analysing the risk of countries with respect to natural and human hazards, a partnership exists between several UN agencies, donors, NGOs and research institutions. The aim of this partnership is to develop a multi-hazard risk index with global coverage, regional scale and seasonal variation. This partnership is called INFORM, and its objective is to create a composite indicator to help in the decision-making process during the prevention, preparedness and response phases of disasters (Joint Research Centre, 2017).

To calculate the risk of a country or region, the following formula is used:

$$\text{Risk} = (\text{Hazard \& Exposure})^{1/3} \cdot \text{Vulnerability}^{1/3} \cdot \text{Lack coping capacity}^{1/3} \qquad (3.1)$$

Each dimension of the risk (hazard and exposure, vulnerability and coping capacity) is calculated with several components that have a score from 0 to 10, and that are combined with a geometric mean. These scores from 0 to 10 are calculated using historical data in order to describe the current level of risk of a country. However, this risk has no predictive purposes and a change in one of the indicators might not lead to a big modification on the overall composite risk score (Joint Research Centre, 2017).

Figure 3.1 depicts the INFORM index for the Philippines, in which the total risk index for the country is 5.5, which indicates that the country is at high risk. The *hazards and exposure* dimension represents the probability of physical exposure associated to a specific hazard. In the case of the Philippines, among all the natural and human hazards that occur in the country the largest probability of exposure is associated with tropical cyclones.

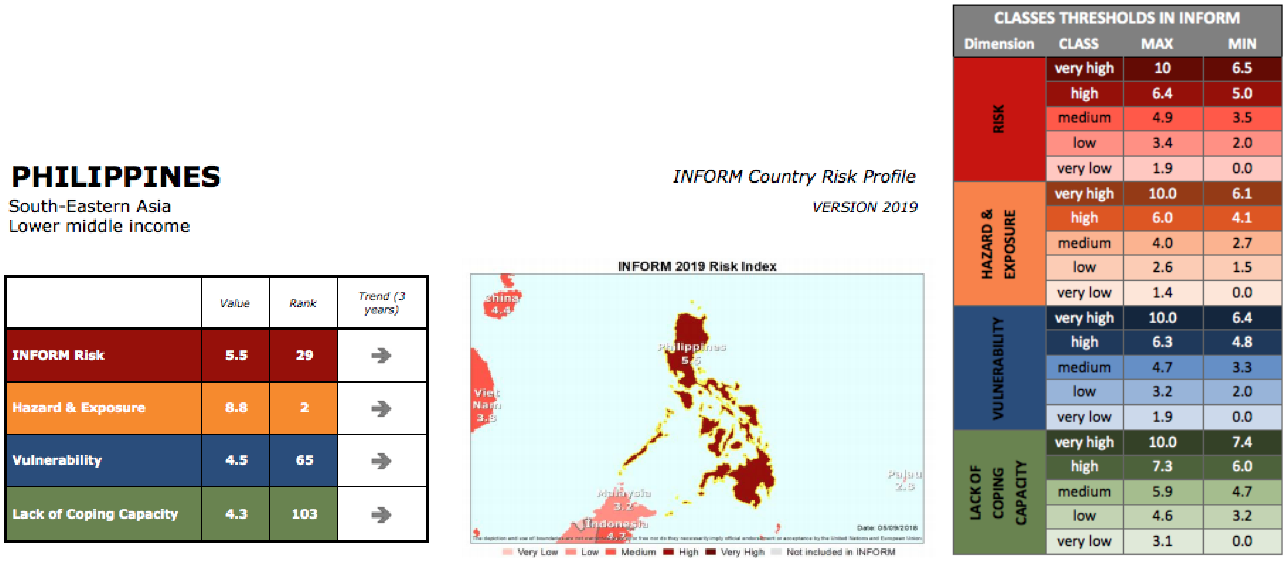


Figure 3.1. INFORM index of the Philippines (Joint Research Centre, 2019)

3.2 Impact-based forecasting

This report focusses on the development of an impact-based forecasting prototype in Manila Bay, Philippines. This section provides an insight on impact-based forecasting systems previously developed around the world, as well as in the Philippines.

3.2.1 Impact-based forecasting: state of the art

With the increasing extreme events expected in the coming years due to climate change, it is getting more necessary not only to know the weather forecast, but also the impact that those events will cause on the population and assets. The forecast of impacts is, therefore, extremely important for both, the disaster managers responsible for mitigating the risks, and for those at risk. For this reason, impact-based forecasting, which aims to predict impacts of disasters and to provide more detailed and understandable warning that can be easily understandable, is becoming more necessary.

Nowadays the number of impact-based forecasting systems being created around the world is increasing. Deltares has developed several projects for impact-based forecasting. The impact-based forecasting systems developed by Deltares have hydrodynamic models as a base (Schotten, 2017). A successful pilot study on the catchment of the River Nith to Dumfries, in Scotland, has been developed in collaboration with the Scottish Environment Protection Agency (SEPA), Deltares and HR Wallingford. This project focusses on three aspects:

1. Live flood maps: forecasting flood inundation;
2. Live impact information: number of properties affected and damages;
3. Ensemble runs: incorporating meteorological uncertainty.

This pilot in Scotland allowed stakeholders to increase their awareness and to learn that forecasts with high uncertainty are still useful to trigger early actions (Deltares, n.d.-a; Stuparu et al., 2017).

Another organisation successfully working with impact-based forecasts is the Red Cross and Red Crescent Movement, that uses IBF in their programme Forecast-based Financing (FbF), further explained in Section 3.2.2. Their IBF uses machine learning techniques in order to combine vulnerability data with data from historical events. The output of this impact-based forecast is used afterwards to take decisions related to humanitarian aid, such as when and where should the population be evacuated or who should get economic help for food or house strengthening toolkits (510.Global An Initiative of the Netherlands Red Cross, 2018).

Finally, a last example of an organisation using IBF is the Hydrologic Research Center. This non-profit research corporation is leader in providing support to the U.S. National Weather Service International Affairs Office on the development and implementation of local-scale impact-based forecasting and warning services in countries of Africa, South America and Asia. Their program aims at improving the current forecast and warning messaging protocol of the National Meteorological and Hydrologic

Services, with the objective of helping making better disaster management decisions (Hydrologic Research Center, 2019).

The organisations using IBF are increasing in all over the world. However, the purposes of IBF are not only related to humanitarian aid or emergency management. An example of this shift *is* Aon Benfield Analytics, which is a company that designs probabilistic impact-based forecasts to enable firms analyse the financial implications of disaster events and get a better understanding of their risks (Aon Benfield Analytics, n.d.).

3.2.2 Forecast-based Financing

As it has been mentioned in the previous section, Forecast-based Financing is a programme of the International Red Cross and Red Crescent Movement, that aims at switching the approach followed in a hazard event, from taking reactive actions after a natural disaster hits, towards taking proactive actions to prevent and/or dampen its potential impacts. The objective of this initiative is to protect the population and their livelihoods by using innovative forecast information and risk analysis (International Federation of Red Cross and Red Crescent Societies & German Red Cross, n.d.-a, n.d.-b).

FbF starts an Early Action Protocol (EAP) once a specific threshold is reached. This threshold is defined based on weather, climate and risk predictions. Once it is triggered, FbF releases humanitarian funding in order to take measures that can reduce the impact of a disastrous event and save human lives. With the release of this funding, the population can take action and protect themselves and their livelihoods (International Federation of Red Cross and Red Crescent Societies & German Red Cross, n.d.-a, n.d.-b).

Figure 3.2 depicts the schematic structure of Forecast-based Financing:

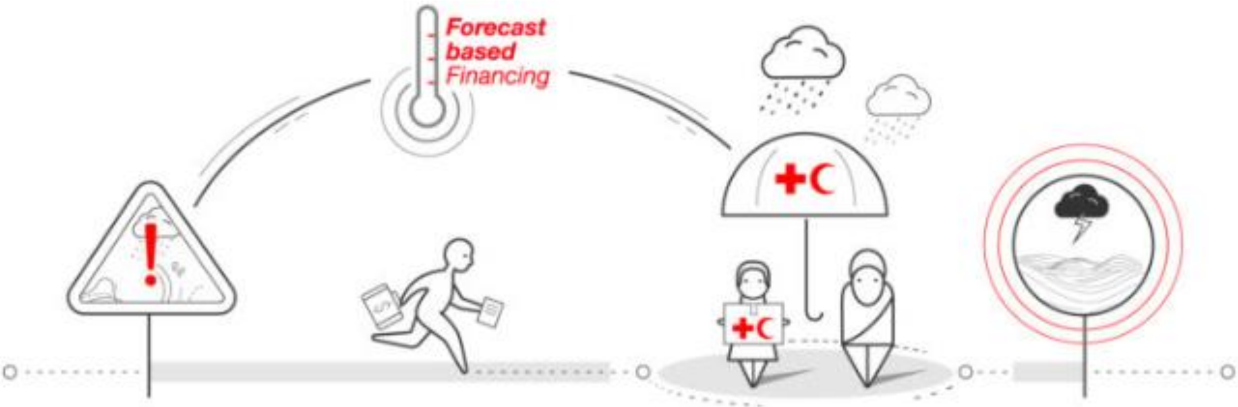


Figure 3.2. Schematic of the structure of Forecast-based Financing (International Federation of Red Cross and Red Crescent Societies & German Red Cross, n.d.-a)

Impact-based forecasting is a key element of FbF, because it allows to predict correctly the impact of a disaster and hence, distribute the funding in a meaningful manner. Impact-based forecasting is used by the Red Cross in order to:

1. Understand the risk: collecting geographic and demographic data, the Red Cross can develop risk models that can define an overview of the most vulnerable areas;
2. Identify the impact: by using machine learning and combining it with vulnerable data and historical events data, the trigger levels related to the potential impact are identified;
3. Forecast triggered action: when the forecast reaches the trigger, the early action can start (510.Global An Initiative of the Netherlands Red Cross, 2018).

3.2.3 Impact-based forecasting in the Philippines

Nowadays the Philippine government does not have any operating impact-based forecasting system that can predict the impacts of natural hazards. However, the Philippines Development Plan 2017-2022 highlights the need of the Philippines for a nationwide climate and disaster vulnerability risk assessment to deal with the impacts of natural hazards. Because of this remark on the Philippines Development Plan, the Climate Change Commission (CCC), which is a body of the Philippine government, has pointed out the need for impact-based forecasting and early warning systems (Climate Change Commission, 2018; Philippines National Economic and Development Authority, 2017).

Although no functional impact-based forecast has been implemented yet by the Philippine government, the Disaster Management Service (DMS) of the Philippines Red Cross (PRC) makes use of an impact-based forecasting system within their Forecast-based Financing methodology. This IBF model has been developed by 510 an initiative of the Netherlands Red Cross and uses machine learning to predict the percentage of affected houses due to typhoon wind damages per municipality. The IBF is trained with historical typhoon data and makes use of several hazard, exposure, vulnerability and coping capacity indicators and impact data on damaged houses (Teklesadik, n.d.). The DMS makes use of this forecasting system in order to set their threshold that, when reached, triggers an Early Action Protocol. Figure 3.3 depicts the *PRC* impact-based forecast of typhoon Mangkhut, which predicts the percentage of damaged houses in the Philippines.

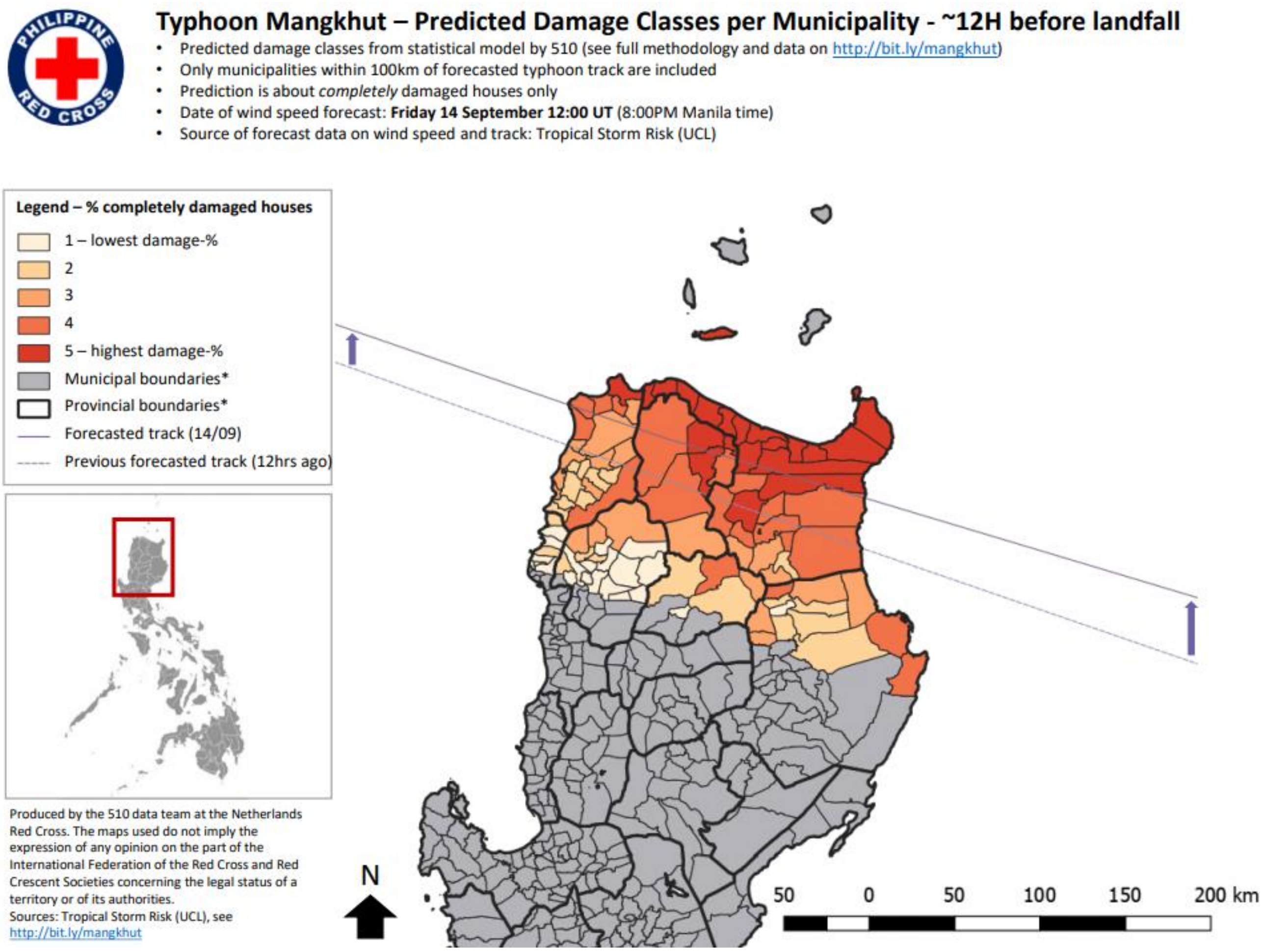


Figure 3.3. Example of the PRC impact-based forecast for typhoon Mangkhut (Teklesadik, n.d.)

Furthermore, the Philippines Red Cross (PRC*)* currently makes use of a dashboard that displays real-time flooding in the Philippines. This dashboard has been developed by FloodTags and partners such as Red Cross Climate Centre, Deltares, VU Amsterdam and Radboud University Nijmegen. The real-time flooding is reported with a technology created by FloodTags, that uses online data in order to detect water management and food security issues immediately. In the Philippines, FloodTags is operational and uses Twitter to detect floods. By combining the data with a digital elevation model, flood extent and impact indicators are provided, and can help the Philippines Red Cross to make more efficient decisions on logistics and resources management. Although this tool is not an impact-based forecasting system, it allows to track the most impacted areas in the Philippines and helps the PRC to prioritise and decide when actions should be taken. Therefore, this software acts as a trigger for response (FloodTags, n.d.).

3.2.4 Cyclone impact-based forecasting for Manila Bay

It has been previously mentioned that Deltares has developed several impact-based forecasts. All these forecasts follow a similar methodology. The flood hazard is calculated using high-resolution hydrodynamic models and applying boundary conditions from global models. Afterwards, the local impact on the population is measured through the overlay of population density with flood maps (Twigt et al., 2016).

One of those impact-based forecasts has been developed for the area of Manila Bay, in the Philippines, and it predicts the impacts of flooding caused by cyclones. Figure 3.4 shows a representation of the steps carried out in the Manila impact-based forecasting system of Deltares:

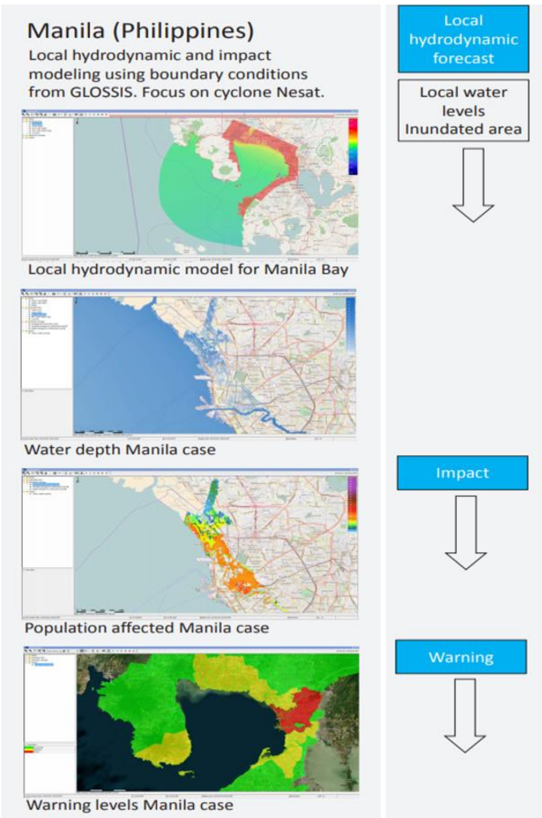


Figure 3.4. Schematic of the IBF of Manila Bay (Twigt et al., 2016)

The modelling process followed for this forecast starts with the input of the meteorological forecasts, and more specifically with the cyclone pathway obtained from the Joint Typhoon Warning Center. In order to predict an accurate flood extent, it is necessary to compute the storm surge that, on its turn, is dependent on the wind speed. Therefore, the Wind Enhance Scheme (WES) is used to obtain a wind speed grid that can be imported subsequently into a hydrodynamic model. With the hydrodynamic model is then possible to determine the water level. The combination of the water level with the bathymetry allows to predict the maximum water depth. Finally, the impact is calculated using the unit-loss method. This method merges hazard maps (in this case of the water depth), exposure data and damage functions to derive a damage map (Deltares, 2019; Schotten, 2017; Twigt et al., 2016). The schematic workflow and software of this impact-based forecasting system can be observed in Figure 3.5.

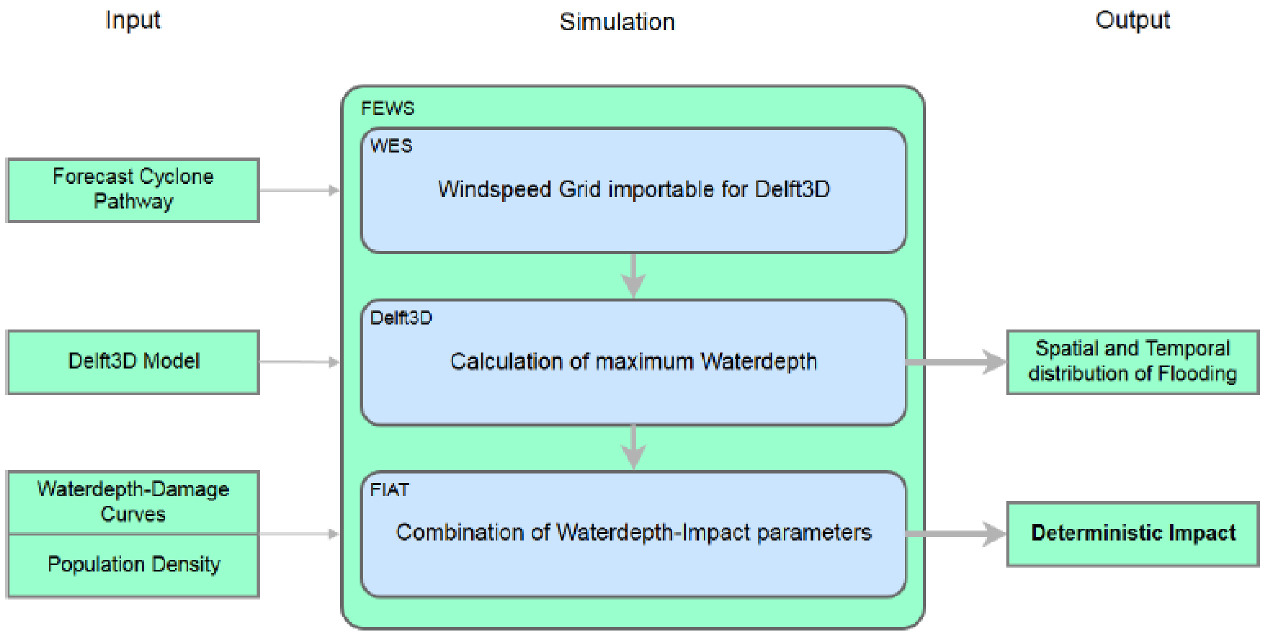


Figure 3.5. Schematic workflow of the IBF of Manila (Schotten, 2017)

In this thesis, this model has been modified and updated. Therefore, further information on the functioning of the forecasting system is provided in Chapters 8 and 9.

Notice that although the IBF system developed by 510 (see Section 3.2.3) predicts the impact of typhoons as well, there are significant differences among these two systems. Table 3.2 presents the comparison between these forecasts.

Table 3.2. Comparison between the impact-based forecasting systems of Deltares and 510.

Feature	**Deltares**	**510 an initiative of the NLRC**
Organisational level	Local level: Manila Bay	National level: Philippines
Modeling technique	Hydrodynamic modelling	Machine learning
Hazard	Storm surge	Wind speed
Definition	Detailed	Coarser
Cost	Expensive	Cheaper

3.3 Disaster management in natural hazard events

Emergency managers coordinate the required actions during natural disasters to mitigate the possible impacts. Usually their decisions are taken under time pressure and stress and hence, it is extremely important that easily readable forecasts are provided to disaster managers in order to facilitate their tasks. In this section, the important factors of decision-making during disaster events are presented.

3.3.1 Human – computer interaction in emergency management

Human – computer interaction (HCI) is a field of research that focuses on the study of how human users make use of computers to perform, simplify or support tasks. This interface between humans and computer must communicate in a meaningful manner the information, in order to deliver a successful interaction (Dix, Finlay, D. Abouwd, & Beale, 2004).

However, due to the peculiarities of emergency management, a unique human – computer interface approach is required in this field. In emergency management external factors such as natural disasters establish the information and actions required by decision makers. This means that the reaction time frame for disaster managers is short. Therefore, there is limited time to digest a large amount of information in order to plan the operations to be taken (Carver & Turoff, 2007).

For decision makers to be able to make the most out of the computer systems used during emergency management, human – computer interaction should be part of each step on the emergency management process (Carver & Turoff, 2007). The target user for the forecasting system developed in this thesis are disaster managers from humanitarian aid organisations, that work at local level. For this kind of user, the disaster management phase of most interest is the preparedness phase, in which the use of an impact-based forecasting prototype can help taking early actions that diminish the damages produced by typhoons.

Understanding the information gap with disaster managers

During natural disasters it is essential to gather and know as much information as needed regarding the hazard and its impact. However, sometimes too much unnecessary information can make the decisions of disaster managers as difficult as the lack of data (Carver & Turoff, 2007; Van Den Homberg, Monné, & Spruit, 2018). Therefore, when developing a forecasting system, it is fundamental to have a good understanding of the information emergency responders need and how it should be provided in order to be relevant and allow them take better and quicker decisions.

An example of the importance of providing relevant information to disaster managers could be seen during typhoon Haiyan in the Philippines. During this typhoon, disaster responders considered the information sources and formats as information overload. Therefore, responders did not get their information needs fulfilled, as the excess of information did not allow them to easily identify which data had priority (Comes et al., 2013). Furthermore, during disaster management it also occurs what is known as cognitive or motivational biases. Van Den Homberg, Monné, & Spruit (2018) provide an explanation of these biases: during a disaster event, local organisations might overreport information, to make sure enough resources are being delivered; on the other hand, national governments might underreport, to avoid having to provide more response and funding. All these biases play a role in the misinformation emergency responders receive.

Furthermore, Van Den Homberg, Monné, & Spruit (2018) mapped the information needs of disaster managers from humanitarian organisations, focussing on a case study of floods in Bangladesh. In order to map the information needs, the coverage of those needs was calculated. Their results showed different needs depending on the person that was interviewed. Factors like the organisation a person was working for or their level of expertise or education marked the difference.

A study carried out by Werner, Winsemius, & Robinson (2011) designed a framework to define the requirements for a flow forecasting system, in order to improve the management of water resources to help stakeholders, such as dam operators, electricity companies and disaster managers, take more informed decisions. This case study reached similar conclusions to Van Den Homberg, Monné, & Spruit (2018) regarding the different forecasting needs among stakeholders.

Therefore, it is important to notice that the forecasting prototype developed in this thesis should be aimed at a specific group of decision makers and could probably not fulfil the information needs for all the disaster managers in general. The IBF prototype designed for this thesis is hence, dedicated mainly to disaster managers at local level, whose interests might be different than those at national or regional level.

3.3.2 Cyclone forecasting and warning in the Philippines

Nowadays cyclone forecasting in the Philippines and in most parts of the world is only reliable three days in advance of the cyclone landfall, although this prediction might still contain uncertainties. Several forecasts can be obtained with a larger lead time. However, the accuracy of those predictions is considerably low. Therefore, this means that disaster managers only have three days to take anticipatory actions that reduce the impact of cyclones on the population and assets (OCHA, 2019).

It is hence, of large importance to have anticipatory actions that allow disaster managers and humanitarian organisations to prepare well and fast, in order to mitigate the effects of cyclones as much as possible. A good example of this preparedness in advanced is the Early Action Plan designed by the Red Cross and already mentioned in Section 3.2.2.

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) is the National Meteorological and Hydrological Services agency of the Philippines. This is the organism in charge of issuing the warning signals during tropical cyclones that will trigger the early actions to be taken (PAGASA, n.d.; World Bank, UNISDR, NHMS, & WMO, n.d.). Table 3.3 provides an overview of the tropical cyclone warning system of PAGASA, that classifies the severity of the cyclones depending on their wind speeds.

Table 3.3. PAGASA tropical cyclone warning system (PAGASA, n.d.)

Tropical Cyclone Warning Signal	Winds (kph)	Impacts of the wind
1	30 – 60	No damage to very light damage
2	61 – 120	Light to moderate damage
3	121 – 170	Moderate to heavy damage
4	171 – 220	Heavy to very heavy damage
5	More than 220	Very heavy to widespread damage

3.3.3 Disaster management structure in the Philippines

In order to be able to respond in an effective manner towards natural disasters, the Philippine Government has designed the National Disaster Response Plan (NDRP). The NDRP is a Multi-hazard Response Plan that aims at improving the efficiency of disaster management. The actions described in the NDRP are split into several phases and are also divided into actions that should be taken at national or at regional level. The disaster stages defined in the response plan are the following: Pre-disaster phase, during disaster phase and post disaster phase. Furthermore, cross-cutting activities are outlined as well. These are to be carried out by the Response Clusters in coordination with Cluster Member Agencies and are divided into the following categories: Early warnings, rapid damage and needs assessment, early recovery, post disaster needs assessment and mobilisation of resources (Office of Civil Defense, 2015; Republic of the Philippines, 2014).

This thesis focusses on the design of a forecasting system that allows disaster managers to take more informed decisions. Therefore, because the benefits of this forecast can be highly appreciated before the landfall of the cyclone, in this section the pre-disaster phase organisational structure of the Philippines is presented.

In the pre-disaster phase, the National Disaster Risk Reduction and Management Council (NDRRMC) chairperson is the person in charge of initiating the pre-disaster risk assessment (PDRA), in which the hazard and its possible impacts are studied in order to start taking actions that can reduce the personal and property damages. PAGASA will be the warning agency in charge of providing the NDRRMC with the landfall date as well as the cyclone track. The PDRA will be done three days before the cyclone touches ground, in order to have enough time to evacuate the areas that are at most risk. Two days before the landfall of the typhoon, the NDRRMC will start the activation of the Response Clusters, which are in charge of coordinating the allocation of resources and assets. In this stage, the Local and Regional National Disaster Risk Reduction and Management Councils (DRRMCs) must activate their Emergency Operation Centres and start the preparation for the typhoon. The Local DRRMCs report to the Regional DRRMCs, that in their turn report the ground situation to the NDRRMC (Office of Civil Defense, 2015; Republic of the Philippines, 2014; World Bank et al., n.d.).

Figure 3.6 depicts a schematisation of the flow of actions taken by the different organisms according to the NDRP:

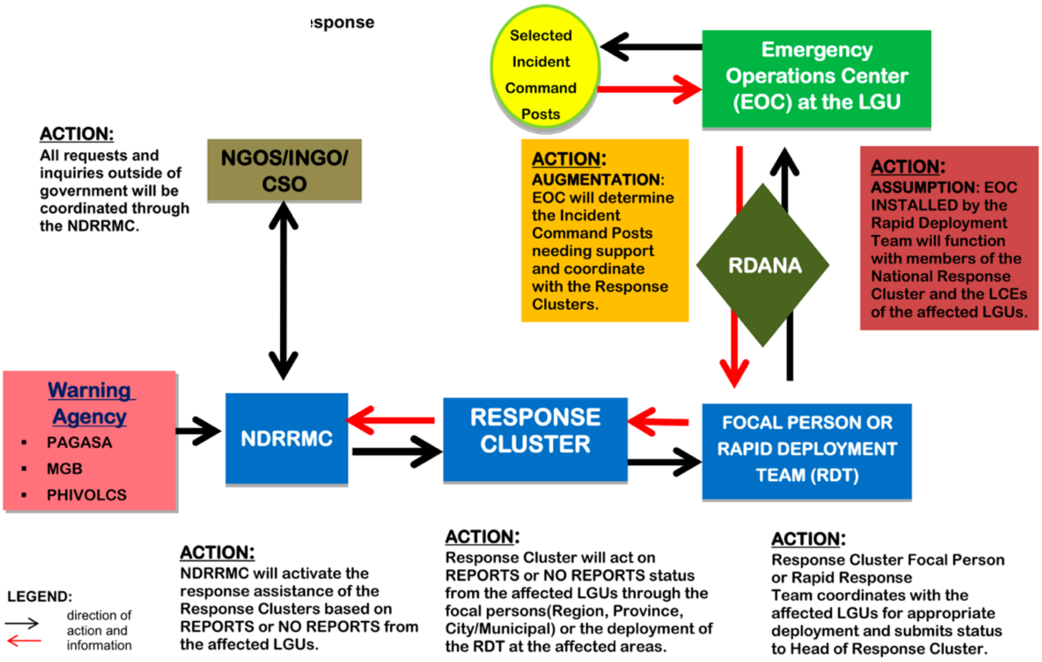


Figure 3.6. Diagram showing the workflow of the National Disaster Response Plan (Republic of the Philippines, 2014)

Furthermore, in the pre-disaster phase there are two cross-cutting activities as well, that have to be done in coordination of the Response Clusters and the Cluster Member Agencies. On the one hand, early warnings and alerts must be delivered in order to guide the operations and security of the Response Clusters. On the other hand, Rapid Damage Assessment and Needs Analysis (RDANA) must be carried out by the Local Government Units (LGUs), and their results will determine whether Humanitarian Assistance is required. If this is the case, all humanitarian agencies related to the affected LGUs will be allowed to provide their help (Office of Civil Defense, 2015; Republic of the Philippines, 2014).

4 Software usage

The impact-based forecasting prototype makes use of several software, that are of special importance to mention in this report in order to better understand the steps followed. Figure 3.5, presented in Section 3.2 showed a schematisation of the workflow of the impact-based forecasting prototype, in which the four main software packages used where depicted. The following sections present a description of what each of those packages does.

4.1 Delft-FEWS

Delft-FEWS is an open data handling platform that collects configurable modules designed for building real time forecasting systems and handling time series data. Delft-FEWS allows to import several datasets from external sources like web services, external databases and different file formats. Furthermore, due to its open interface nature, a wide range of numerical models and scripts, such as HEC-RAS, SOBEK, Delft-3D and HBV, can easily be integrated into the forecasting system. The modules mentioned in the following sections (WES, Delft3D and Delft-FIAT) are implemented into Delft-FEWS and run within that platform. Besides all the advantages of this flexible platform, Delft-FEWS provides a structured, concise and highly configurable set of displays, and it includes an interactive map display with geographic navigation which can include icons and warning levels. Moreover, data can be displayed in bars, points, lines, longitudinal profiles, grids and polygons, which makes it well understandable for its end users (Deltares, n.d.-c, n.d.-b).

Within Delft-FEWS, there are mainly three parts of the platform that have been used in this research and therefore, need to be understood:

- The General Adapter is the part of Delft-FEWS that allows to run external modules, such as numerical models and scripts;
- The Transformation Module is a module that allows the manipulation of time series data within Delft-FEWS;
- The Spatial Display is the part of Delft-FEWS that allows to display time series data (Deltares, 2018).

4.2 WES

Wind Enhance Scheme (WES) is a two-dimensional model for hurricane calculations. The model generates surface winds and pressure in concentric circles around the tropical cyclone centre, given certain cyclone specific parameters such as maximum wind speed, pressure drop, radius of maximum wind and position of the cyclone (Deltares, 2019).

4.3 Delft3D

Delft3D is a multi-dimensional (2D or 3D) modelling suite that allows to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments. The FLOW module is the core of Delft3D and calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary fitter grid or spherical coordinates (Deltares, n.d.-d).

4.4 Delft-FIAT

Delft-FIAT (Flood Impact Assessment Tool) is a toolset that allows building and running impact models based on the unit-loss method. This method consists of using a hazard map (i.e. water depth map), exposure data (i.e. objects in a map and maximum damages of the objects), and a relationship between the objects and the flood impact (damage functions, relating for example water depth and impact). All those inputs can be designed by the user with tools such as ArcGIS, QGIS, Python or Matlab (Deltares, 2016). Figure 4.1 depicts the Delft-FIAT schematic workflow.

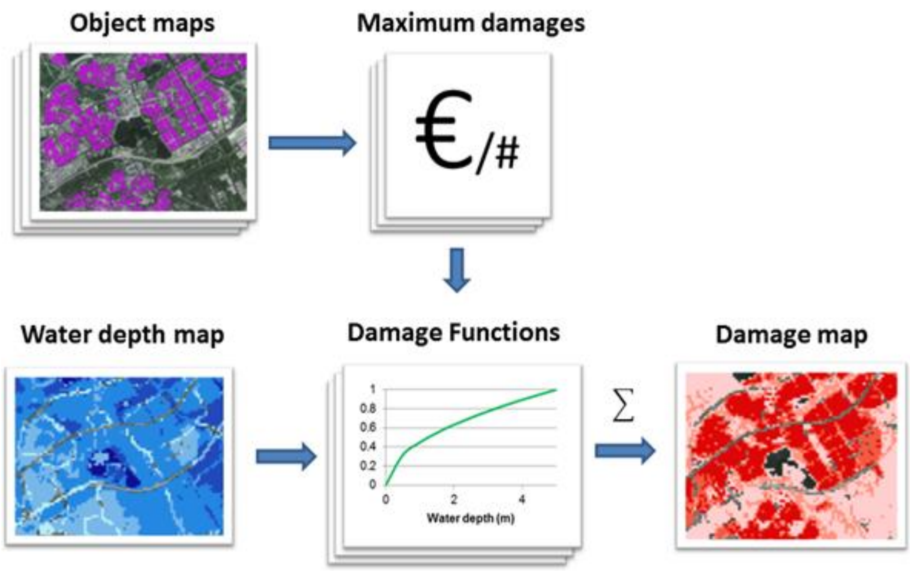


Figure 4.1. Delft-FIAT schematic workflow (Deltares, 2016)

Notice that for the purpose of this thesis, work has been performed especially using Delft-FEWS and Delft-FIAT.

5 Research approach

The research on this thesis focusses on the design of a forecasting prototype, considering the information needs of disaster managers. In order to understand the behaviour and needs of disaster managers, this thesis makes use of social science methodologies that allow, on the one hand, to have a logical thesis structure, and on the other hand, to better gather and understand the information needs of emergency responders. In the first section of this chapter, an introduction to social science methods used in this research are introduced. In the second section of this chapter, the specific research approach of this thesis is presented.

5.1 Social science research

Science is defined as the systematic body of knowledge that is acquired using the 'scientific method'. Within science, there are two main disciplines: Natural science and social science. The first term is the branch of science concerned about natural occurring phenomena, whereas the second term focusses on understanding the individual or collective behaviours of people. While natural sciences are very precise, accurate and not related to the person making the scientific observations, social sciences tend to be less deterministic. The reason for this larger imprecision is because there are no instruments capable of measuring people's behaviours. Furthermore, even if instruments existed, the outcome of the behaviour of a person, for instance, might differ from day to day or time to time, under the same conditions (Bhattacherjee, 2012).

Within social sciences exist two main research strategies: quantitative and qualitative research. On the one hand, in quantitative research the data collected is fundamentally numerical and statistically driven, using numeric scores and metrics that allow to find relationships between theory and research, in an objective manner. On the other hand, qualitative research aims at understanding a phenomenon using non-numeric data like interviews and observations. Quantitative research is objective and does not strongly depend on the perception of the researcher, whereas qualitative research is dependent on the researcher's interpretation and knowledge of the social context where the data is gathered (Bhattacherjee, 2012; Bryman, 2012).

Because the aim of this thesis is to better understand the information needs of disaster managers, rather than intending to find a specific relationship and numerical result out of it, in this research a qualitative strategy has been used.

5.1.1 Qualitative research methodologies

Within qualitative research, multitude of methodologies exist. In this section, the methodologies used for this thesis are explained.

Case study method

A case study method is used when detail research is focused on a single case. Although a series of case studies might be done in the same research project, their aim is not the comparison to one with another (Bhattacherjee, 2012; University of Huddersfield, 2011).

Action research

This methodology consists of the performance of actions and the observation of their consequences, in order to find the solution to a problem. Therefore, the researcher carries out an action and studies its effects. This allows to gain knowledge and understanding of the effects of the action, which help to plan the next steps or action to be taken. This methodology permits the researcher to refine the actions to be taken (Bhattacherjee, 2012; Bryman, 2012; University of Huddersfield, 2011).

Comparative analysis

This methodology analyses the similarities and differences of data gathered from different settings or groups over a period or point in time, by using tables, matrices or a similar resource (University of Huddersfield, 2011).

Template analysis

This research approach is used to organise the gathered data in a meaningful manner. First, observing a small selection of the gathered data, the most prominent themes are identified. These themes are then organised in a relevant way creating a template. Afterwards, the template is used to analyse the entire data set. When newer important themes rise, or others get less important, the template is updated. This process is an evolving process that finished with the definitive template once all the data set has been studied (University of Huddersfield, 2011).

5.1.2 Qualitative interviewing

Within qualitative research, one of the most widely used methods for data gathering is qualitative interviewing. Although quantitative research also makes use of interviewing as a data gathering method, its aim is to fulfil the researcher's interests, whereas in qualitative research the objective of the interview is to obtain information on the interviewee's opinion. Therefore, qualitative interviewing is usually less straight forward and more flexible on the questions, that can vary according to the context and the interviewee's replies. Within qualitative interviewing, one of the main types of interviews are semi-structured interviews, which are used in order to let unforeseen but relevant topics rise from the interviewees. In semi-structured interviews, the interviewers have a list of questions of topics to cover. However, the questions have usually a general character and are adapted to the interviewee's responses (Bhattacherjee, 2012).

5.2 Thesis methodology

In order to design a forecasting prototype that fulfils the information and delivery needs of disaster managers, a specific location has been chosen as a case study. The Philippines has been selected as the study country because of its location in the typhoon belt of the Pacific, which makes it extremely prone to several natural disasters, among which cyclones are the most catastrophic. Furthermore, because of the heterogeneity of the Philippines, with geographical characteristics that vary within few kilometres, a specific forecasting area has been considered more meaningful, rather than predicting the effects of cyclones nationwide. Therefore, within the Philippines, Manila Bay has been selected as the study area due to its dense population and its coastal location, which makes it storm surge prone.

The general methodology in this report follows an action research approach. This thesis aims to create a forecasting prototype considering the input of disaster managers in an iterative process, in order to consider their information and delivery needs. Therefore, the "action" performed in this thesis is the design of the forecasting system, which is modified when disaster managers provide their inputs. This allows the "action" to improve towards a more refined forecasting system that better fulfils their information and delivery needs.

In the following section, a more detailed explanation about the thesis research approach is provided.

5.2.1 Research structure

To implement the action research methodology mentioned above, the structure of this thesis has been divided into four different steps: Input, model, output and feedback. These parts do not follow a strict order. Instead, an iterative process is performed in which the feedback of disaster managers can lead to a modification of the model and hence, a change on the output. A scheme of the research approach followed in this thesis can be observed in Figure 5.1.

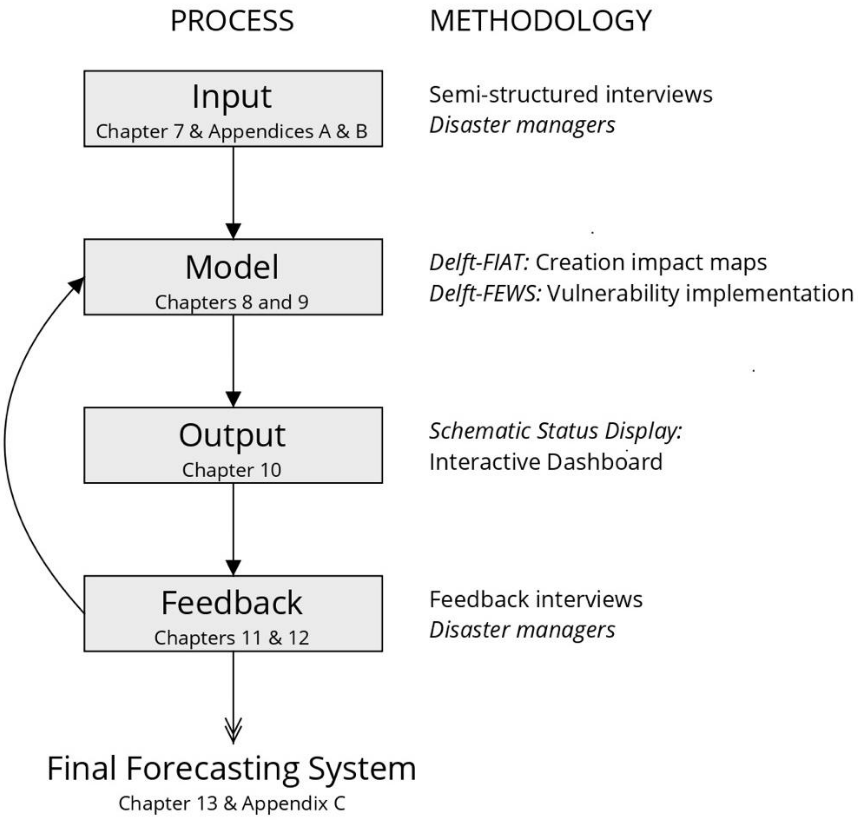


Figure 5.1. Diagram of the research approach followed in this thesis

Input: qualitative data gathering

It is of especial importance to start designing the model once the input from emergency responders is obtained, because they are the potential users of the forecasting prototype. To develop more functional and relevant forecasts for disaster managers, it is essential to understand their information needs (van den Homberg, Visser, & van der Veen, 2017). Therefore, the first part of this thesis consists of performing semi-structured interviews, in order to define what the forecasting prototype should contain and how it should look from the point of view of disaster managers. The questions in these interviews have an open-ended character, that allows the interviewees to provide their own ideas and rise interesting topics unforeseen by the interviewer. At the same time, new questions that rise along the conversation are asked.

To process the interviews, a comparative analysis is carried out first, in order to find the similarities among the participants regarding the information and display needs of disaster managers. With these similarities a template analysis is then performed. In this analysis, the data is clustered and organised in a useful and meaningful manner. The theme coding of this research is structured in a hierarchical way, in which broader themes encompass successively more specific ones. This template is updated after new interview inputs and the themes are modified.

More information about the procedure followed during the interviews and the inputs of disaster managers can be found in Chapter 7 and Appendix A.

Model: Development of the impact-based forecasting system according to disaster managers

Once the interviews have been carried out and the information obtained has been processed, the model is designed according to the decision makers' needs. Within the forecasting system, the platforms Delft-FEWS and Delft-FIAT are used to forecast the weather and predict the impact on the assets of interest for disaster managers. Furthermore, vulnerability data is incorporated as well to the system, in order to create a fair impact-based forecasting prototype.

A detailed explanation about the system development can be read in Chapters 8 and 9.

Output: dashboard that connects the forecasting system

The third step of this thesis regards the output of the model and how this output is presented in order to be easily accessible and relevant to disaster managers. To organise the prototype, a dashboard is created to provide cohesion among the information delivered, and to display the forecast in a visual and understandable manner. Chapter 10 presents the dashboard created for this impact-based forecasting system.

Feedback: qualitative data gathering

Finally, once the model has been designed, disaster managers are interviewed about the forecasting system, in order to obtain feedback. Afterwards, the model can be updated and improved with the new inputs of the disaster managers. Chapters 11 and 12 provide the feedbacks of disaster managers.

Final forecasting system

The final forecasting system after all these steps and iterations have been done is presented in Chapter 13. Furthermore, Appendix C provides the hazard and impact maps created in the prototype. This final forecasting system is a representation of how the information needs of crisis managers can be integrated into fair impact-based forecasting in order to improve forecast-based emergency management.

6 Initial IBF model

It is important to clearly define the starting point of the model that has been used in this thesis, in order to better appreciate the work done by the author. Therefore, in this section an explanation of how the model was before this thesis is presented.

The structure of the existing model could be divided into three categories: hazard, impact and risk. For each of those categories, the components that were already on the system before this thesis are presented in the following sections.

Notice that this model has been designed without talking with disaster managers in order to understand what their information and delivery needs are.

6.1 Hazard

The following hazard features are part of the starting point of the IBF model:

Storm track: The storm tracks are imported to the Delft-FEWS system from the JTWC Best Track Archive. The track provides information on the location and wind speed of the storm at a specific time.

Wind grids: The wind grids of the storm are calculated using the WES model mentioned in Chapter 4. In this model, the surface winds and pressures are generated in concentric cycles around the tropical cyclone centre. Within Delft-FEWS it is possible to observe the evolution of the wind grids along the path of the cyclone.

Water level: The water level is calculated with the hydrodynamic model of Delft3D. With Delft-FEWS the water level in the Manila Bay can be observed throughout time.

Water depth: In Delft3D, the water level and the bathymetry data are combined in order to obtain the water depth. With Delft-FEWS the water depth in the Manila Bay can be observed throughout time. Furthermore, the maximum water depth is calculated as well.

Figure 6.1 depicts an example of what the impact-based forecasting system could do before this thesis, related to the hazard of cyclones. On the left image, the cyclone track over Luzon is depicted. In the middle image, the wind grid is shows, whereas in the right image the maximum water depth map can be observed.

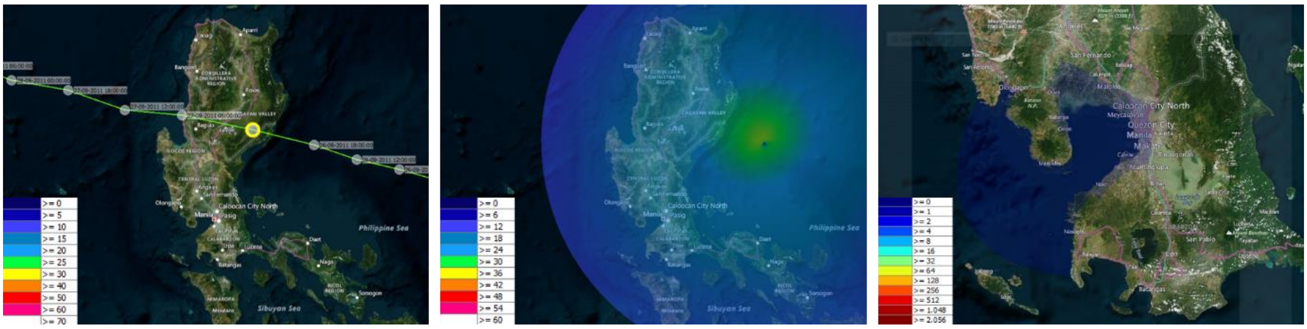


Figure 6.1. Screens of the IBF model. Left: cyclone track; Middle: wind grids; Right: maximum water depth

6.2 Impact

The impact measured in the old system of the IBF has been calculated using Delft-FIAT. However, the impact was calculated only considering hazard and exposure, and omitting vulnerability. Therefore, the water depth (output from Delft-FEWS) and the exposure data (maps of population density and of mobile and immobile assets) were combined in Delft-FIAT, together with predefined damage curve functions and maximum damages.

The impact on the population and on mobile and immobile damages for artificial land use was calculated and represented as a grid and as a colour coded warning map. Figure 6.2 depicts the grid of the impacts on the population and assets.

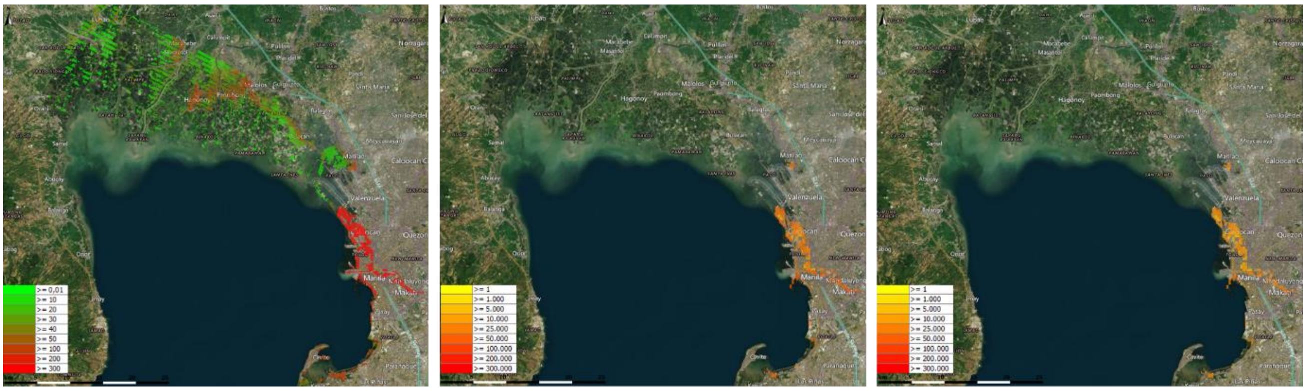


Figure 6.2. Impacts grids on the old configuration of the IBF. Left: affected population grid; Middle: mobile damage grid; Right: immobile damage grid.

6.3 Risk

The sections mentioned above define the existing deterministic hazard and impact of the model. However, before starting this thesis also the probability was implemented in the model, in order to calculate not only the impact but also the risk of a cyclone in Manila Bay.

Because of the uncertainty related to cyclones, several possible pathways were created for a storm cell with an associated probability. This set of meteorological events is called ensemble. For each ensemble, there is a different probability of occurrence, that increases when the track is nearer the deterministic track (Schotten, 2017).

For each ensemble generated, the wind speeds, the maximum water depth and subsequently the impact are calculated. Once the impact for each ensemble is produced, the risk is generated by multiplying the impact of each ensemble by their associated probability. Furthermore, a colour coded categorisation of the risk was done, considering the sum of the risk of the cyclone (Schotten, 2017).

Figure 6.3 depicts the ensemble of storm tracks of the old impact-based forecasting configuration. These ensembles are used in the model to calculate the risk on the population and on mobile and immobile damages.

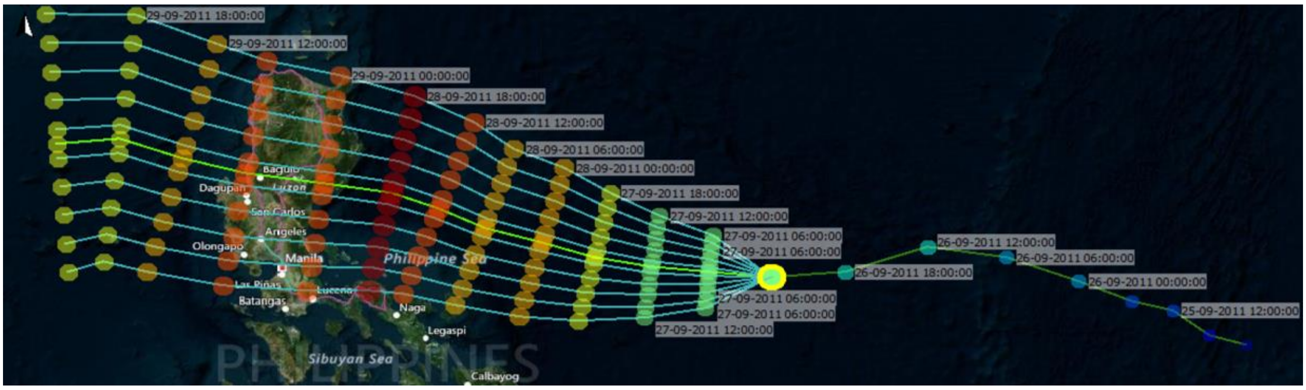


Figure 6.3. Full ensemble of the storm track of the old IBF configuration (Schotten, 2017)

7 Input: Semi-structured interviews to disaster managers

Disaster managers are usually users of forecasts, which help them take decisions on where and when to act in order to prevent and/or reduce the damage caused by catastrophes. However, forecasting models are often designed by scientists without considering the needs of disaster managers. Therefore, in this thesis, before starting developing any predictive model, disaster managers have been contacted with the intention to understand what information is required in the field, and how that information should be provided in order to be useful.

7.1 Methodology: Interviews to disaster managers

Because of the importance of delivering disaster managers a forecasting prototype that fits their needs, semi-structured interviews have been the first active step in this thesis. In order to avoid influencing unnecessarily the disaster managers, it was decided not to provide an example of the prototype to the interviewees. Instead, they would start from a blank state. Only in the invitation for the interview a small representation of impact-based forecasting was delivered, with the purpose of making more understandable to decision makers what the topic of the interview would be about.

7.1.1 Setup of the semi-structured interviews

The interviews carried out in the first phase of this thesis were done to disaster managers that worked in different parts the world. The reason to perform interviews with interviewees from many parts of the world that suffer from weather events and not only from the Philippines, was because for this first stage, it was more important to get general knowledge about information and delivery needs, rather than getting specific information localised in the Philippines.

Table 7.1 provides an overview of the stakeholders that were contacted for the semi-structured interviews. That table shows which organisation the participants worked for, as well as their position, through which source they were contacted and whether they responded and were available for the interview or not.

Table 7.1. Stakeholders approached for the interviews

#	Organisation	Position	Connection	Responded	Available
1	510.Global	FbF project lead	510 office	Yes	Yes
2	The Netherlands Red Cross	Disaster manager	510 office	Yes	Yes
3	Red Cross Red Crescent Climate Centre	Climate science adviser	510 office	Yes	Yes
4	Croix-Rouge Française. Plate-forme d'Intervention Régionale Océan Indien	Deputy Head of the Delegation	Stakeholder #10	Yes	Yes
5	German Red Cross	Project manager	510 office	Yes	Yes
6	Zambia Red Cross Society	Disaster manager	510 office	Yes	Yes
7	Philippines Red Cross	Disaster Preparedness and Risk Reduction Unit head	510 office	Yes	Yes
8	Red Cross Red Crescent Climate Centre	Technical advisor	Stakeholder #11	Yes	Yes
9	510.Global	Country representative in Uganda	510 office	Yes	No
10	510.Global	Country representative in Kenya	510 office	Yes	No
11	Red Cross Red Crescent Climate Centre	Technical advisor	510 office	Yes	No

To find participants for the interviews, first the social network of 510 an initiative of the Netherlands Red Cross was contacted. Subsequently, other participants were reached through snowball technique, as potential participants provided the connection to future candidates.

Most of the interviews were carried out through Skype due to the location difference between the interviewer and the interviewees. When internet connection was not good enough or when it was more convenient for the interviewees, the answers of the interviews were written and sent to the author of this thesis. Notice that in the interviews performed through Skype, the interviewees were asked for their consent to digitally record the interviews. The recordings allowed for further work after the interviews were finished. A summary of the interviews is provided in Appendix A[1].

Table 7.2 depicts an overview of the details of the interviewed stakeholders, including their organisation, position within the organisation, the location of their works, the natural disasters they face and the interview mode and language.

[1] For further detail on the contents of the interviews, their recordings can be provided upon request.

Table 7.2. Details of the interviews

#	Organisation	Position	Location	Natural disaster	Interview mode	Interview language
1	510.Global	FbF project lead	Netherlands Malawi Kenia Ethiopia Uganda	Floods Droughts	Skype	English
2	The Netherlands Red Cross	Disaster manager	East Africa Region	Floods Droughts Epidemic diseases	Skype	English
3	Red Cross Red Crescent Climate Centre	Climate science adviser	Philippines Ecuador Peru	Cyclones	Written	English
4	Croix-Rouge Française. Plate-forme d'Intervention Régionale Océan Indien	Deputy Head of the Delegation	South-Western Indian Ocean islands	Cyclones Floods Volcanic eruptions	Skype	English
5	German Red Cross	Project manager	Philippines	Cyclones Floods Droughts	Skype	English
6	Zambia Red Cross Society	Disaster manager	Zambia	Floods Droughts	Skype Written	English
7	Philippines Red Cross	Disaster Preparedness and Risk Reduction Unit head	Philippines	Cyclones Flash floods Land slides	Skype	English
8	Red Cross Red Crescent Climate Centre	Technical advisor	Philippines Bangladesh Nepal	Cyclones Floods Droughts Landslides River erosion Earthquakes Epidemic diseases Malaria	Skype	English

7.1.2 Invitation to the interview

The participants of the semi-structured interviews were contacted through email. Figure 7.1 provides an overview of the general letter sent to the interview candidates. Besides the invitation email, a document explaining briefly the project was also attached in the email. That document with the project description can be seen in Figure 7.2.

Dear *Name of the stakeholder*,

My name is Irene Benito. I am writing you because I would like to interview you regarding your knowledge on humanitarian aid and emergency decision making. I am a master student in The Netherlands, and I am doing a thesis in Deltares in cooperation with the 510 initiative of The Netherlands Red Cross. In the 510 initiative of The Netherlands Red Cross Aklilu Teklesadik is my supervisor and he has facilitated me your contact.

My thesis will focus on providing humanitarian organisations with a cyclone impact-based forecast that fulfils their information needs and delivers them actionable information in a relevant manner. The desired forecast should provide information to improve the actions following a forecast. The information to be prepared for a decision maker contains several layers and dimensions. Cyclone impacts, hazard calculations, vulnerability of exposed people as well as probabilities for impact are only a few mentioned.

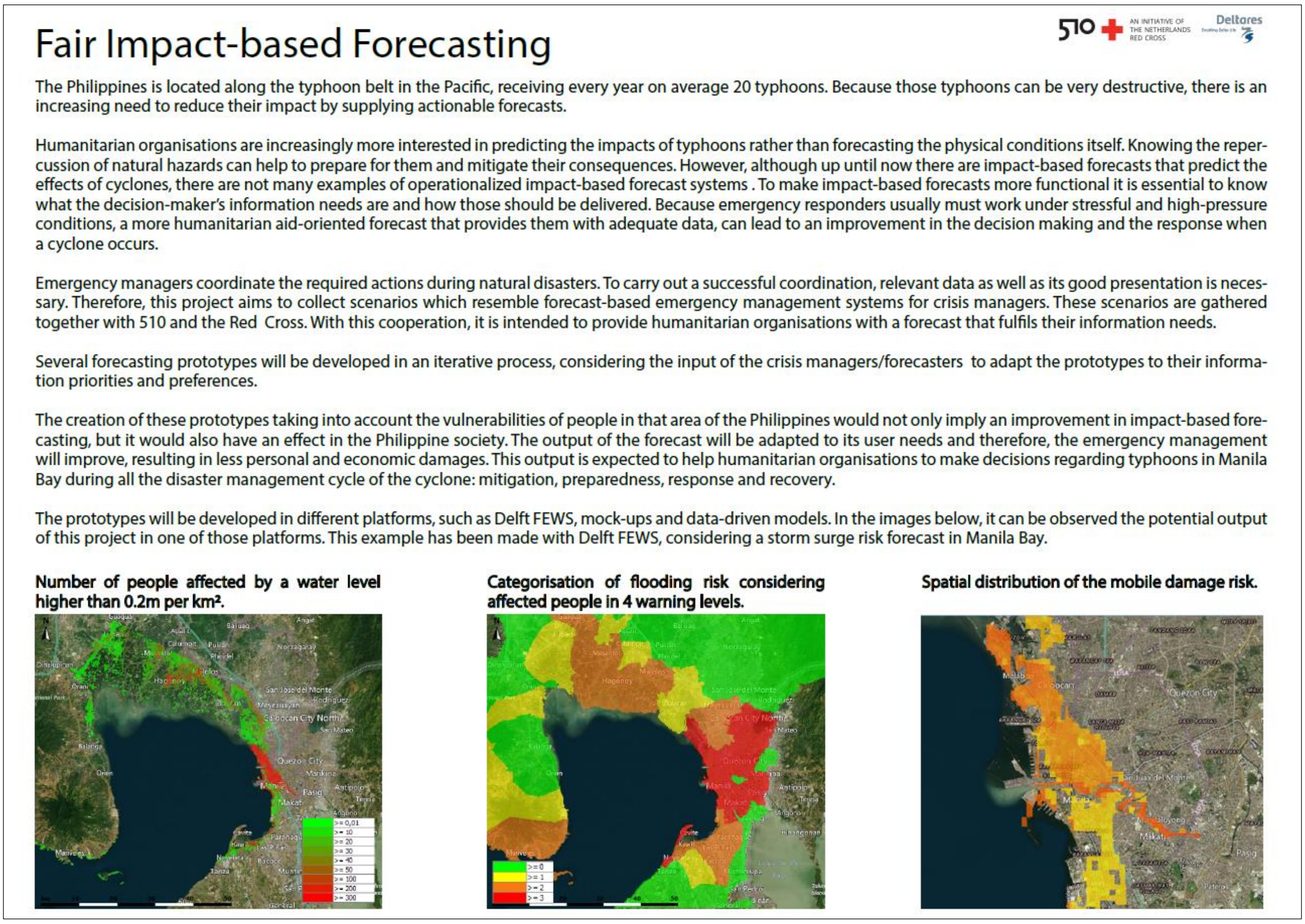
However, before starting designing the forecasting system it would be necessary to have input on the information that is most needed by crisis managers when facing a meteorological hazard. It would also be important to obtain information about how the results of that impact forecast should be presented so that they are more useful and understandable for the emergency decision makers.

Please find attached in this email a better explanation of the project itself and how the output of the forecast would look like.

Your input regarding this topic would be useful for the development of this forecasting system and much appreciated.

Questions that we might discuss together are for example:

Figure 7.1. Invitation email sent to the interview candidates



Fair Impact-based Forecasting

510 AN INITIATIVE OF THE NETHERLANDS RED CROSS Deltares

The Philippines is located along the typhoon belt in the Pacific, receiving every year on average 20 typhoons. Because those typhoons can be very destructive, there is an increasing need to reduce their impact by supplying actionable forecasts.

Humanitarian organisations are increasingly more interested in predicting the impacts of typhoons rather than forecasting the physical conditions itself. Knowing the repercussion of natural hazards can help to prepare for them and mitigate their consequences. However, although up until now there are impact-based forecasts that predict the effects of cyclones, there are not many examples of operationalized impact-based forecast systems . To make impact-based forecasts more functional it is essential to know what the decision-maker's information needs are and how those should be delivered. Because emergency responders usually must work under stressful and high-pressure conditions, a more humanitarian aid-oriented forecast that provides them with adequate data, can lead to an improvement in the decision making and the response when a cyclone occurs.

Emergency managers coordinate the required actions during natural disasters. To carry out a successful coordination, relevant data as well as its good presentation is necessary. Therefore, this project aims to collect scenarios which resemble forecast-based emergency management systems for crisis managers. These scenarios are gathered together with 510 and the Red Cross. With this cooperation, it is intended to provide humanitarian organisations with a forecast that fulfils their information needs.

Several forecasting prototypes will be developed in an iterative process, considering the input of the crisis managers/forecasters to adapt the prototypes to their information priorities and preferences.

The creation of these prototypes taking into account the vulnerabilities of people in that area of the Philippines would not only imply an improvement in impact-based forecasting, but it would also have an effect in the Philippine society. The output of the forecast will be adapted to its user needs and therefore, the emergency management will improve, resulting in less personal and economic damages. This output is expected to help humanitarian organisations to make decisions regarding typhoons in Manila Bay during all the disaster management cycle of the cyclone: mitigation, preparedness, response and recovery.

The prototypes will be developed in different platforms, such as Delft FEWS, mock-ups and data-driven models. In the images below, it can be observed the potential output of this project in one of those platforms. This example has been made with Delft FEWS, considering a storm surge risk forecast in Manila Bay.

Number of people affected by a water level higher than 0.2m per km².

Categorisation of flooding risk considering affected people in 4 warning levels.

Spatial distribution of the mobile damage risk.

Figure 7.2. Project description document attached in the invitation email

7.1.3 Interview structure

Because of the character of the topic and the stakeholders, it was decided to carry out semi-structured interviews. Structured interviews with specific questions that do not allow for diversion were not possible in this topic, as most disaster managers have lived extraordinary experiences that bring emotions into the conversations, which makes it difficult to get concrete answers for a determined question. Furthermore, it was considered that semi-structured interviews of open character would allow to squeeze better the large knowledge of the participants in disaster management, which would even help to sometimes gather relevant information on unforeseen topics by the interviewer (Bryman, 2012).

During the semi-structured interviews, a set of open-ended questions were asked to the participants. Based on the response of the interviewees, follow-up questions, were asked. The follow-up questions were only asked when the open-ended questions did not provide the required answer for the research. Those follow-up questions were more specific, allowing to obtain a more precise answer on the topic. All the questions (open-ended and follow-up), were tailored to the specific participant and conversation, sometimes changing the order of the questions, modifying or skipping some of them when necessary.

Table 7.3 provides an overview of the questions asked to the participants during the semi-structured interviews. In the table it can be observed that the questions are divided into five categories. Notice that the questions under *general information* are not as general as the questions in the other topics, due to the specific character of the topic.

Table 7.3. Table of questions asked to the participants of the semi-structured interviews

#	Open-ended questions	Follow up questions
General information		
1	What team do you work in?	
2	How many years of experience do you have? In what function?	
3	Where have you worked?	Location and scale of the decision making?
4	What devices do you use?	Is it for work or for personal use?
5	Which programs do you usually use?	Which programs are for works and which ones are for your personal use?
Forecast information		
6	What was the last disaster that you experienced?	What kind of natural hazards do you face in your area as a disaster manager? What would you have changed from previous forecasting systems used?
Display information		
7	If you could design a computer program/app that could have helped you, what would that look like?	How do you relate impact and hazard information and how could that look in a forecast system? What is your preferred way of displaying hazard information (grids, icons, graphs…)?
Information needs		
8	What information would it contain?	What kind of information triggers your actions? Do you consider probabilities of hazard or impact? Which kind of vulnerability prioritises your actions?
Closing		
9	Do you have any suggestion for this research/next interviews?	

At the end of the interviews, the participants were asked whether they would like to be updated on the progress of the project and whether they would be eager to provide more help with future interviews.

7.1.4 Processing the interviews

After carrying out the semi-structured interviews, the data obtained has been processed by listening to the recordings again and observing the summaries of the interviews. In order to make the outputs of the interviews more understandable, first the main information has been clustered. Afterwards, using the clustered data, mock-ups have been developed in order to better comprehend how the information needs of disaster managers should be represented in the IBF prototype, and hence, get a clearer idea of how the model should look like.

From the recordings and summaries of the meetings with disaster managers, the output of the interviews was analysed following two approaches. First, a comparative analysis was made, in which a comparison of the data obtained from the interviews was done. From this comparison, it was aimed to find the similarities among the interviewees' answers. Secondly, once those similarities were known, a template analysis approach was followed, in which the data that shows similarities among the interviewees was clustered and organised in a useful and meaningful manner. The theme coding was organised in a hierarchical approach, in which broader themes encompass successively more specific ones. The template was updated after new interview inputs, and the themes were modified according to them.

7.2 Results: Disaster managers' information needs

With the transcripts of the interviews, a word cloud has been developed with a generator, in which the key words during the interviews are depicted. The larger the words, the more often they were mentioned by the interviewees.

Figure 7.3. Word cloud of the semi-structured interviews to disaster managers

Figure 7.3 shows the word cloud designed, in which it can be observed that the key topics of the semi-structured interviews were, among others, impact, forecast, vulnerability, affected people, hazard, early and time. This gives an idea of the outcomes of the interviews. In this section, the results of the semi-structured interviews to disaster managers have been processed, clustered, and finally mock-ups have been designed in order to better comprehend the information needs of disaster managers.

7.2.1 Clustered data obtained from the interviews

The main themes on the semi-structured interviews can be divided into three categories: crucial information needs, information that triggers actions and delivery of information needs. Below, characteristics of each of those three themes are explained.

Crucial information needs: The crucial information needs can be grouped in four categories. From those four categories, two are related to static information: coping capacity and social structure; and two are related to forecasting: hazard and impact.

Disaster managers require information on the coping capacities of the area. Coping capacities such as an adequate warning system and shelter or local stock availability can reduce the vulnerability of the population and hence, reduce their impact. Furthermore, they also require understanding on the social structure of an area. It is important to know if there will be enough social cohesion between the population to help each other during an emergency event.

The information needs associated to the hazard of decision makers are related to their location, timing, lead time, intensity, duration and probability. On the other hand, information needs of the impact focus mainly in four categories: impact on the population, the infrastructures, the households and the livelihoods. However, the importance of these impacts differs at national, regional and local level. Whereas at national level it is more necessary to have gross information of the impacts, such as the affected population per district, at regional level the impact on the critical infrastructures and livelihoods is more relevant.

Information that triggers actions: Usually actions in disaster management are triggered by a threshold or a probability being exceeded. The threshold points usually depend on the hazard or on the impact level. An example of a threshold depending on the hazard could be the exceedance of a certain water depth, whereas an example of a threshold depending on the impact could be the percentage of housing being destroyed in a municipality. Regarding probabilities, usually action is taken when a certain probability of the event occurring is exceeded. However, from the interviews it was derived that although probabilities are sometimes being used, they are not used adequately. Decision makers are often reluctant to take actions for probabilities that are less than 100%. However, when the probability of occurrence of a disaster is 100%, the disaster is already happening and hence, there is no time anymore for preventive measures.

Deliver information needs: Disaster managers agree that the information should be delivered in a visual manner, such as maps or graphs. However, there is a distinction between the end users of the forecast. This distinction is made between the end user's role and decision-making level. Whereas for branches of the Red Cross and local and national levels a simpler model would be required, at regional level and when the end users are disaster managers with technical background, a more complex model would be preferred.

Figure 7.4 depicts the clustered information obtained from the semi-structured interviews. Notice that in the schematic representation, vulnerability is not a category because it is included in the impact.

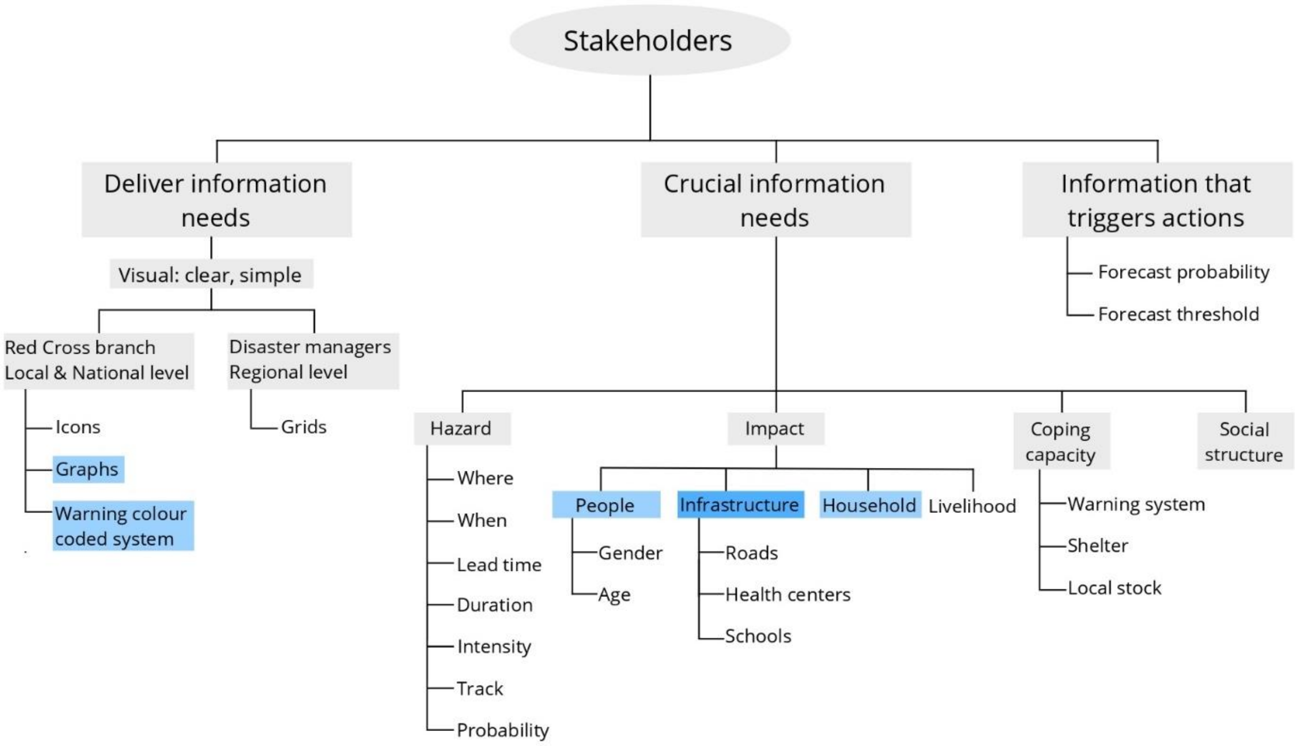


Figure 7.4. Schematic representation of the answers from the semi-structured interviews with disaster managers. The topics in blue have been considered of more importance, as they have been mentioned in most of the interviews. The darker the blue, the more relevance it had for the candidates.

7.2.2 Mock-ups derived from the interviews

Based on the clustered information obtained from the semi-structured interviews, mock-ups have been derived in order to get a clearer understanding of the actual needs of disaster managers, before the actual forecasting prototype is developed.

The mock-ups have been structured in four sections, according to the crucial information needs of disaster managers: hazard, impact, coping capacity and social structure.

Hazard: The hazard mock-up developed provides information on the landfall date and time, the duration and the category of the cyclone, according to the Saffir-Simpson scale. Within the hazard category, the track, the wind grid and the water depth grid are displayed, and their evolution throughout time can be observed. Figure 7.5 provides an overview of the mock-ups developed for the hazard section.

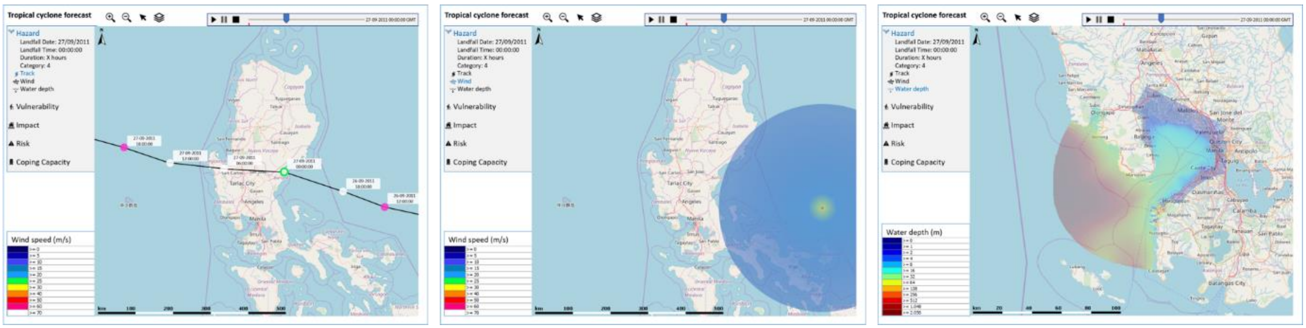


Figure 7.5. Hazard mock-up. Left: track of the cyclone; Middle: wind grids; Right: water depth grid

Impact: In order to represent the impact of cyclones, four subcategories have been derived from the clustered interviews: people, infrastructures, households and livelihoods. However, livelihoods have not been represented in the mock-ups and will not be included in the prototype because of their complexity. Most livelihoods in the Philippines are based on agriculture. Nevertheless, the impact on crops is dependent on many factors such as the soil moisture, the crop season, the type of crop, among others, which make it more complicated to predict the impact by using damage curves.

Regarding the representation of the impact, several mechanisms have been chosen depending on the suitability for the specific asset.

Population: Because the impact on the population is important for all decision-making levels, it has been considered valuable to provide the affected people in a grid format as well as on a warning colour coded system, as both methods are fast and easily readable. Furthermore, given the interest of disaster managers on having more information about the characteristics of the affected population, it has also been assumed of importance to provide the percentage of women and men affected, as well as their age ranges. With this information disaster managers can have a better idea on how many of those affected persons belong to a more vulnerable group. In order to deliver those statistics, graphs for the affected population per barangay have been considered as the clearest solution. Figure 7.6 provides an overview of the mock-ups developed for the affected population.

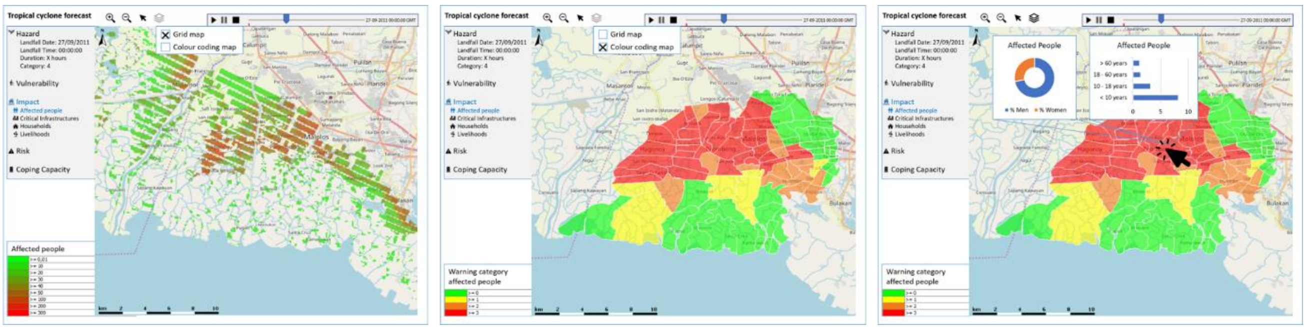


Figure 7.6. Affected people mock-up. Left: Grid of the affected people; Middle; colour warning code for the affected people; Right: colour warning code for the affected people with statistics based on gender and age

Infrastructure: Because infrastructures do not occupy the hole grid, those would be difficult to be observed. Therefore, it has been considered more appropriate to represent the impact on infrastructures in a colour coded warning system where all the infrastructures can be observed. Furthermore, colour coded icons for each infrastructure that show their warning category was appreciated by the interviewees. Besides, the failure of critical infrastructures depends on the water depth of the flooding. Hence, it has been considered of relevance to have graphs that show the water depth before, during and after the cyclone, in order to help disaster managers understand the most critical moments for the infrastructures. Figure 7.7 provides an overview of the mock-ups developed for the affected critical infrastructure.

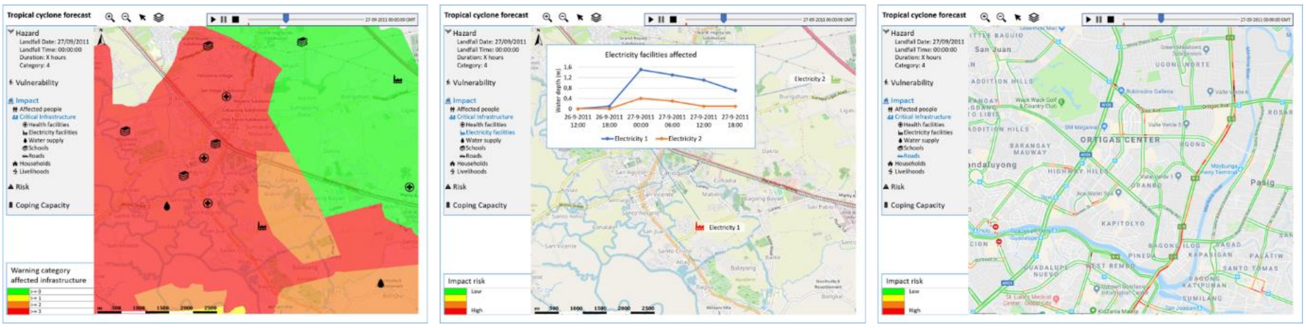


Figure 7.7. Affected infrastructure mock-up. Left: colour coded map with all the critical infrastructure; Middle: map with the colour coded icons and water depth time series for critical infrastructure; Right: colour coded warning map of the roads

Nevertheless, usually critical infrastructures are not only impacted when the flood reaches the facilities. Instead, many infrastructures can be affected because of the failure of other infrastructures. For example, when a power plant fails due to flooding, a water plant might fail as well due to the power shortage. Therefore, it has been considered of interest not only including the facilities that fail because of flooding, but also to show the ones that suffer from cascading effects and are impacted due to the failure of other infrastructures. Figure 7.8 shows the mock-up of the cascading effects, which change throughout time, because the indirect failure of critical infrastructures does not necessarily occur exactly when the main infrastructure is affected. The arrows in the mock-up represent the connections between the infrastructures, with a colour code depending on their impact, ranging from minimal to severe.

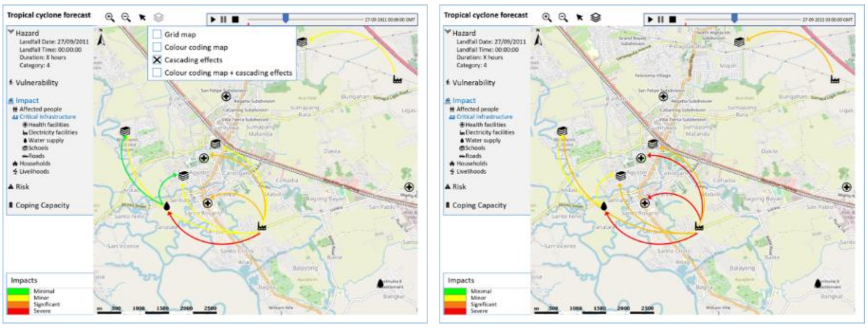


Figure 7.8. Critical infrastructure cascading effects mock-up. Left: cascading effects at the landfall time of the cyclone; Right: cascading effects three hours after the landfall of the cyclone

Household: According to the interviewees, forecasting at household level can provide valuable data, especially when information regarding the vulnerable population is provided. Therefore, in Figure 7.9 a mock-up is proposed in which characteristics about the inhabitants is provided. This information can include, for example, the amount of people below 5 or above 60 years, or the number of disabled people in a certain area.

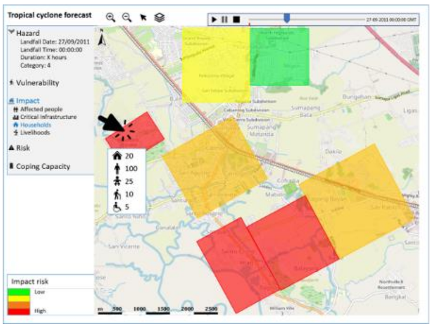


Figure 7.9. Mock-up of the affected households, in a colour coded system. Information about the affected households and the vulnerable groups of their inhabitants can be observed

Coping capacity: During the interviews, it was remarked the importance of having a map that shows the location of the coping capacity facilities, such as shelter, available drinking water or food stock. Therefore, in Figure 7.10, a mock-up of the coping capacity facilities is depicted.

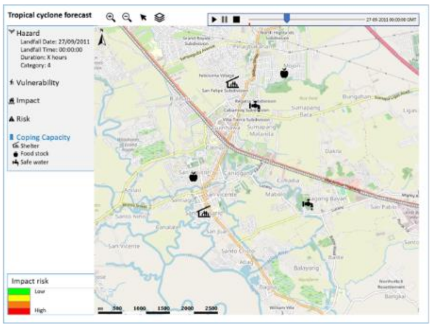


Figure 7.10. Mock-up that shows the location of the coping capacity facilities in the area

Social structure: The knowledge of the social structure is of importance for disaster managers in order to better understand the social cohesion of the area, that can help to reduce the vulnerability of its inhabitants towards a disastrous event. However, because this information can be known in advance and is specific for a certain area, it has not been included in this study. Furthermore, the Red Cross Chapters, which are the deployed organisations of the Red Cross at barangay level, usually have enough knowledge about the area in order to understand the reaction of the population towards a hazard.

For a better observation of the mock-ups, please see Appendix B.

8 Model (I): New impact models

This chapter provides the methodology and results of the impact models that have been created based on the mock-ups derived from the semi-structured interviews to disaster managers. In order to make the impact models, Delft-FIAT, has been used, coupled with Delft-FEWS.

8.1 Methodology: Combining hazard, exposure and damage functions

In Chapter 4 it has been described how Delft-FIAT works, using exposure maps and maximum damages, that combined with water depth maps and damage curves produce a damage map. For this thesis, new Delft-FIAT models have been created for several critical infrastructures. Furthermore, although the impact on population is calculated, the Delft-FIAT model for impact on people has been taken from the old model explained in Chapter 6. However, in this thesis the population data has been postprocessed in order to include the vulnerability dimension, which was not included in the previous version of the impact-based forecast. The explanation about the implementation of vulnerability can be read in Chapter 9.

8.1.1 Critical infrastructures

In the new impact models, the damage on several critical infrastructures has been predicted. The critical infrastructures considered for the model have been schools, hospitals and roads. These infrastructures have been chosen because they resulted to be the assets of most relevance for disaster managers.

For emergency responders, information about the state of roads is of special importance, because of their crucial function for the transport of humanitarian aid, and for accessing hospitals and shelter for the population. Furthermore, the knowledge on the impact of flooding on hospitals is necessary, in order to understand whether the health facilities will be functional or not. Finally, schools are usually used as shelter during disasters and hence, it is essential to know their availability to be able to improve the decision making and better inform the population.

The schools implemented in this impact-based forecast model are the Public Elementary Schools. However, any kind of school of critical infrastructure could be assessed. Besides, for simplification and a better representation, in this thesis only the major roads of the Manila Bay area have been taken into account, instead of all the road network of Manila Bay.

8.1.2 Hazard maps

The hazard map used in Delft-FIAT has been obtained from the hydrodynamic model run within Delft-FEWS, coupled with Delft3D. This hazard map provides the water depth produced by a storm surge in the area of Manila Bay. Because Delft-FIAT can only process water depth netCDF files with one-time step, the time series water depth maps of Delft-FEWS are transformed with a transformation module into one water depth map with the maximum water depths throughout the whole time series period. Therefore, the impact maps produced with Delft-FIAT provide the maximum damages caused by a certain event. Furthermore, the hazard maps output of Delft-FEWS have a flexible grid cell size. However, Delft-FIAT requires a regular grid. Hence, the maximum water depth map is transformed, also with a transformation module, into a regular grid water depth map of 300x300meters, and a sub-grid of 50x50 meters.

8.1.3 Exposure maps

For the exposure maps, vector and polygon layers have been converted into GeoTIFF layers, for each of the three critical infrastructures. This conversion has been done in QGIS, in which for each GeoTIFF layer, each grid cell has a value corresponding to the number of critical infrastructures in that cell (for example, when on a grid cell there are 2 hospitals, the value of that grid cell is 2).

Because the grid definition of the exposure and hazard maps need to match in order to run Delft-FIAT, the grid definition of these layers is of 50x50 meters and occupies the area of Manila Bay.

Figure 8.1 provides a close look to 2 exposure maps created in order to calculate the damage. On the left side, the exposure map of the public elementary schools is provided, in which the white colour indicates that there is no school in that grid cell, the grey colour indicates that there is 1 school in that grid cell, and the red dots indicate the actual location of the schools. On the right image, the GeoTIFF of the roads can be observed, in which the white colour indicates there is no road in that grid cell and the grey colour indicates the presence of 1 road.

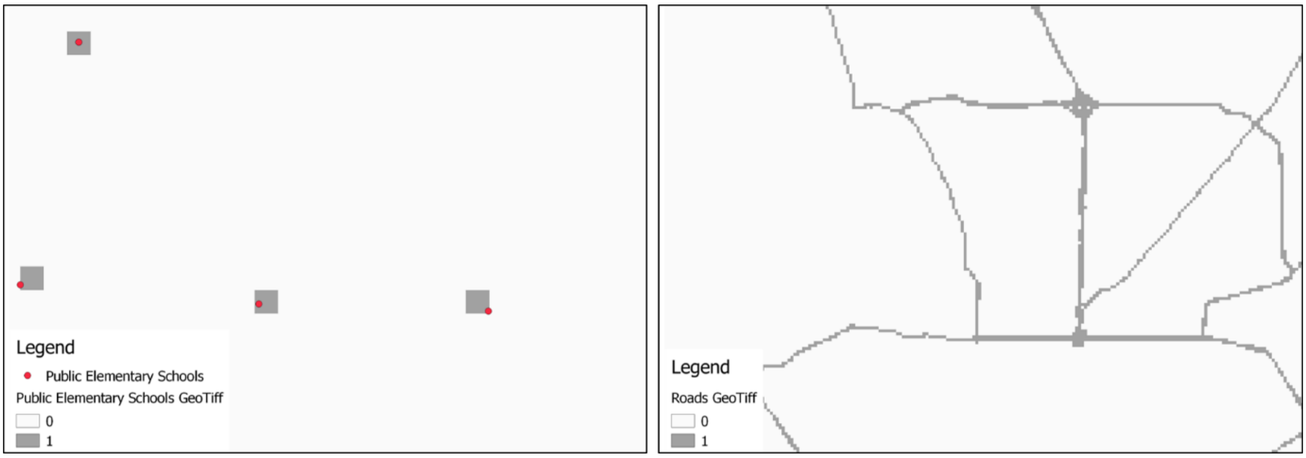


Figure 8.1. Close look at the exposure maps of critical infrastructures. The white colour (0 value) means the absence of critical infrastructure. The grey colour (1 value) means the presence of infrastructure. Left: close look at the map of Public Elementary Schools. The red dots represent the actual location of the schools. Right: close look at the map of Roads. The grey colour (1 value) means the presence of infrastructure.

8.1.4 Damage functions

The damage functions, also called vulnerability curves, are the relation between the water depth and the damage produced by the flooding and indicate vulnerability of the affected assets (Papathoma-Köhle, 2016). The damage fraction (vertical axis) of the damage curves ranges from 0 (no damage) to 1 (maximum damage).

The damage to buildings depends on their material and their land use (Aritua Hasiholan Sagala, 2006; Budiyono et al., 2015; Huizinga, De Moel, & Szewczyk, 2017). Unfortunately, there is no accurate information on the material of the buildings in the Manila Bay area. However, the exposure in this thesis is categorised by critical infrastructure (schools, hospitals and roads). Therefore, it has been assumed that the damage functions only vary according to their land use.

In the Philippines, and more specifically in the Manila Bay area, there are no officially recognised damage curves currently available. For this reason it has been decided to use the global flood depth-damage functions provided by Huizinga et al. (2017). Huizinga et al. (2017) is a technical report made by the Joint Research Centre (JRC), the European Commission’s science and knowledge service. In this report, damage curves per land use class (residential, commerce, industry, transport, railroads, agriculture) and for each continent (Africa, Asia, North-America, South/Central-America, Oceania and Europe) have been derived.

Because of the location of the Philippines, the damage curves corresponding to Asia have been used. Huizinga et al. (2017) categorises hospitals and schools within the commercial class, and the roads within the infrastructure class. Therefore, in this thesis the same approach has been followed.

Figure 8.2 and Figure 8.3 depict the damage curves for the commerce (hospitals and schools) and infrastructure (roads) classes. Table 8.1 and Table 8.2 provide the damage function for both classes.

Table 8.1. Commerce damage function (Huizinga et al., 2017)

Water depth (m)	Damage factor
0	0
0.5	0.38
1	0.54
1.5	0.66
2	0.76
3	0.88
4	0.94
5	0.98
6	1

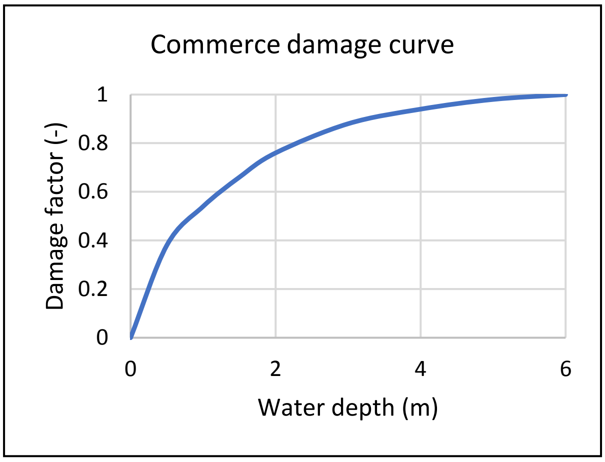


Figure 8.2. Commerce damage curve (Huizinga et al., 2017)

Table 8.2. Infrastructure damage function (Huizinga et al., 2017)

Water depth (m)	Damage factor
0	0
0.5	0.25
1	0.42
1.5	0.55
2	0.65
3	0.80
4	0.90
5	1
6	1

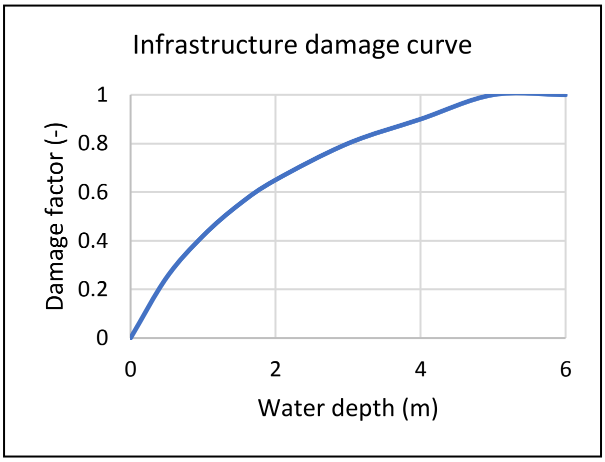


Figure 8.3. Infrastructure damage curve (Huizinga et al., 2017)

8.1.5 Maximum damages

To predict the actual damage to the infrastructures, the damage curves require associated maximum damage values. The damage values used in this thesis have been obtained from Huizinga et al. (2017), which classifies the maximum damages in the same manner as the damage curves mentioned in the previous section (per continent and class). Therefore, the maximum damages due to flooding in Asia are used in this thesis.

Because the grid resolution used in this impact-based forecast prototype is of 50x50m, the values of the maximum damages should be in € per 2500m^2.

Table 8.3 provides the maximum damages per class, and on €/m^2 and €/2500m^2.

Table 8.3. Maximum damages for the commerce and infrastructure in Asia (Huizinga et al., 2017)

Damage class	Maximum damage (€/m^2)	Maximum damage (€/2500m^2)
Commerce (hospitals, schools)	138	345,000
Infrastructure (roads)	4	10,000

Notice that because the maximum damages on the infrastructures are represented as economic costs, the units of the impact will be in euros (€).

8.1.6 Delft-FIAT execution

In order to predict the impact on the critical infrastructures, the Delft-FIAT tool coupled with Delft-FEWS is used. To execute Delft-FIAT, a general adapter is used, which allows to supply input parameters from Delft-FEWS and import the output of external applications back to Delft-FEWS. The hazard maps used in Delft-FIAT for the impact forecast are predicted in Delft3D within Delft-FEWS. These maps are the imported to Delft-FIAT thanks to the general adapter. Besides this input, Delft-FIAT uses the damage functions mentioned in the previous sections, defined as Comma Separated Values (CSV) files. These are combined with the GeoTIFF exposure maps created in QGIS, and the maximum damages for each infrastructure. The output of Delft-FIAT is then imported back to Delft-FEWS, also through the general adapter.

8.1.7 Representation of the impact on critical infrastructures

The results of the damage maps on critical infrastructures are obtained as a grid. However, this grid is too fine, and the critical infrastructures are not easily visible. Therefore, in order to improve its visualisation, the critical infrastructure impacts are also represented as icons and colour coded warning maps.

To create the icons and colour coded warning maps, transformation modules within Delft-FEWS are used. For the icons, a transformation is made from the impact grid to the critical infrastructure location. This representation mode shows the location of the infrastructures with the icons, and at the same time it shows the dimension of the impact with a coloured legend. On the other hand, the colour coded warning maps are created in a transformation module, interpolating the grid of the affected infrastructures into barangays. Afterwards, warning categories are incorporated, and when an established threshold is triggered, the warning category changes per barangay. Table 8.4 provides an example of the colour code warning categorisation made for critical infrastructures.

Table 8.4. Example of the colour code warning categorisation for critical infrastructure

Warning category	Colour	Costs affected infrastructure
0	Green	0 – 10,000 €
1	Yellow	10,001 – 25,000 €
2	Orange	25,001 – 50,000 €
3	Red	> 50,000 €

Furthermore, for disaster managers is also important to know the water depth on a specific critical infrastructure. Therefore, a transformation module has been used in order to interpolate the water depth time series to the location of each critical infrastructure. This allows disaster managers to observe the water depth time series at each hospital and school.

8.2 Results: Impact maps on critical infrastructures

Because disaster managers had several preferable methods for visualising the impact, impact maps on critical infrastructures have been represented in two ways, as mentioned in the previous section. On the one hand, icon maps with colours that indicate a range of economic impact have been designed. On the other hand, colour coded maps have been created, in which the colour code changes per barangay.

In Figure 8.4 the impacts on critical infrastructures can be appreciated. On the left side, the icons with the Public Elementary Schools can be observed, together with the economic impact of the disaster. In the middle, the colour coded warning system for elementary schools is depicted. On the right side, the economic impact map of the roads is presented, with the icons that delineate the roads' impact. It can be observed that for both critical infrastructures the impact in the area of Metro Manila is one of the most affected.

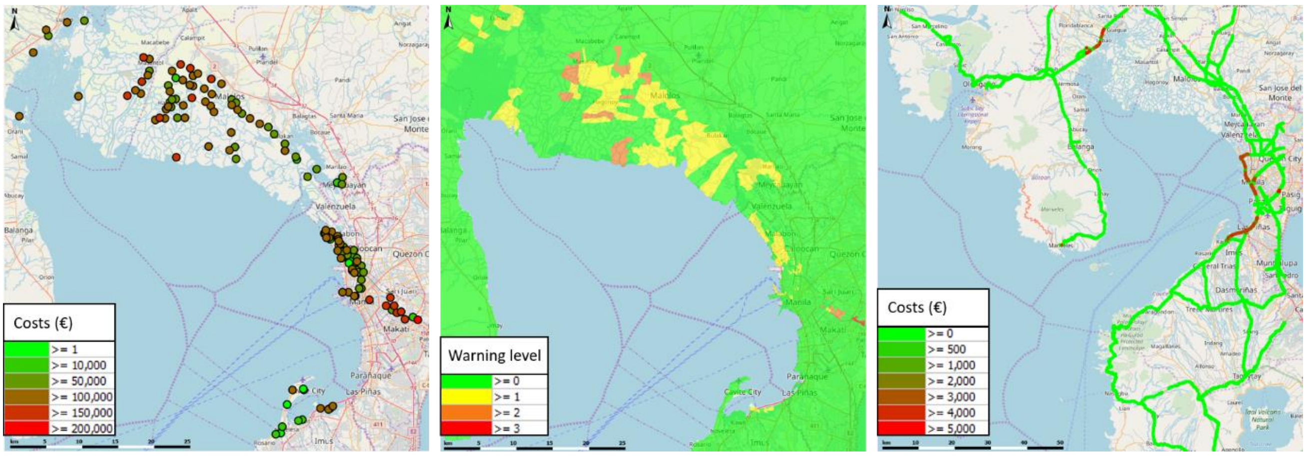


Figure 8.4. Left: Icons indicating the impact costs on Public Elementary Schools; Middle: Colour coded warning for Public Elementary Schools; Right: Icons delineating the roads and their impact costs.

Sometimes it is also necessary for decision makers to know the water depth time series for a specific critical infrastructure. Therefore, water depth time series for hospitals and schools in Manila Bay have been created. Figure 8.5 depicts these time series for a specific hospital and elementary school. The red line indicates the hindcast, whereas the blue line indicates the forecast. It can be observed that for both critical infrastructures, when the typhoon makes landfall and is nearer to their location the water depth increases. In the case of the elementary school (right), the water depth change is more abrupt due to its proximity to the coast.

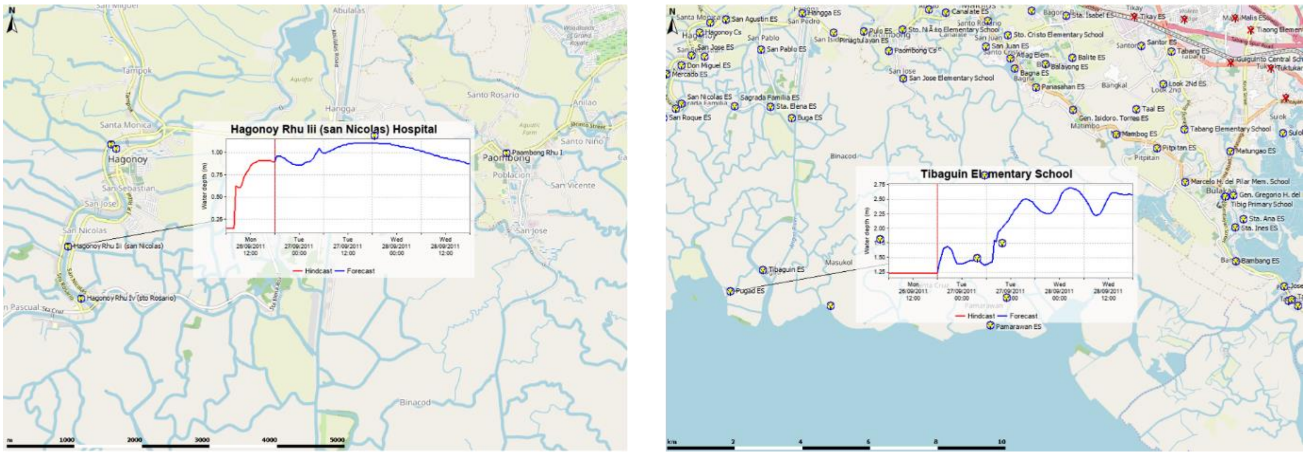


Figure 8.5. Left: Water depth time series of the Hagonoy Rhu Iii Hospital; Right: Water depth time series of the Tibaguin Elementary School. The red light indicates the hindcast, whereas the blue light is the forecast.

9 Model (II): Postprocessing vulnerability

The importance of considering vulnerability when calculating disaster risk, has already been mentioned in Chapter 2. In this thesis vulnerability has been added to the forecasting prototype and is explained in this section.

9.1 Methodology: Implementing vulnerability in impact-based forecasting

In the previous chapter, the methodology and results obtained from implementing Delft-FIAT at critical infrastructures have been explained. However, the Delft-FIAT model for impact on people has been taken from the initial model explained in Chapter 6. Although the methodology followed to create the impact maps is the same, a step function has been used in order to predict the affected population, instead of a damage function. This step function defines that a person is affected when the flooding exceeds 20 centimetres water depth. Nevertheless, this step function is a threshold for the hazard and does not include vulnerability. Therefore, this section will provide an explanation and representation of which kind of vulnerability data has been implemented and the methodology followed to do so.

9.1.1 Vulnerability

The vulnerability data used for this prototype has been obtained from the Community Risk Assessment dashboard created by 510 an initiative of the Netherlands Red Cross. This initiative has developed this dashboard in order to help humanitarian organisations make decisions on whether they should take action. This solution proposed by 510 integrates all the relevant open or closed data sources on a detailed geographical level, with indicators that rang hazard, exposure, vulnerability and coping capacity among other variables (510 an initiative of the Netherlands Red Cross, n.d.).

The dashboard is available for the Philippines, and it contains information in different organisational levels, from provincial level up to barangay level. Figure 9.1 provides an overview of the Community Risk Assessment dashboard of 510.

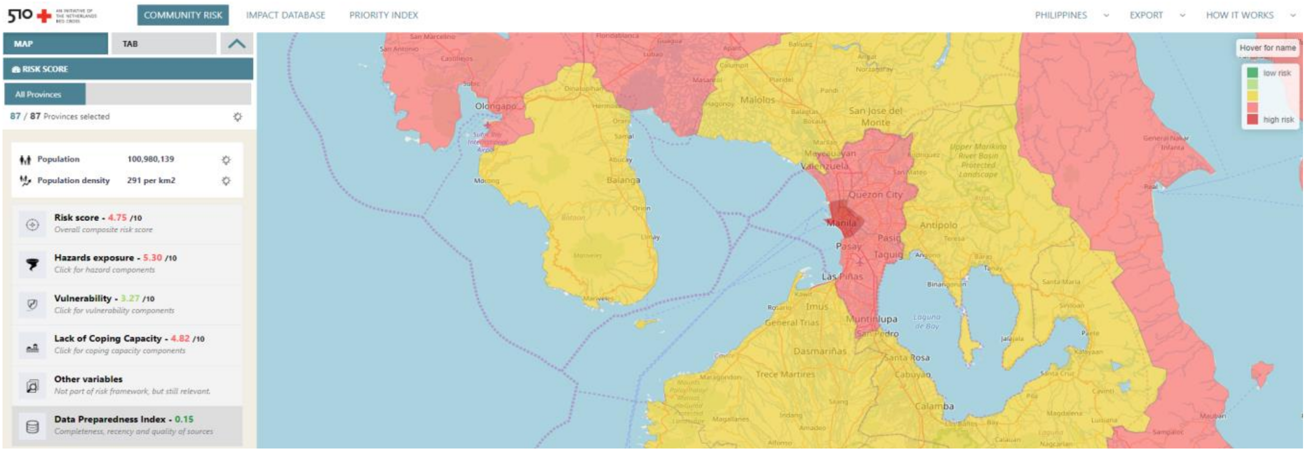


Figure 9.1. Community Risk dashboard from 510 in Manila Bay (510 an initiative of the Netherlands Red Cross, n.d.)

The vulnerability data in the dashboard is provided at provincial and municipal level. Unfortunately, data at barangay level is still scarce. Hence, for this thesis it has been decided to use municipal level information. A vulnerability composite index is provided in the dashboard in a score from 0 to 10, in which 0 would mean the municipality is not vulnerable at all and 10 would mean maximum vulnerability. In order to calculate this composite index, 510 has considered several parameters that have been rescaled to a factor from 0 to 10. Afterwards the composed vulnerability has been calculated with the geometric mean of those parameters. Table 9.1 provides a description of the parameters considered to calculate the vulnerability index:

Table 9.1. Vulnerability parameters used to calculate the vulnerability score (510 an initiative of the Netherlands Red Cross, n.d.)

Vulnerability parameter	**Description**
Pantawid (4P) beneficiaries	Number of beneficiaries of Pantawid (4P) poverty program, made relative to population.
% strong roof type	Percentage of buildings with (partly) concrete or iron or aluminum roofs.
% strong wall type	Percentage of buildings with (partly) concrete or iron or aluminum walls.
% children U5	Percentage of population under 5 years old. The younger the child, the more vulnerable it is.
Poverty incidence	Estimated poverty incidence per ward.
% of HH occupying lot rent-free	Percentage of households occupying a lot they live on rent-free. This is meant as a proxy of informal settlements, which represents an important vulnerable group.
% vulnerable population	Vulnerable population as percentage of total. Vulnerable groups include: Child-head of HH, Single-head of HH, disabled persons, solo parents, older persons.

The data of the dashboard can be easily exported as a CSV file or as a GeoJSON file. In this thesis, the data has been downloaded as a GeoJSON, and afterwards the shapefile from the vulnerability score has been obtained.

9.1.2 Implementation of vulnerability data into impact-based forecasting

For the purpose of this thesis, the vulnerability parameter *% vulnerable population,* within the composite index, has been used in order to estimate the vulnerable affected population.

The affected people has been calculated using Delft-FIAT, considering the hazard (water depth), the exposed population and a step function in which population is affected when there is a 20cm water depth. Unlike a damage curve, a step function does not provide a vulnerability indication and hence, in the initial system vulnerability had not been taken into account when calculating the impact. This dimension has been implemented on the affected population as a postprocess of Delft-FIAT.

It has been mentioned before that the formula used to calculate the risk of impact is the following:

$$\text{Risk of impact} = \text{Hazard} \cdot \text{Exposure} \cdot \text{Vulnerability} \qquad (7.1)$$

In order to incorporate the vulnerability, a transformation module within Delft-FEWS has been created. In this transformation module, the percentage of vulnerable population has been first defined as a coefficient set function, in order for Delft-FEWS to import the attribute values of the shapefile to the system. Afterwards, the polygon vulnerability (per municipality) has been interpolated to a 50x50m grid. Once a vulnerability grid has been obtained, a transformation has been done in order to convert the time step to non-equidistant. Finally, the vulnerability grid has been multiplied by the affected people grid obtained from Delft-FIAT.

Figure 9.2 shows, in a simplified and schematised manner, the workflow followed to predict the affected people considering hazard, exposure and vulnerability.

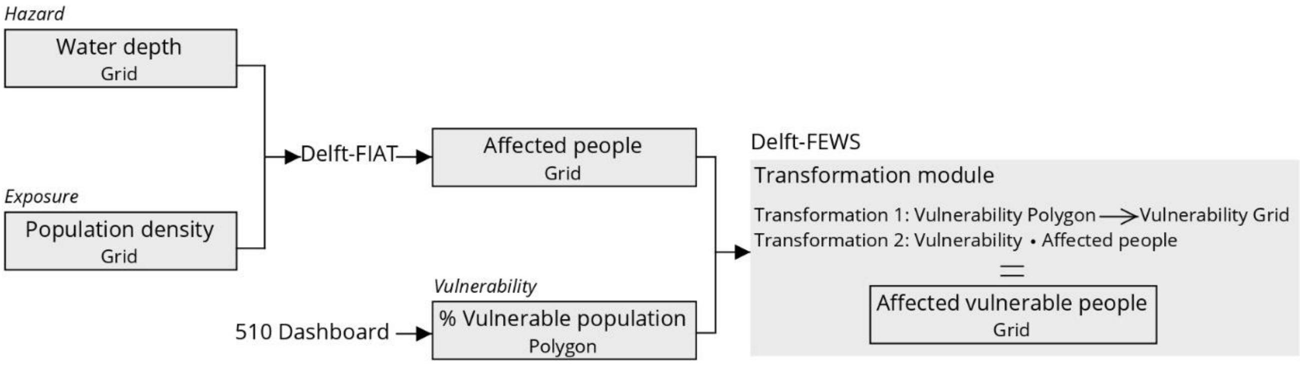


Figure 9.2. Schematisation of the workflow to predict the affected people, considering vulnerability

9.1.3 Representation of the impact on vulnerable population

The results of the affected vulnerable people are obtained in a grid shape. However, in order to make its representation more understandable, a transformation module is used. In this transformation module, the grid is interpolated into barangays. Afterwards, another transformation is made in order to establish warning categories per barangay. Hence, when an established threshold of a certain amount of people being affected is triggered, the warning category changes. Table 9.2 shows an example of the categorisation performed for the affected vulnerable people.

Table 9.2. Example of the colour code warning categorisation for affected people

Warning category	Colour	Affected vulnerable people
0	Green	0 – 10
1	Yellow	11 - 25
2	Orange	26 - 50
3	Red	> 50

9.2 Results: Impact maps on vulnerable population

This research has incorporated vulnerability into the forecasting system of Manila Bay. In Figure 9.3 it can be appreciated the affected vulnerable population. On the left side, the grid of the affected vulnerable population can be observed, in which it is indicated the number of vulnerable affected people per grid cell. On the right side, the colour coded designed for the affected vulnerable population is depicted.

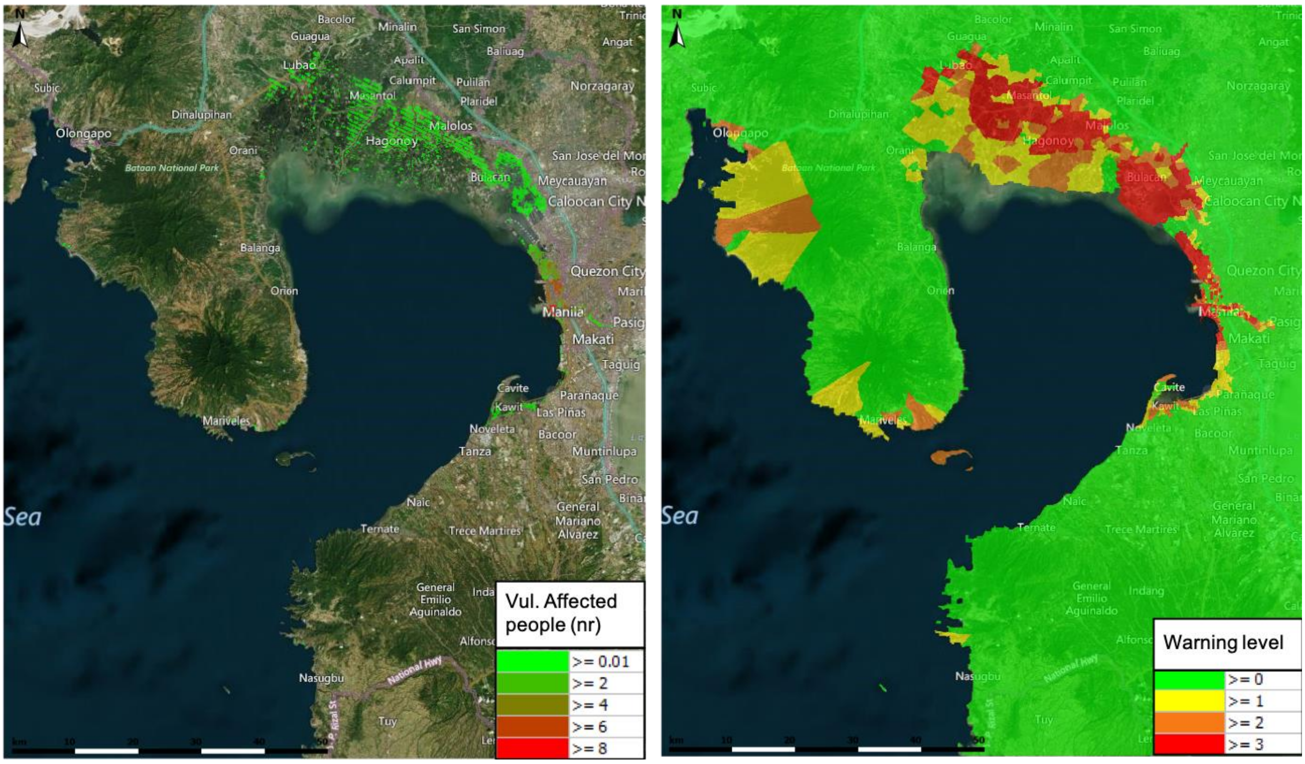


Figure 9.3. Left: Grid of the vulnerable affected people. Right: Colour coded warning for the vulnerable affected people

The importance of incorporating vulnerability in impact-based forecasting has been outlined in this thesis and can be better appreciated in Figure 9.4. In the left image the affected population is depicted (predicted by Delft-FIAT when vulnerability post-processing has not been done); in the middle image, the percentage of vulnerable population obtained from the 510 dashboard can be observed; on the right image the affected vulnerable population (affected population forecasted with Delft-FIAT plus post-processing of vulnerability) is presented. The highlighted area with a white square indicates Metro Manila, which is a large and dense area formed by different cities in the Manila Bay area. It can be observed that within Manila Bay, this area is the most affected by the typhoon due to storm surge. However, Metro Manila is too large and therefore, a distinction needs to be done in order to prioritise where the actions of disaster managers should focus on. The map with percentage of vulnerable people in Manila Bay indicates a certain area within Metro Manila with larger vulnerability than the rest. This can also be observed in the vulnerable affected people map on the right side, in which now vulnerability is also incorporated. Therefore, the impact map on vulnerable people depicts the areas in which people is affected and intensifies those areas in which there is a larger vulnerable population, which allow a more informed decision making when a hazard event is approaching.

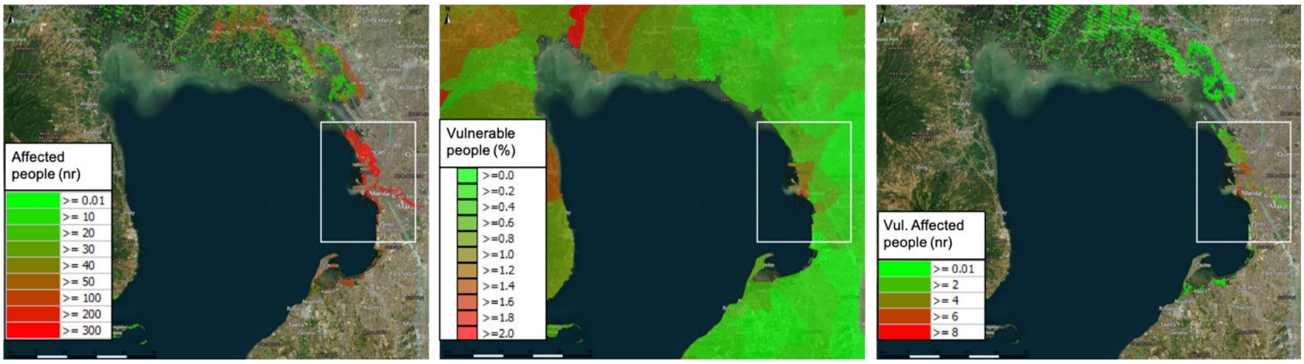


Figure 9.4. Left: Affected people in Manila Bay; Middle: Percentage of vulnerable people in Manila Bay; Right: Vulnerable affected people in Manila Bay. The white square indicates Metro Manila

10 Output: Dashboard

Although this thesis aims at making the forecasting system more user oriented, the Delft-FEWS system is still complex for decision makers with no technical background. Therefore, an interactive dashboard has been designed in order to make the use of the impact-based forecast prototype easier and more intuitive. This interactive dashboard depicts the main information required during an emergency event and connects it with more detailed data that can easily be accessible with a simple mouse click.

10.1 Methodology: Creation of the dashboard

The Schematic Status Display (SSD) is a plug in Delft-FEWS used for displaying and monitoring data. This display shows configurable schematic views that represent data values in a certain way.

There are several steps that have been followed in order to develop a Schematic Status Display:

1. Create an SVG file. This file has been created using the vector graphics software Inkscape. Each of the features of the SVG file that have to vary according to the values in Delft-FEWS must have an Object ID defined within Inkscape. This file has been added to the Report Image Files of Delft-FEWS.
2. Create an Extensible Markup Language (XML) file with a name format *SSD_NameOfTheSVGFile.xml*. In this file, each Object ID has been associated to a time series and to a component behaviour that can be of text or shape. A text component behaviour defines the properties of text associated to a time series. Instead, a shape component behaviour defined the shape properties associated to a time series. This file has been added to the Display Configuration Files of Delft-FEWS.
3. In order to associate colour warnings to shapes (of assets and municipalities), thresholds have to be defined. For that, three more XML files are required to be added to the Region Configuration Files of Delft-FEWS:
   a. Thresholds.xml file: associates threshold groups to threshold warning levels.
   b. ThresholdsValueSet.xml file: associates each threshold group to a time series, and each threshold warning level of each group to a specific value.
   c. ThresholdWarningLevels.xml file: associates each threshold warning level to a colour and icon.

Within the Schematic Status Display of this prototype, a distinction has been made among three kinds of data provided:

Hazard data: information on the time to landfall and the maximum water depths and maximum wind speeds are provided. The time series for each of these features is associated to an Object ID of the SVG file in the *SSD_NameOfTheSVGFile.xml* file.

- Time to landfall: in order to calculate the time to landfall of the cyclone, first a transformation module within Delft-FEWS has been developed. In this transformation module, first a transformation called *independentPeaks* is used to find the largest water depth in Manila Bay throughout all the time series. Afterwards, a second transformation, called *timeToSelection* is used in order to create an output time series with the value, for each time step, of the nearest data point in the input time series.
- Maximum water depth and maximum wind speed time series were already calculated in the initial forecasting system.

Warning data: the impact data of each critical infrastructure and of the vulnerable affected population is interpolated to the Manila Bay area using a transformation module. The output of this transformation module is a time series for each impact asset. Those time series are then associated to an Object ID of the SVG file in the *SSD_NameOfTheSVGFile.xml* file.

Colour code map: the creation of the colour code map consists of two phases:

- Creation of the SVG map of the municipalities. In order to create the SVG map of the municipalities, first a shapefile imported of the municipalities is exported from QGIS in an SVG format. Afterwards, the SVG file is imported in Inkscape, and each municipality polygon is then associated to an Object ID.
- The vulnerable affected population is interpolated to each municipality using a transformation module. The output of this transformation module is a time series. This time series is then associated to an Object ID of the SVG file in the *SSD_NameOfTheSVGFile.xml* file.

10.2 Results: Interactive dashboard

The interactive dashboard created in this forecasting system is depicted in Figure 10.1. The dashboard is organised in hazard, warnings and a colour coded map.

Hazard*:* provides information on the time to landfall and the maximum water depth and wind speeds in Manila Bay for each time step. When clicking in the landfall feature, the Time Series Display screen appears, and it is possible to observe the time series of the time to landfall. Furthermore, when selecting the water depth or wind speed features, the Spatial Display screen opens and it is possible to observe the hazard map for the selected characteristic (water depth map or wind speed grid).

Warnings: provides information on the affected critical infrastructures and on the population. For each asset, the colour code updates in every time step provides information on the severity of the impact. Furthermore, pressing in *Impact* in each of the assets shows the Spatial Display with the respective impact maps. Besides, clicking on *Flooding* provides the general time series for a specific kind of infrastrcture in Manila Bay.

Colour code map: provides information on the severity of the affected vulnerable population in each municipality.

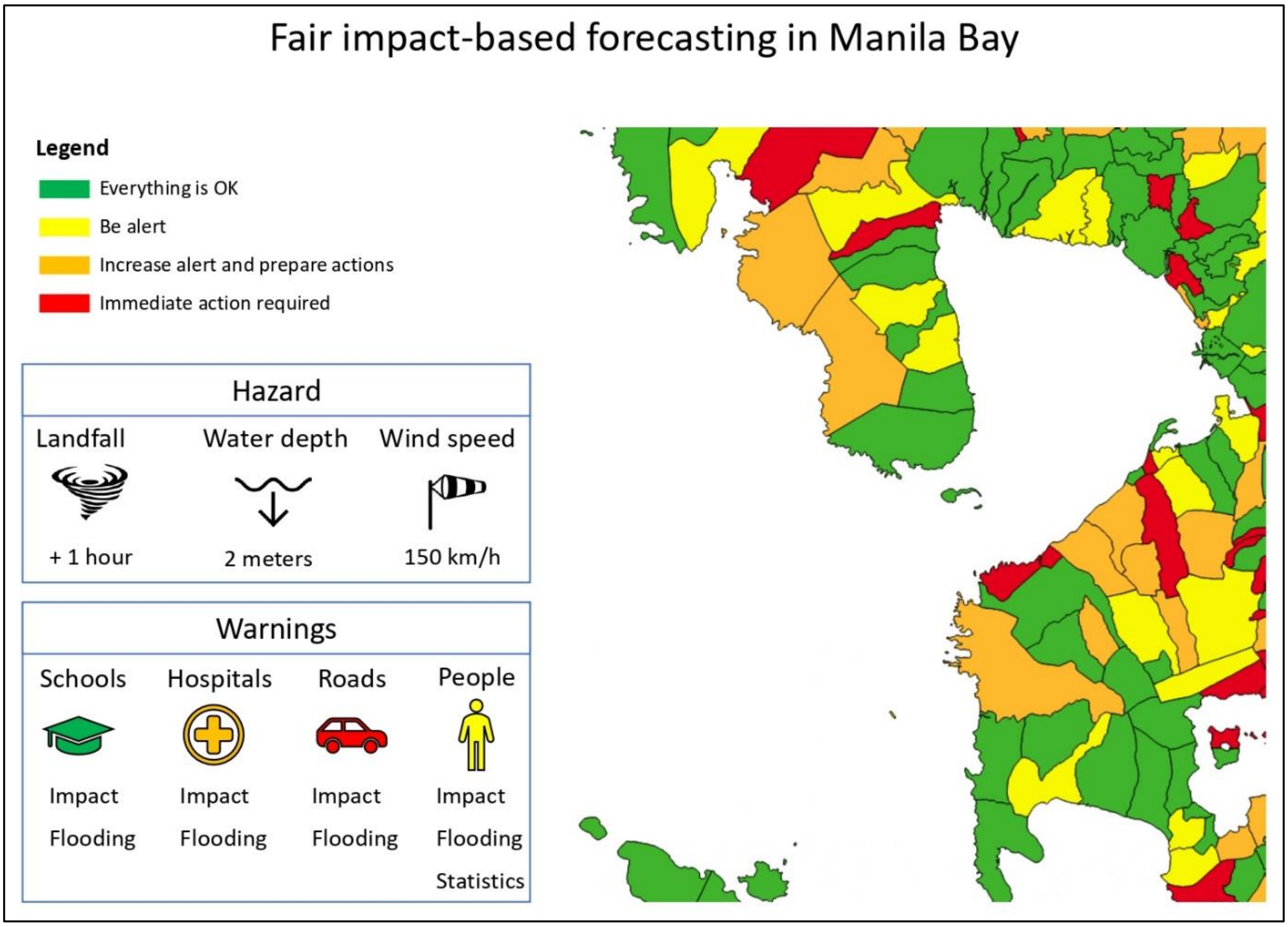


Figure 10.1. Fair impact-based forecast prototype dashboard

11 Feedback (I): 3rd Asia Pacific Regional Dialogue Platform on FbF

Between the 25th and the 27th of June 2019, the 3rd Asia Pacific Regional Dialogue Platform on Forecast-based Financing took place in Manila. The Dialogue Platform is done once a year in the Asia Pacific region. This event gathers humanitarian actors, meteorologists, climate scientists, national governments and decision makers, with the intention to discuss how to improve Forecast-based Financing and implement it into projects (see Section 3.2.2), and to figure out how to speed up the use of weather and climate data that helps on the FbF methodology (International Federation of Red Cross and Red Crescent Societies & German Red Cross, 2019).

Because this thesis focusses on the development of an impact-based forecasting pilot considering the information and delivery needs of disaster managers, the attendance to the Dialogue Platform allowed not only to showcase the research done to its potential users, but also to gather a better background understanding on emergency response, decision making and on what is understood in the ground as Forecast-based Financing and impact-based forecasting.

11.1 Methodology: setup of the Dialogue Platform

The Dialogue Platform was organised by the International Federation of Red Cross and Red Crescent Societies and the German Red Cross and was structured into three days. During those days, presentations were carried out by several organisations with undergoing projects in countries of Asia and the Pacific. Some of the participating organisations were: Red Cross Red Crescent Societies, the Red Cross Red Crescent Climate Centre, the Food and Agriculture Organisation of the United Nations (FAO), the World Food Programme (WFP), the World Meteorological Organisation (WMO), met offices such as the Philippine, the UK and the Vietnam met offices, and the National Aeronautics and Space Administration (NASA).

During these presentations, topics such as Forecast-based Forecasting and Impact-based Forecasting were introduced, and several projects that were following the FbF methodology in Asia and Pacific were presented. Furthermore, on the third day special attention was given to impact-based forecasting. That day there was the opportunity to present the work performed in this thesis, during the *Innovative ideas for IBF* session. Furthermore, afterwards the author of this thesis helped on the organisation of a workshop, in which humanitarian actors and decision makers talked about the future of impact-based forecasting, and the information that should be taken into account within these models in the future.

During the visit to the 3rd Asia Pacific Regional Dialogue Platform on Forecast-based Financing, notes were taken in order to be able to reproduce afterwards the outcomes of the visit.

11.2 Results: Terminology consensus and new vulnerabilities

During the 3rd Asia Pacific Regional Dialogue Platform on Forecast-based Financing that took place in Manila, Philippines, several initiatives to implement anticipatory approaches were presented. However, during the Platform conceptual misunderstandings arose regarding what Forecast-based Financing stands for. At the same time, various organisations using this same methodology named it differently, which rises confusion among the practitioners. Therefore, one of the main conclusions of this platform was the need of cooperation between all the agencies applying anticipatory approaches, in order to establish a general concept and to share knowledge and expertise in this topic through common platforms that speed up its implementation and efficiency.

The Forecast-based Financing methodology makes use of a trigger to start an Early Action Protocol that aims to reduce the risk of the population potentially affected by a hazard. This trigger should ultimately be defined based on the effects of the disaster, using an impact-based forecasting system, instead of defining it based on meteorological parameters. There are some countries that have already started using impact-based forecasting systems in order to define this threshold. The Philippines, however, has no official impact-based forecasting system in use yet. Nevertheless, PAGASA, the NMHS of the Philippines, is already developing an IBF model for typhoons, based on wind speed damages. Furthermore, the Philippine Red Cross has started using an IBF system as well, developed by 510 an initiative of the Netherlands Red Cross, which defines a trigger based on the percentage of households affected due to wind speed damages.

During the Dialogue Platform, several points of improvement and difficulties arose within the discipline of impact-based forecasting. On the hazard side, it was discussed the need of multi-hazard impact-based forecasting, in which the trigger is established as a combination of several hazards, instead of focusing in a single threat. The reason to stand for this statement is the fact that if the trigger is defined with only one hazard (for example, wind speeds in the case of typhoons), the threshold might not be reached, but there might still be calamities produced by a different hazard (flooding, for example). Besides, regarding the vulnerability side of the impact, the complexity of the vulnerability concept was highlighted. This led to the desire of establishing a common definition of the term among all the agencies and to enhance the inter-agency cooperation. As an outcome of the

Dialogue Platform, two new considerations should be taken into account when talking about vulnerability: The first one is the change of vulnerabilities of an area due to climate change. The vulnerabilities should be updated according to the new hazards appearing in a certain location. The change of weather patterns might imply a difficulty in data-driven models that look at the effects of past events to predict future impacts; The second consideration regarding vulnerability is the need of including the conflict and displacement areas within one of the parameters of vulnerability, as population under those circumstances is extremely more susceptible to disasters.

12 Feedback (II): Semi-structured interviews at PRC

In order to verify the forecasting prototype created according to the first round of interviews carried out to disaster managers (see Chapter 7), the impact-based forecasting prototype was presented to disaster managers working in the Philippines. During the field trip to Manila, Philippines, the impact-based forecasting prototype was introduced to two agencies within the Philippine Red Cross, which would be their potential users. The two organisations that were visited were the Disaster Management Service and the Operations Center, both in charge of the disaster response in the Philippines.

12.1 Methodology: Interviews to disaster managers

In this section, the methodology carried out to obtain feedback from disaster managers working in Manila is presented.

12.1.1 Setup of the semi-structured interviews

The interviews carried out in this phase of the thesis, after having created the impact-based forecasting prototype, were done to disaster managers of the Philippines that work in the Philippine Red Cross. At that stage of the research it was important that the interviews were carried out with interviewees from the Philippines, and more specifically that were familiar with the Manila Bay area, in order to provide accurate input to the system.

Table 12.1 provides an overview of the stakeholders that were contacted for the semi-structured interviews. That table shows which organisation the participants worked for, as well as their position, through which source they were contacted and whether they responded and were available for the interview or not.

Table 12.1. Stakeholders approached for the interviews

#	Organisation	Position	Connection	Responded	Available
1	Disaster Management Service	Disaster managers' team	510 office	Yes	Yes
2	Operations Center	Disaster managers' team	510 office	Yes	Yes

510 proposed the two agencies mentioned above, as good source of information for the research purposes required for this thesis. The Philippine Red Cross is an organisation with large relevance in the country regarding emergency response and relief and hence, the input of their emergency response agencies is extremely valuable.

Both interviews were carried out in their respective offices, in the Philippine Red Cross headquarters, with the manager as well as part of the team of that agency. Those interviews were directed by the author of this thesis and members of Deltares and 510. Notes were taken by the three members guiding the interviews, and after the compliance of the interviews those notes were shared among each other in order to compare the information received. The most relevant information obtained from those meetings was selected and clustered, and summaries were written. Those summaries were reshared with the interviewees in order to verify the gathered data was licit. Modifications to the forecasting system were done after the outcomes from the interviews were processed. The summaries of the outcomes as well as their implementation in the impact-based forecasting prototype are presented in Section 12.2.

Table 12.2 depicts an overview of the details of the interviewed stakeholders, including their organisation, position within the organisation, the location of their works, the natural disasters they face and the interview mode and language.

Table 12.2. Details of the interviews

#	Organisation	Position	Location	Natural disaster	Interview mode	Interview language
1	Disaster Management Service	Disaster managers' team	Philippines	Any natural disaster occurring in the Philippines	Face-to-face	English
2	Operations Center	Disaster managers' team	Philippines	Any natural disaster occurring in the Philippines	Face-to-face	English

12.1.2 Invitation to the interviews

The Philippines has a hierarchical organisation that makes it not possible to establish meetings without passing through several steps and the contact chain required. For this visit to the Philippine Red Cross, 510 contacted the Netherlands Red Cross country representative in the Philippines. The country representative organised the meetings with the heads of the Disaster Management Service and the Operations Center, which in their turn invited members of their teams to assist to our meetings as well.

12.1.3 Interviews structure

Because of the character of the topic and the stakeholders, it was decided to carry out semi-structured interviews, for the same reason why in the first step of this thesis semi-structured interviews were chosen (see Section 7.1.3). Structured interviews with specific questions that do not allow for diversion were not possible in this topic, as most disaster managers have lived extraordinary experiences that bring emotions into the conversations, which makes it difficult to get concrete answers for a determined question. Furthermore, it was considered that semi-structured interviews of open character would allow to squeeze better the large knowledge of the participants in disaster management, which would even help to sometimes gather relevant information on unforeseen topics by the interviewer (Bryman, 2012).

Operations Center interview structure

Two visits were performed in the Operations Center. The first visit was focussed on understanding what the Operations Center does and how they work, whereas the second visit was aimed at showing the impact-based forecasting system.

The first visit allowed to understand the technical knowledge of the team, by comprehending the proficiency of their work. During the second visit to the Operations Center, the team and its software developer attended the meeting. Because of the level of work observed during the first visit, it was considered that during the second visit showing the prototype itself, instead of showing scenarios, would provide a more enriching outcome. In order to show the prototype, first a guided tour throughout the system was carried out, showing the basics of the information provided by the pilot. Afterwards, the information of more interest for the Operations Center was shown in detail. While displaying the system, the team already provided large amounts of feedback about the content and the display of the information. Furthermore, the team provided useful input about unforeseen topics of importance for the developer of the prototype.

Once the Operations Center employees comprehended well the pilot of the impact-based forecasting system, questions were carried out on the topics that had not been previously addressed.

Table 12.3 provides an overview of the open-ended questions prepared for the meeting with the Operations Center team. The questions are organised in several groups. Notice that the questions under *general information* are not as general as the questions in the other topics, due to the specific character of this theme.

Table 12.3. Open-ended questions asked to the Operations Center

#	Open-ended questions
General information	
1	What actions are taken in the Operations Center?
2	Does a regional focus help the Operations Center?
3	Which portals/tools are used by the Operations Center during a disaster event to coordinate the actions to be taken?
4	Which trigger is used by your team?
5	Is the Disaster Management Service already implementing Early Action Protocols?
Forecasting information	
6	Which forecasting system are you currently using?
Display needs	
7	If you could design a dashboard for disaster management, how would it look like?
Information needs	
8	Which assets impacted are of most importance?
9	Is it the economic impact on critical infrastructures useful for disaster management, or a more actionable impact would be preferred?
10	Do you consider or would like to consider probabilities of the forecast? How would be useful to provide these probabilities?

Not all the questions prepared beforehand were asked during the meeting due to the flexible character of the interview, in which some questions had been answered before the actual questions turn started, and others were considered of non-relevance anymore after getting a better understanding of the Operations Center work. Therefore, the questions were tailored according to the situation. Furthermore, as it has been mentioned before, the Operations Center team provided important answers to questions that had been unforeseen by the interviewer.

At the end of the meeting, the participants were informed that a summary of what had been talked would be sent to them in order to know whether they agreed with what had been understood from the discussion.

Disaster Management Service interview structure

During the visit to the Disaster Management Service, the first part of the meeting was used to understand the work carried out on this thesis, and the work carried out by the Disaster Management Service. First, a presentation of this thesis was shown, with illustrations on the impact-based forecasting prototype designed. It was considered a better option to provide illustrations of the pilot rather than the system itself, due to the large amount of features the system has. Therefore, some scenarios were introduced, in order to provide a general idea of the content and structure of the forecasting system.

Figure 12.1 depicts one of the scenarios of the impact-based forecasting pilot shown to the Disaster Management Service.

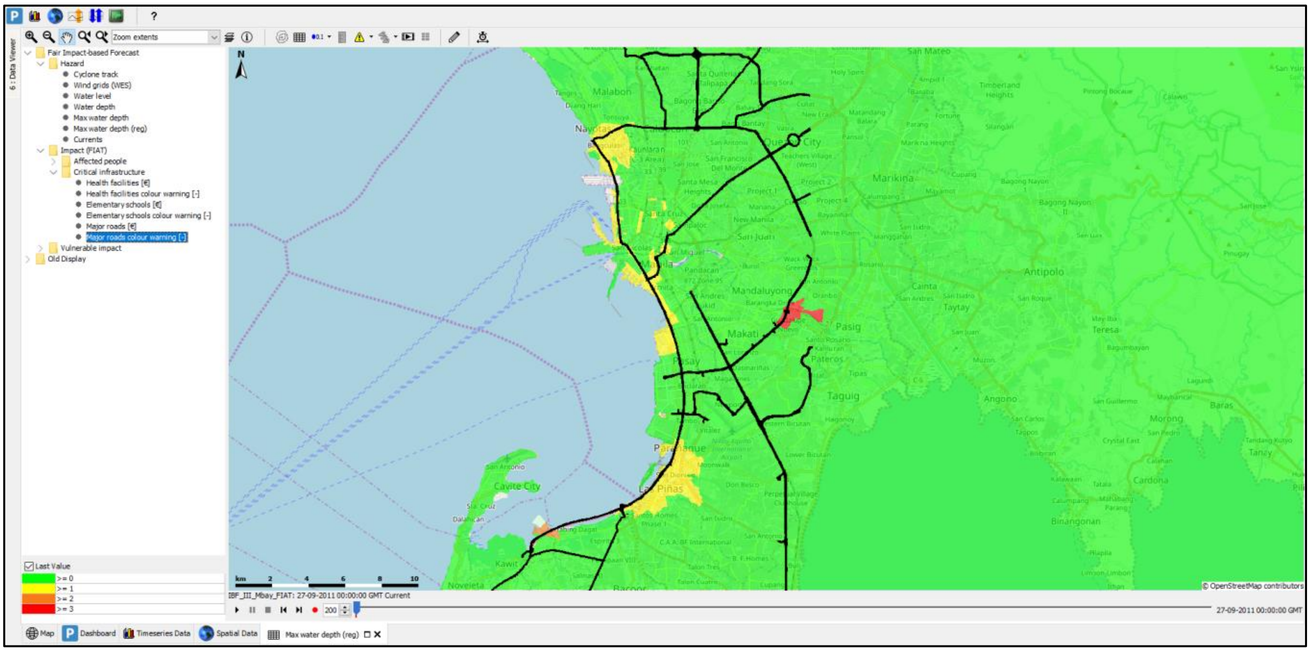


Figure 12.1. Scenario with the road impact map in a colour code format

Afterwards, the DMS presented their work, followed up by a fluent discussion about impact-based forecasting and their information needs. Beforehand, a set of open-ended questions had been prepared, in order to obtain the required information for this research. However, due to the conversation with the team, many of those questions had been answered before they were asked. Therefore, only the questions that had not yet been answered as a result of the conversation were demanded. Furthermore, as a result of the discussion and because of a better understanding of the functions of the Disaster Management Service, new queries arose and were asked in situ, and other questions were neglected due to their irrelevance within the context.

Table 12.4 provides an overview of the open-ended questions prepared for the meeting with the Disaster Management Service team. The questions are organised in several groups. Notice that the questions under *general information* are not as general as the questions in the other topics, due to the specific character of the theme.

Table 12.4. Open-ended questions asked to the Disaster Management Service

#	Open-ended questions
General information	
1	What works does your team do?
2	What actions are taken by your team as an emergency response?
3	What is the methodology used by your team?
4	Which trigger is used by your team? And by the Philippine Government?
5	Is the Disaster Management Service already implementing Early Action Protocols?
Forecasting information	
5	How is FBF evolving in the long future? Global, regional, local?
6	Currently the methodologies of FBF are focused on a national scale. Is there a trend?
Information needs	
7	Is the economic impact on critical infrastructures useful for disaster management, or a more actionable impact would be preferred?
8	Which assets impacted are of most importance for the Disaster Management Service?

At the end of the interview, the participants were informed that a summary of what had been talked would be sent to them in order to know whether they agreed with what had been understood from the discussion.

12.2 Results: Feedback and improvement of the forecasting system

In this section of the report, first the knowledge gathered during the semi-structured interviews on the background of the Philippine Red Cross is presented. A better understanding of their role can help to understand the feedback provided on the forecasting system. Afterwards, the feedback on the prototype and its improvement are explained. The feedback provided by the disaster managers has been classified according to the following topics: general, hazard, exposure, vulnerability, impact and others. Each of these feedback categories has been split in sub-categories with subjects that the disaster managers considered of importance. In order to make the structure of this section more understandable for the reader, Table 12.5 provides an overview of the topics addressed in this results section, with an hyperlink to each of the categories and sub-categories obtained from the feedbacks of disaster managers.

Table 12.5. Structure of the results section, with the feedback categories and sub-categories derived from the interviews to disaster managers

Feedback category	Sub-category
Understanding PRC	Introduction to the Operations Center
	Introduction to the Disaster Management Service
General feedback	Distinction between static and forecasted data
Hazard feedback	Clearer representation of the probability as a set of typhoon tracks
	The human depth of flooding
	Distance from each municipality to the typhoon
Exposure feedback	Population comes first
	Elementary schools, a relevant point of contact
Vulnerability feedback	Validating the advantage of vulnerability in forecasting
Impact feedback	Display organisation according to municipalities
	Functional rather than economic impact
Others	Triggers are not always important
	Forecast interval every three hours
	Danger: the eye of the cyclone gives the impression the cyclone is over
	Zero causalities competition

Each feedback sub-category is explained in this report and split in three parts: the forecasting system before visiting the Philippines, the feedback provided by the Philippine Red Cross and the forecasting system after implementing the inputs of disaster managers from Manila.

12.2.1 Understanding PRC

A visit to Manila, Philippines, has been done during this research in order to improve the forecasting prototype. The first week of the visit, as mentioned in the previous section, the author of this thesis attended to the 3rd Asia Pacific Regional Dialogue Platform on Forecast-based Financing. Thanks to the participation in this Platform, a better understanding of the framework of disaster management in the Philippines was gathered. This allowed to improve the design of the impact-based forecasting system. Furthermore, during the second week of the field visit, the Philippine Red Cross headquarters were visited, and meetings with the Disaster Management Service and the Operations Center were carried out. These visits provided enriching information for the research.

In this section some of the knowledge and inputs obtained from those two weeks in the Philippines are presented. Furthermore, when possible the inputs gathered in the Philippine Red Cross have been implemented in the forecasting system and hence, a comparison of the prototype before and after the visit to Manila has been provided. Only input from the visits to the Philippine Red Cross have been implemented in the prototype, as those visits had an intention to gain understanding in the information and display needs of disaster managers, whereas the visit to the Dialogue Platform had an educational objective, in order to gain knowledge regarding the disaster management framework in the Philippines.

Introduction to the Operations Center

During the visit to the Operations Center, a better understanding of their task on emergency response was gathered. Therefore, in this section the Operations Center tasks are presented, in order to comprehend why the feedback of this stakeholder is of large value for this research.

History and task of the Operations Center

The Operations Center of the Philippine Red Cross is the organisation in charge of receiving the data and information from the PRC Chapters and volunteers, for all the emergencies and disasters occurring in the Philippines. Besides, the Operations Center is in charge of mobilising the volunteers and staff when there is an incident. This organisation must take actions for any emergency they are notified of, once this one is verified is true. The Operations Center has 143 volunteers spread nationwide, that inform of the incidents on the field. Furthermore, elementary schools are a key element as well, because many of them act as evacuation centres and are a contact point for the Operations Center to know what is happening on the field. Once the dimension and characteristics of the emergency are understood, the Operations Center informs the Philippine Red Cross Chapters and the Disaster Management Services (DMS) on where to act (further information on the DMS is presented in the next section).

Nowadays, the Operations Center makes use of state-of-the-art techniques to process disaster data and coordinate the emergency response, using platforms and tools that allow to take fast and decisive decisions easier. The Operations Center was redesigned in 2015, evolving from gathering all the emergency information through phone calls to being one of the world’s reference centres is today. During this reform, a dashboard was designed by the manager of the Operations Center, which integrates several of the requirements for a better coordination in the organisation, such as the location of volunteers on the field and the real time situation of ambulances.

Ultimately, once impact-based forecasting is implemented in the Philippines, the Operations Center should be the organisation looking at these systems in order to coordinate the emergency response and notify the DMS once the trigger is reached.

Tools of the Operations Centre

Since 2015, the Operations Center uses several tools and platforms that allow for a more integrated and decisive decision-making during emergency situations. The Operations Centre makes use of a dashboard, in which real time information on the location of ambulances is available, thanks to the installation of GPS systems. Besides knowing their position, the dashboard allows to know whether those ambulances are occupied, empty or whether they are damaged. Furthermore, the dashboard contains the contact and location information of their 143 volunteers, in order to know who is able to help in the emergency, but also to know whether some volunteers have been affected by the disaster. This dashboard provides information as well on the location of critical infrastructures, such as hospitals and elementary schools, which are a contact point in the field, especially relevant to understand the circumstances of the disaster. Because during an emergency the responders must react in short time under stressful situations, a check list has been designed for the workers of the Operations Centre not to miss any information that is relevant.

Besides the dashboard, other tools are used by the Operations Centre in order to improve the decision making during a disaster. The Flood Tags Tool is used to know the flooded areas in real time, based on social media publications. Once this information is verified by the volunteers on the field, the emergency actions start.

Furthermore, unusual movements of population can indicate an unpredicted disaster in a certain area. In order to detect this mass displacements, the Operations Center uses GeoInsights, a tool developed by Facebook that provides near-real time information on the location of population, how they are moving and whether they are safe (Maas et al., 2017). Facebook also helps on the coordination and verification of disasters through Facebook groups, in which volunteers and workers communicate and share images that confirm the emergencies.

For a better understanding of the impact a typhoon can cause, during a disaster situation, the employees of the Operations Center analyse the data of similar past typhoons, in order to know the casualties those had, and the areas that were more affected. Having this information can help prioritise the locations that will need humanitarian aid. Besides the impact of past data, information on the vulnerabilities of the area is also important.

Relations of the Operations Center

The Operations Center does not work alone on the disaster management tasks and receives information from different organisations. PAGASA provides typhoon forecast data to the Operations Center, updating the track of the typhoon every six hours before it makes landfall, and every three hours once the typhoon has touched the ground. Moreover, the Philippine Statistics Authority provides data on building materials per barangay, which allows to identify vulnerable locations. The Operations Center and the Philippine Disaster Resilience Foundation (PDRF) also collaborate during a disaster situation, exchanging information. The Philippine Disaster Resilience Foundation has the first private operations centre in the world, and the difference with the PRC Operations Center relies on their focus. While PDRF concentrates on the affected infrastructures, PRC puts its attention on the affected communities. Furthermore, the Operations Center is always in contact with the local communities, and especially with the elementary schools, which operate as evacuation centres during disasters. With these communities there is an exchange of information, in which the schools provide information on whether there is a lot of population in the centres and how the situation is on the field, while the Operations Center delivers knowledge on the hazard and provides instructions on how to act.

Besides this transfer of information between several organisations, the Operations Center is also in close contact with the Disaster Management Service of the Philippine Red Cross. This department is in charge of the disaster coordination when major disasters affect nationwide. Therefore, the Operations Center gathers the data and information, and once a forecasted trigger is reached, the DMS is advised to take action. However, for less intense disasters, the Operations Center is the organisation that acts and coordinates the aid actions.

Introduction to the Disaster Management Service

During the visit to Disaster Management Service (DMS), a better understanding of their task on emergency response was gathered. Therefore, in this section the DMS tasks are presented, in order to comprehend why the feedback of this stakeholder is of value for this research.

Early Actions and Plans for disasters with nation-wide relevance

The Disaster Management Service is one of the largest services provided by the Philippine Red Cross and is the lead of the disaster coordination. It acts during major disasters affecting nationwide, mainly delivering humanitarian assistance. Besides acting during emergency and disaster situations, it focuses as well on building the capacity of communities to minimise their risks, and to immediately cope and recover after disasters (Philippine Red Cross, 2019).

The Disaster Management Services has four core programs in order to fulfil their objectives: Disaster Risk Reduction, Disaster Preparedness, Disaster Response and Disaster Recovery. Within the Disaster Risk Reduction and the Disaster Preparedness programs lies the Forecast-based Financing methodology, in which an Early Action Protocol is activated once a forecasted trigger is reached. This methodology aims to reduce the impact of disasters on the population. Nowadays, the trigger for typhoons DMS uses is defined by a statistical model provided by 510. Actions are activated once it is predicted that more than 10% of the households will be totally damaged in more than three municipalities (Philippine Red Cross, n.d.-a, n.d.-b).

Since the year 2018, DMS has started applying Early Action Protocols for typhoons. These actions are focused on the reduction of the impacts with more priority for the Disaster Management Service: loss of lives, loss of income of farmers and fishermen and damages to houses. The disaster risk reduction actions implemented consist on the pre-empty evacuation of the population to shelter centres 24 hours before the landfall, on the cash for work for farmers and fishermen and on house strengthening kits distribution. For cash-for-work for early harvesting, monetary help is provided to farmers in order to allow harvesting before the typhoon makes landfall. In two days, 50 teams of 20 to 30 workers cover the harvesting of 100 farms and are paid 1500 php/worker/2days of work. For the distribution of shelter strengthening kids, the materials of the household are considered. Nowadays, wooden or mixed wall houses with deficiencies are provided with the kits. Furthermore, since 2019, evacuation of livestock has been implemented, where DMS takes care for the rental of trucks to transport the animals, for the food provision to small livestock and for the construction of a fencing system (Philippine Red Cross, n.d.-a, n.d.-b).

Restoring shelter and livelihood assets

The Disaster Management Service has a program focused on the recovery phase of a disastrous event, with a time frame up to one year. In this program several actions are carried out. On the one hand DMS performs activities related to providing shelter to the most vulnerable, including permanent resettlement, temporary shelter and shelter repair. On the other hand, actions related to the livelihood of the population are carried out, such as activities at household level, skills trainings, enterprise developments and community managed projects (Philippine Red Cross, 2019).

12.2.2 General feedback

In this section, feedback provided by the Philippine Red Cross regarding the forecasting system in general is presented.

Distinction between static and forecasted data

During the visit to the Operations Center, the distribution of the forecasting system screen was commented. The obtained feedback allowed to improve the IBF prototype. In the following paragraphs, the forecasting system presented to the disaster managers will be introduced, as well as the feedback obtained, and the final prototype created.

Forecasting system presented to the Operations Center

The forecasting system shown to PRC presented no distinction between static and forecasted data. All the data was depicted together in the same screen location. Besides, the static and forecasted information could not be superposed in order to observe different data overlapped.

Figure 12.2 below provides an example of the forecasting system presented in the Philippines. The left image shows the percentage of vulnerable population (static data), whereas the right image shows the predicted impact on the vulnerable population (forecasted data).

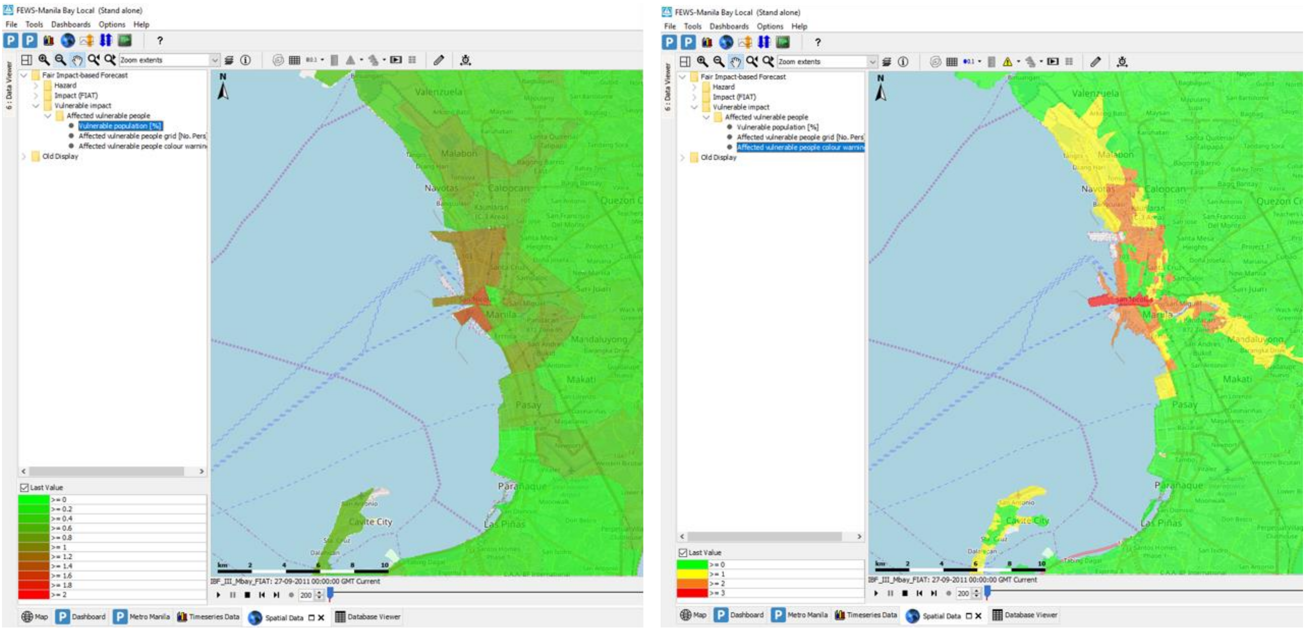


Figure 12.2. Example of the forecasting system before the visit to the Philippine Red Cross. Left: static data. Right: Forecasted data

Operations Center's feedback

According to disaster managers from PRC, there should be a clear distinction between the static and the forecasted data in the system. Information such as population maps, vulnerability maps and the location of volunteers and ambulances should be provided and indicated differently in the prototype.

Although the forecasting system shown to the Operations Center provides information on the impact on population, it is still necessary to have information on the population of the area, as a density function or in total numbers. There are locations that might not be flooded and hence, population might not be directly affected. However, population might still decide to displace to evacuation centres as a preventive measure or in order to have access to aliments.

Vulnerability maps are of importance as well in order to help disaster managers decide where to act. It is necessary to know where the poor areas are and which kind of materials the buildings are made of.

Besides, the information on the location of the volunteers is of relevance because it allows to know whether these responders can assist in case of an emergency, or whether they have been affected as well by the emergency. Furthermore, having real-time information of the location and status of the ambulances allows decision makers to better coordinate the actions during an emergency.

New system

In the new system, static data has been implemented as different layers, that can be toggled and superposed with forecasted information. The forecasting system contains now density population maps. These maps are static and do not show real time movement of the population. Although they do give an indication on where the population is more concentrated. Moreover, a vulnerability map has been provided. This map indicates the percentage of vulnerable population per municipality. Vulnerability maps at building level are still not available for this area of Manila Bay, however maps of the percentage of buildings with strong roofs and strong walls per municipality have been taken from the 510 dashboard and are available in the forecasting system as well. Unfortunately, the location of the volunteers and ambulances has not been placed in the system due to lack of data.

In Figure 12.3 it can be observed how the static and the forecasted data are now placed in different locations of the screen and can be superposed by toggling the desired layers. In the screen of the forecasting system depicted, the affected health facilities are superposed with the population density in Metro Manila.

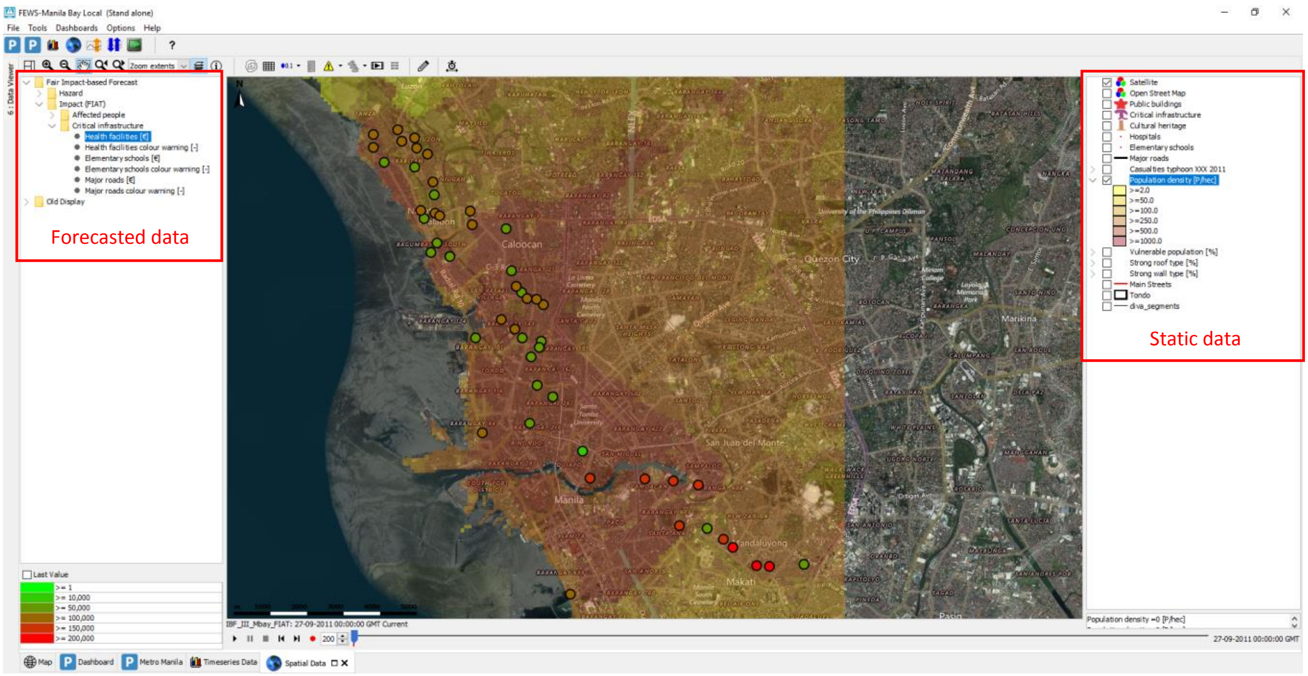


Figure 12.3. New forecasting system with static and forecasted data differentiated

12.2.3 Hazard feedback

In this section the feedback provided by the Philippine Red Cross related to the hazard side of the forecasting system is presented. The following topics have been tackled in this section:

- Clearer representation of the probability as a set of typhoon tracks;
- The human depth of flooding;
- Distance from each municipality to the typhoon.

Clearer representation of the probability as a set of typhoon tracks

During the visit to the Operations Center, the representation of the typhoon tracks was commented. The obtained feedback allowed to improve the IBF prototype. In the following paragraphs, the forecasting system presented to the disaster managers will be introduced, as well as the feedback obtained and the final improved prototype.

Forecasting system presented to the Operations Center

During the visit to the Operations Center, ten track ensembles of typhoon Nesat (2011) were shown, in which each track had a different probability of occurrence. Figure 12.4 shows the ten track ensembles (in blue), and the best track provided by the Joint Typhoon Warning Centre (in white).

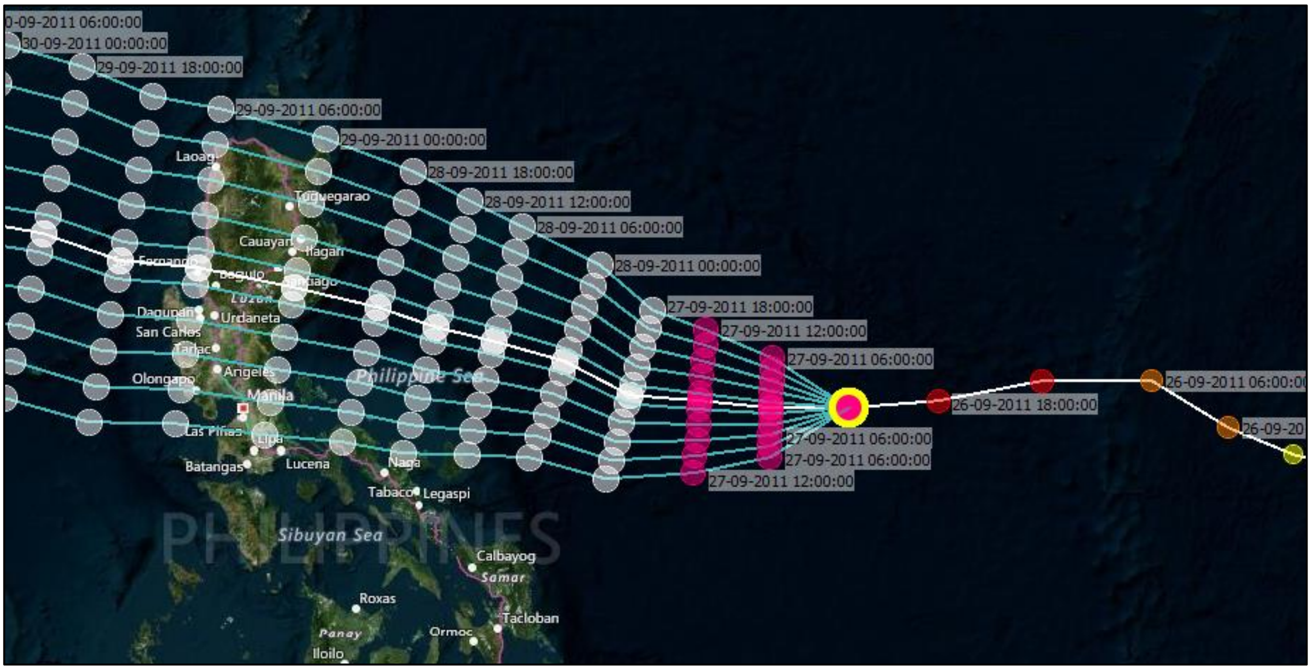


Figure 12.4. Track ensembles for typhoon Nesat in 2011

Operations Center's feedback

According to the Operations Center, the delivery of a large number of tracks does not help in the decision process to determine the location where actions should be taken. For disaster managers it is preferable to provide a set of two or three tracks with their corresponding probability. PAGASA nowadays provides three tracks: two tracks that delimit an area of uncertainty, and an average track. The Operations Center uses this forecast provided by PAGASA, and acts within the areas of uncertainty. This representation of the typhoon pathway helps the Operations Center to decide where early actions should be taken.

Figure 12.5 below shows an example of the typhoon path forecast provided by PAGASA, in this case for Typhoon Mangkhut.

Figure 12.5. Track of Typhoon Mangkhut delivered by PAGASA (Philippine Latest News, 2018)

New system

Because the uncertainty area of the typhoon track can be as large as the forecaster wants, for this impact-based forecasting system it has been decided to display only the most outer ensembles, in which the probability of occurrence is the lowest, and the two ensembles in which the probability of occurrence is the largest. Furthermore, the best track provided by JTWC is displayed as well in white.

Notice that the forecasting platform used, Delft-FEWS, does not allow yet to depict uncertainty areas within track ensembles. For this reason, the representation of certain typhoon tracks has been presented instead. Figure 12.6 depicts the new forecasting system with less typhoon track ensembles.

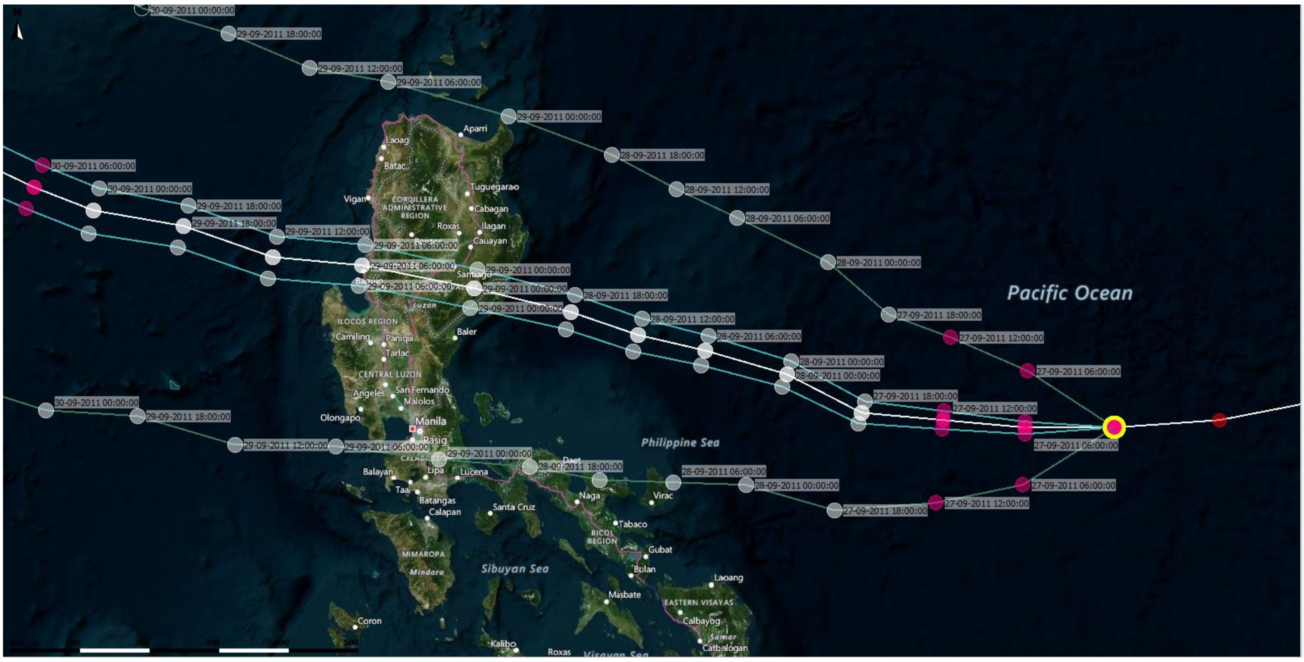


Figure 12.6. New forecasting system with fewer typhoon track ensembles

The human depth of flooding

During the visit to the Operations Center, the need for a more comprehensive flooding unit was expressed. The obtained feedback allowed to improve the IBF prototype. In the following paragraphs, the forecasting system presented to the disaster managers will be introduced, as well as the feedback obtained and the final improved prototype.

Forecasting system presented to the Operations Center

The water depth maps and the water depth times series of the forecasting system were shown in PRC, in which meters were the unit used to represent the dimension of the flooding. Figure 12.7 depicts the original system presented to the Operations Center.

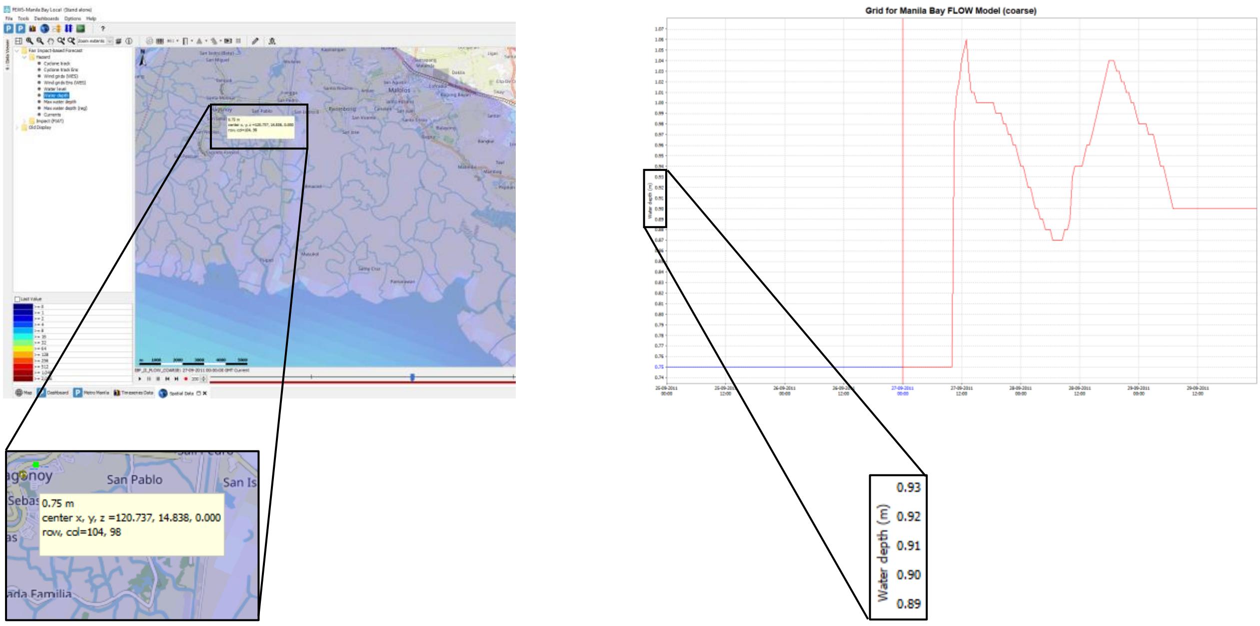


Figure 12.7. Forecasting system with the water depth units in meters.

Operations Center's feedback

When informing the volunteers and population about the severity of the flooding, the Operations Center needs to make use of units that are comprehensible for non-technical people. An example of a flooding unit adapted to its users' needs has been created by the Philippine government. This government uses the height of a famous kickboxer, Eduard Folayang, a to give a reference to the population on how high the water will be during a certain event.

New system

In order to make the water depth more comprehensible, a more familiar unit has been implemented in the forecasting system. The same metric used by the Philippine government has been chosen (the height of the kickboxer Eduard Folayang). The water depth in meters has been converted to feet, and from feet to Eduard Folayang, which is 5.7ft height. These conversions have been done within Delft-

FEWS using a Unit Conversion module. Hence, the water depth is now provided in the forecasting system with the Eduard Folayang unit. Figure 12.8 depicts the new forecasting system with the water depth in Eduard Folayang units.

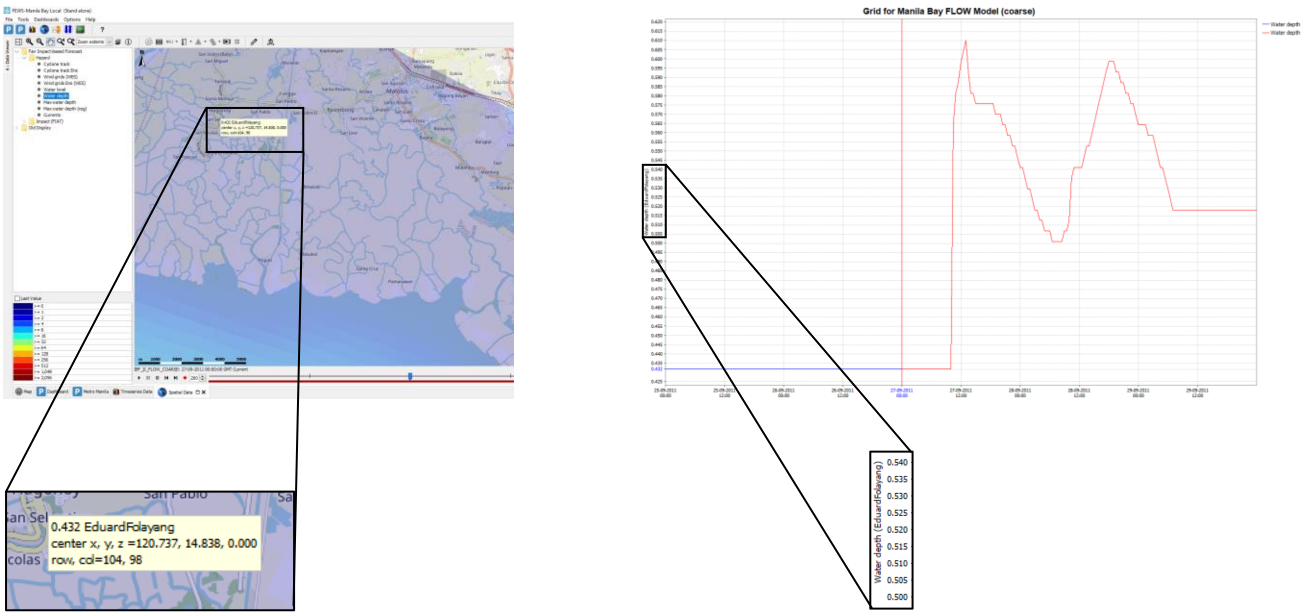


Figure 12.8. New forecasting system with the units in Eduard Folayang

Distance from each municipality to the typhoon

The need of disaster managers to know the distance from each municipality to the typhoon was understood during the visit to the Operations Center. The obtained feedback on the forecasting system allowed to improve the IBF prototype. In the following paragraphs, the forecasting system presented to the disaster managers will be introduced, as well as the feedback obtained and the final prototype.

Forecasting system presented to the Operations Center

The system shown in the Operations Center provided the following hazard information: Ensemble of the cyclone tracks, the time to landfall, the wind speeds and the water depths. However, it did not give information on the distance from each municipality to the cyclone track.

Operations Center's feedback

The distance of each municipality/province to the landfall point is important, in order to know in which municipalities assets can be pre-deployed, which municipalities could help the most affected areas by the typhoon and how much time in advance this help should be provided.

New system

In the updated forecasting system, the distance from each centroid of a municipality to the cyclone has been provided, throughout all the forecasting time. The distance of each centroid of a municipality has been calculated defining a Transformation Module within Delft-FEWS. The outcome has been represented in a map. This map shows the distances to the cyclone in a colour range from yellow to red (yellow indicates that the municipality is further to the cyclone, whereas red indicates more proximity). The distance can be visualised as well in a time series for each municipality, to know when the cyclone will be the nearest to that specific municipality. Notice that the distance to the typhoon is not the distance to the centre of the typhoon, but the distance to the maximum wind speeds. The reason chosen for that is because the maximum wind speeds hit earlier and are more damaging than the centre of the typhoon itself. Therefore, it is of larger importance to know the distance to this point rather than to the eye of the typhoon.

Figure 12.9 depicts the distance map between the municipalities and the typhoon for two different time steps. On the left side, the municipality locations have yellow dots because the typhoon is still far from Manila Bay, whereas on the right map the municipalities have red dots, which indicates the typhoon is nearer. This can also be observed in the time series map shown for the municipality of Mariveles, in which when the municipality centre is yellow the time series indicates a large distance to the typhoon, whereas when the municipality centre is red the typhoon is much nearer. Notice that among the municipalities there are also colour differences in both maps, because some municipalities are nearer to the typhoon than others.

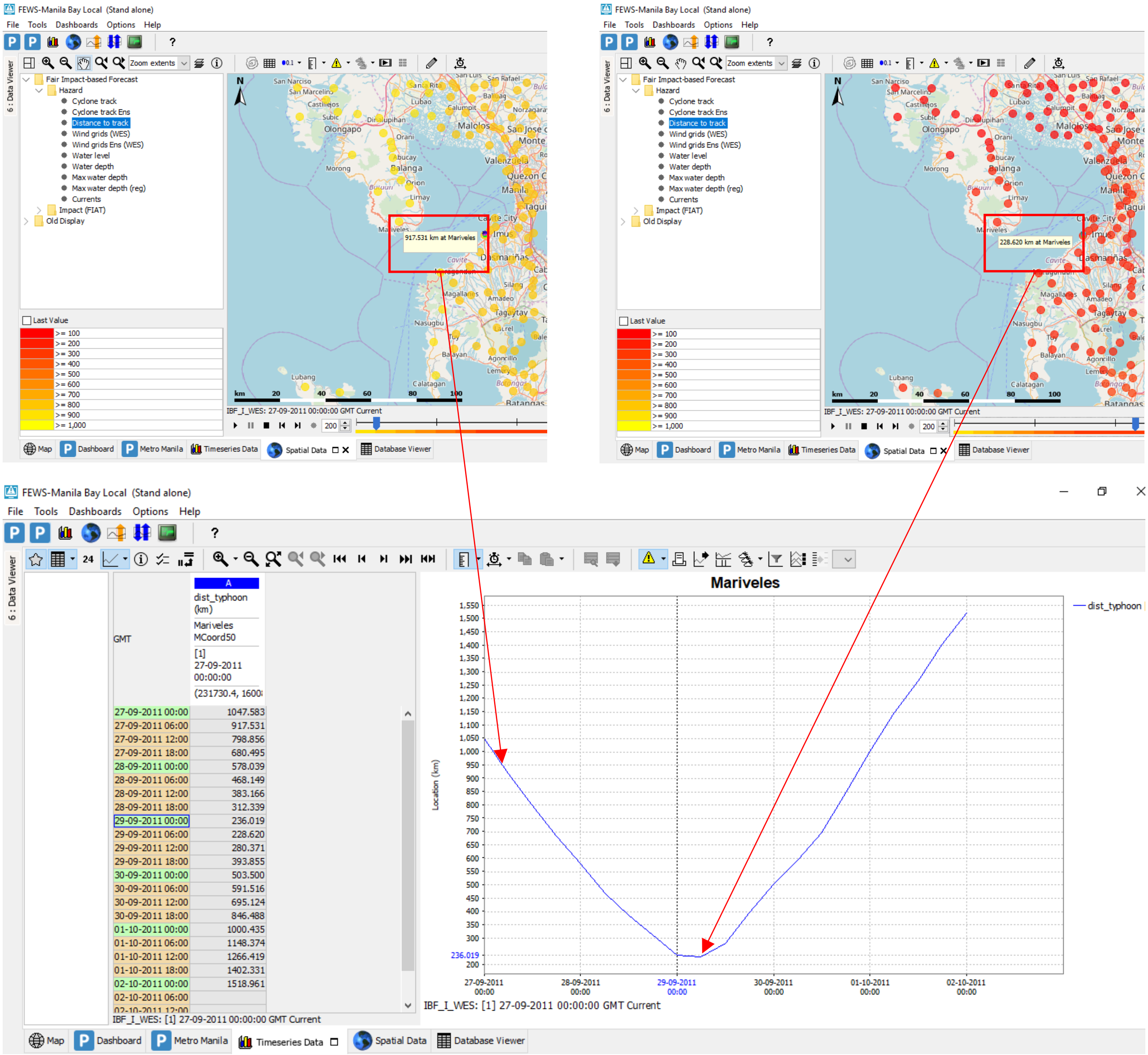


Figure 12.9. New maps in the forecasting system that indicate the distance from each municipality to the typhoon. Top left: Distance map from municipalities when the typhoon is still far. Top right: Distance map from the municipalities when the typhoon is nearer. Bottom: Time series of the distance between the municipality of Mariveles and the typhoon.

12.2.4 Exposure feedback

The feedback provided by the Philippine Red Cross regarding the exposed assets considered in the forecasting system is presented in this section. The following topics have been tackled in this section:

- Population comes first;
- Elementary schools, a relevant point of contact.

Population comes first

The importance of knowing the impact on population for local forecasts was mentioned during the visit to PRC. The obtained feedback on the forecasting system allowed to improve the IBF prototype. In the following paragraphs, the forecasting system presented to the disaster managers regarding this topic will be introduced, as well as the feedback obtained.

Forecasting system presented to the Operations Center

The forecasting system presented to the Operations Center provided information on the affected vulnerable population as well as information on the location and impact on elementary schools, health facilities and roads in Manila Bay. Figure 8.4 and Figure 9.3 depict the forecast on critical infrastructures and on affected vulnerable population.

Operations Center's feedback

The Operations Center has a community-based approach, in which the most relevant impacts are the affected communities, their households and their livelihoods. Once response has been sent to those assets, other assets become of importance. Therefore, impact on hospitals, schools and roads is only relevant when the population is affected.

New system

In this case, no modification has been done in the system, as affected population was already considered as one of the important assets for which the impact should be predicted.

Elementary schools, a relevant point of contact

Elementary schools are a relevant point of contact for the Operations Center during disaster events. In the following paragraphs, the forecasting system presented to the disaster managers regarding this topic will be introduced, as well as the feedback obtained.

Forecasting system presented to the Operations Center

The forecasting system presented to the Operations Center provided information on the location and impact on elementary schools in Manila Bay. Figure 8.4 depicts the forecast on elementary schools.

Operations Center's feedback

During a disaster event, most elementary schools act as evacuation centres. These centres are an important contact point for the Operations Center, which is informed on the amount of people reaching each evacuation centre and are provided with first-hand information of the situation on the ground. At the same time, the Operations Center communicates the hazard characteristics and advices on how to act. Elementary schools are a good indicator on what happens on the field, since they are often preferred as evacuation centres by the local population rather than shelters built strictly for evacuation purposes, due to their lack of facilities.

Therefore, it is important to know the impact on elementary schools that act as evacuation centres, in order to know whether those should be reinforced with early actions or to inform the population about changing their shelter location if the evacuation centre is not going to be a safe place.

New system

In this case, no modification has been done in the system, as schools were already considered as one of the important assets for which the impact should be predicted.

12.2.5 Vulnerability feedback

This section explains the feedback given by the Philippine Red Cross regarding the vulnerability dimension implemented in the impact-based forecasting system.

Validating the advantage of vulnerability in forecasting

During the visit to the Operations Center, the results of the impact-based forecasting system were shown in the Operations Center. In this forecasting system, the impact on vulnerable population was calculated combining hazard (storm surge water depth), exposure (population density) and vulnerability data (percentage of vulnerable population) in Manila Bay.

In this visit, the Operations Center team pointed out the special attention that they need to pay to Tondo, a district in Manila, because of the high vulnerability of that area. When the forecasted affected vulnerable population map was presented to the Operations Center, the team confirmed the good result of the system, in which the forecast indicates that within Metro Manila, Tondo is a location that emergency responders should pay special attention to.

Figure 12.10 depicts the maps of affected population when vulnerability is not considered (two left pictures) and when vulnerability is taken into account (two right pictures). On the top left image, it can be observed the large concentration of population affected around the region of Metro Manila. However, as it can be seen in the bottom left image, the red area is still too large to be able to define priorities regarding emergency management. The right image, instead, depicts the affected vulnerable population in the area. In the bottom right image, it can be observed that within Metro Manila, Tondo stands out by having more affected vulnerable population than the remaining area. Therefore, the implementation of vulnerability into the forecasting systems allows disaster managers to quickly decide where to act and to prioritize their actions.

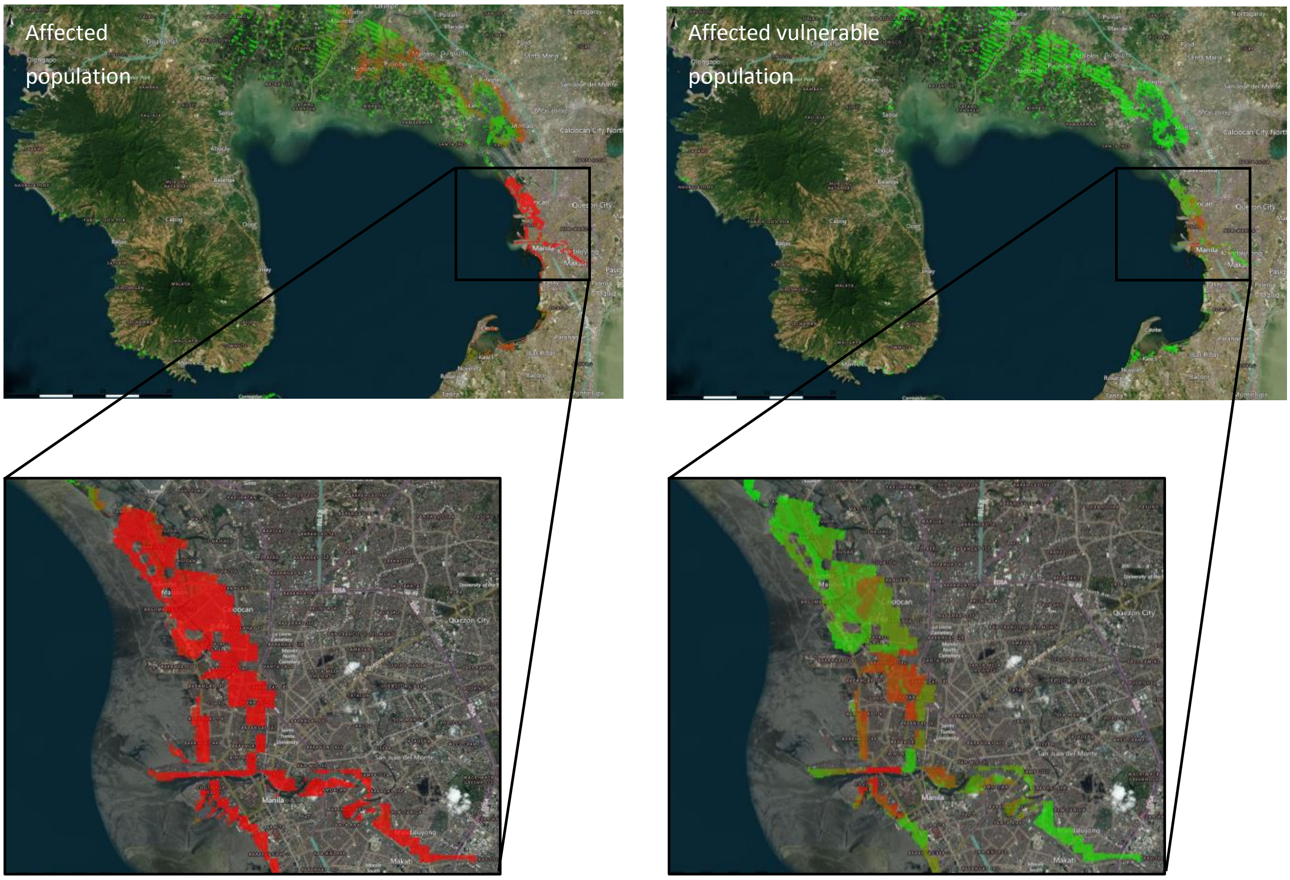


Figure 12.10. Top left: Grid map of the affected population in Manila Bay. Bottom left: Close look at the affected population in Tondo. Top right: Grid map of the affected vulnerable population in Manila Bay. Bottom right: Close look at the affected vulnerable population in Tondo. The colour code ranges from green (no population affected) to red (large population affected).

12.2.6 Impact feedback

This section presents the feedback on the impact maps provided by the Philippine Red Cross. For each feedback, first the forecasting system presented in PRC is explained. The following topics have been tackled in this section:

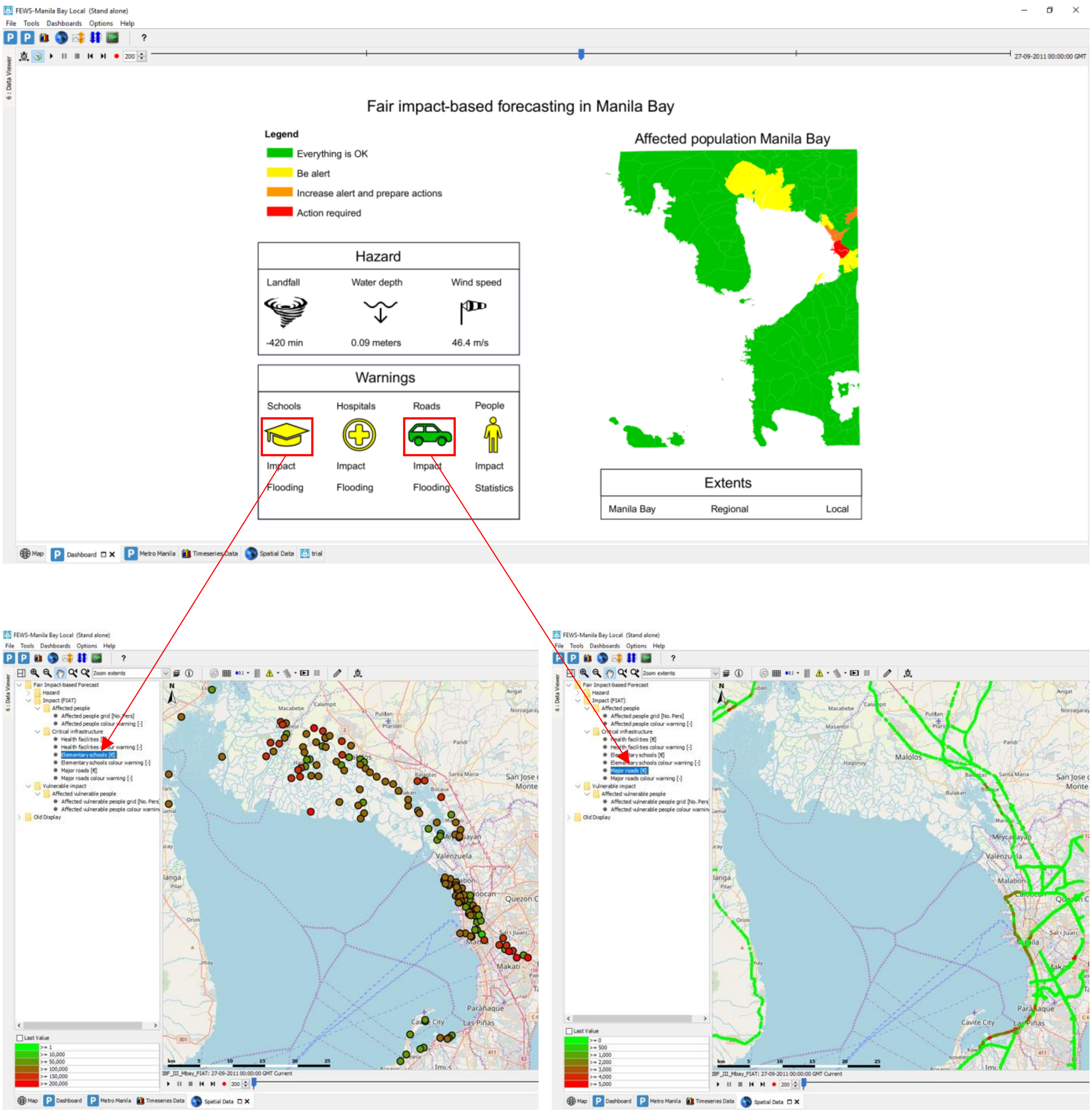
- Display organization according to municipalities;
- Functional rather than economic impact.

Display organisation according to municipalities

The need of disaster managers to get most forecasted information in one screen was mentioned during the visit to the Operations Center. The obtained feedback on the forecasting system allowed to improve the IBF prototype. In the following paragraphs, the forecasting system presented to the disaster managers will be introduced, as well as the feedback received and the final prototype.

Forecasting system presented

In the visit at the Operations Center, an interactive dashboard of the Manila Bay area was presented, in which a colour coding map showed the impact on the population in Manila Bay, per municipality. Besides, this dashboard provides information as well about the hazard and the impact on critical infrastructures. Once the user clicks in one of the critical infrastructures, a map of the impact of that infrastructure can be observed. However, the impact of each critical infrastructure is shown in different maps.



Operations Center input

The Operations Center performs the in-depth analysis of a disaster situation at provincial or municipal level, rather than focusing on a specific asset. Therefore, the dashboard should allow to zoom in a specific location to see the impact on all the critical infrastructures, on the population and the location of responders and ambulances. The display organisation should be organised per municipality or province, instead of organising it per parameter (hospitals, roads, schools). Nevertheless, the interactive dashboard was considered a useful and understandable tool for the forecasting system.

New system

In Delft-FEWS it is not possible yet to show in the same map the impact on several assets. However, a new feature called *Dashboard* has been developed in which it is possible to drag several maps into one window, showing the same location for all the maps. Therefore, in order to show all the impacts at the same time, this tool has been used, in which the impacts on the Spatial Display are dragged into this dashboard, and where a specific location can be selected in the *Zoom extents* button. Besides, the interactive dashboard can still be used as a starting point, in order to guide the user when using the forecasting system, and to provide fast information on the hazard (time to landfall, maximum water depth and maximum wind speeds) and on the impact of an event.

Figure 12.11 depicts the Delft-FEWS *Dashboard*, in which the impacts on vulnerable people, health facilities, elementary schools and major roads. Vulnerable population impacts are provided as a grid and as a colour code warning system, while impacts on the critical infrastructures are provided as icons and as colour code warning systems.

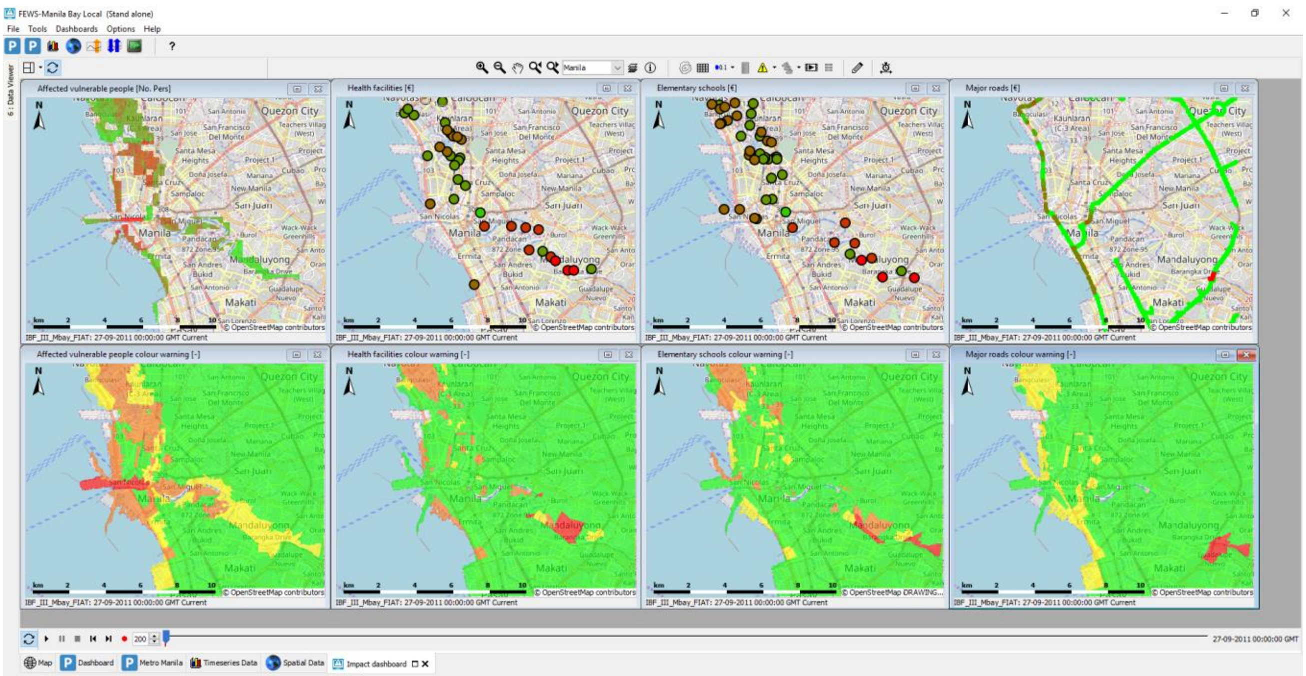


Figure 12.11. Dashboard with the impacts on vulnerable population, health facilities, elementary schools and roads, in grid and icon format as well as in colour code warning.

Functional rather than economic impact

The need of disaster managers to receive functional rather than economic data before a disaster event was commented during the visit to the Operations Center. The obtained feedback on the forecasting system allowed to improve the IBF prototype. In the following paragraphs, the forecasting system presented to the disaster managers will be introduced, as well as the feedback received and the final prototype.

Forecasting system presented

The forecasting system presented in the Operations Center showed maps on the affected vulnerable population, in grid format (providing the number of vulnerable affected people per grid cell) and in colour code warning format (created based on the number of vulnerable people affected). Furthermore, the forecasting system shown provided the economic impact on critical infrastructures: hospitals, elementary schools and roads. The impact on this critical infrastructure was represented as icons (providing the economic impact on each critical infrastructure), and in a colour code warning format (created based on the economic impact of each critical infrastructure type).

Figure 12.12 depicts the economic impacts on health facilities, elementary schools and major roads forecasted for typhoon Nesat.

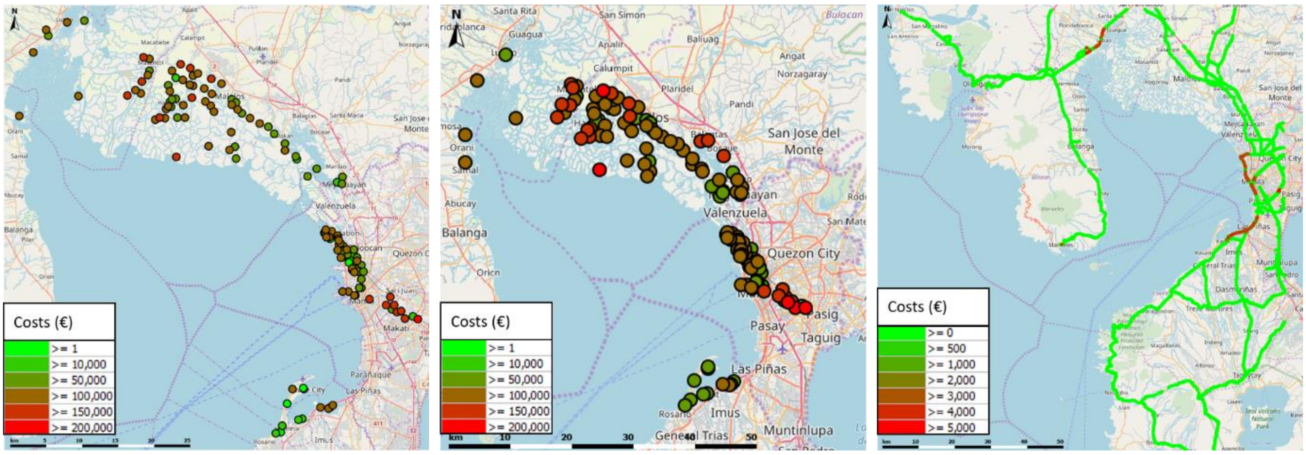


Figure 12.12. Left: Economic impact on health facilities; Middle: Economic impact on elementary schools; Right: Economic impact on the major roads

Operations Center's feedback

The economic impact is of less importance for the Operations Center during the preparedness and response phase of an event. In those stages it is more important to know whether the critical infrastructures will still be functional or not. For example, knowing if there will be road blockages that will not allow ambulances to pass. However, during the recovery face it is important to know the economic damage in order to understand which actions should be taken.

New system

In this section, the new impact maps for each critical infrastructure (roads, hospitals and schools) are presented.

Road damage. In the updated forecasting system, the road damage is not provided as economic damage. Instead, a classification is made, that distinguishes among roads not flooded, roads flooded, and non-passable roads (blocked). Pregnolato, Ford, Wilkinson, & Dawson (2017) developed a function that relates the water depth with the speed of vehicles, in order to better define the road functionality depending on the flooding depth. To define this curve, video analysis combined with quantitative data from existing studies was used. After analysing previous researches and the performance of driving tests, Pregnolato, Ford, Wilkinson, & Dawson (2017) concluded that the maximum threshold for safe driving without losing the control of the car is 30cm water depth. Therefore, a road has been assumed to be impassable only when the 30cm of water depth are reached. Hence, for this forecasting system a classification has been made according to the functionality of the roads: *Road not flooded*, when there is no water in the road; *Road with flooding*, when there is water on the road with a water depth of less than 30cm and hence, the road is still usable; and *Not passable road* when the road is not passable anymore due to more than 30cm flooding depth. This classification has been implemented by obtaining the damage factors related to each of the water depths mentioned to classify the functionality of the roads. With those damage factors obtained from Delft-FIAT, the categorisation has been created in the Spatial Display of Delft-FEWS. Figure 12.13 depicts the new road impact map.

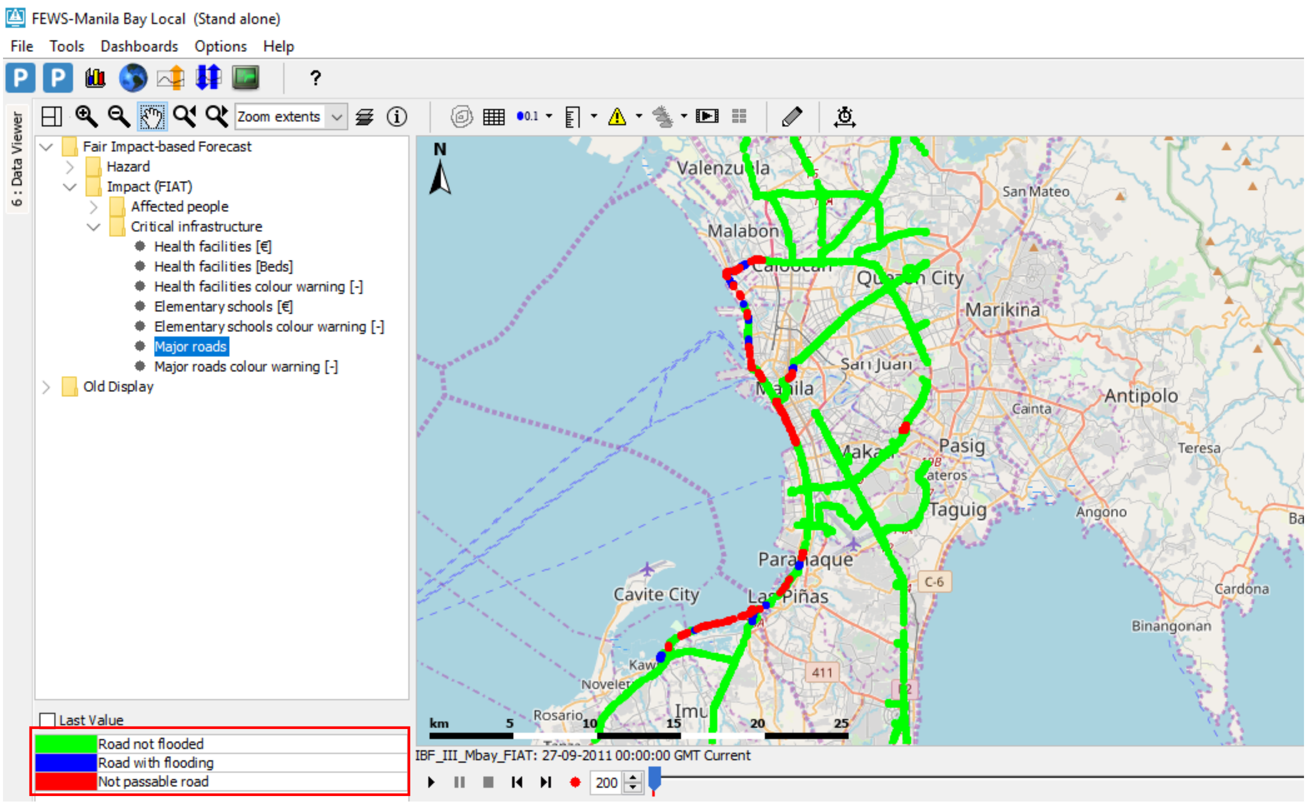


Figure 12.13. New impact map of the major roads

Hospital damage. In the updated forecasting system, information on the potential number of beds affected during a typhoon is provided, in each health facility in Manila Bay. This information is relevant to know, in order to decide whether hospital buildings should be reinforced before the disaster hits, or whether the patients in the hospitals should be transferred to a different location or if the population should be warned to attend to a different hospital in case of emergency. To estimate the number of affected beds per health facility, the Delft-FIAT model for hospitals has been redefined, in which the maximum damages have been defined as 1, in order to obtain information on the damage factor each hospital had individually. The output from Delft-FIAT has then been combined in a Transformation Module of Delft-FEWS with the information provided by the Operations Center of the Philippine Red Cross, that contains data on the number of beds per health facility in Manila Bay. Figure 12.14 depicts the new impact map of the health facilities, in which the impact is described according to the number of beds affected.

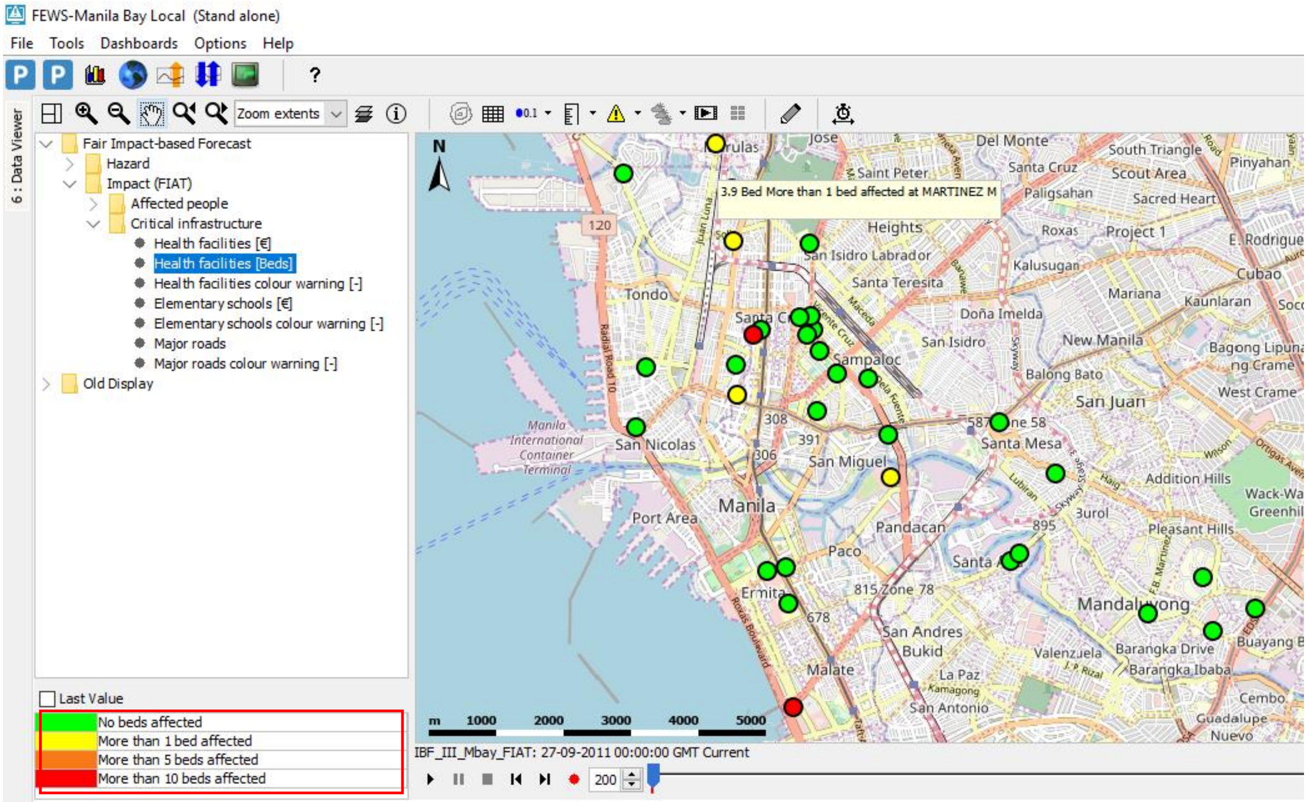


Figure 12.14. New impact map of health facilities

Elementary schools damage. Many elementary schools are used in the Philippines as evacuation centres. Therefore, with data on the area of each elementary school, it would be possible to calculate the squared meters that will be affected during a typhoon, for each evacuation centre. This would provide a guidance on the amount of usable ground available for people to shelter from the disaster. This information, however, has not been found and hence, it will be left as a recommendation for future research.

12.2.7 Others

In this section, other relevant information provided by the Philippine Red Cross related to forecasting systems is presented.

Triggers are not always important

Trigger levels are defined in order to decide when an organisation should or should not act in case of an emergency or disaster. These triggers can be based on the hazard or on the impact. The Disaster Management Service of the PRC follows the Forecast-based Financing methodology, in which when a certain threshold is reached, actions can be taken. Nowadays, the trigger of DMS is reached when the forecast predicts that 10% of the households will be totally damaged in at least three municipalities. This threshold allows them to define when early actions should start, with the intention of reducing the risk of the population. Nevertheless, the Operations Center, instead, has a different *modus operandi*, in which it is necessary to act for any emergency they are informed of, independently on the severity of the disaster. Therefore, an actionable trigger is not always relevant, as their actions need to be taken regardless the dimension of the damage.

Lessons learned: The use of a trigger depends on the kind of emergency response of each organisation.

Forecast interval every three hours

PAGASA provides updates of a cyclone forecast every 6 hours to the Operations Center. However, when the cyclone hits the ground, the forecast is published every 3 hours. During an intense situation like the landfall of a cyclone, it is important to have more frequent updates that provide more accurate information about the hazard.

Lessons learned: It is necessary to have forecasts that can be updated every 3 hours when a cyclone makes landfall.

Danger: the eye of the cyclone gives the impression the cyclone is over

In the locations where the centre of the cyclone passes, there are two large storm events, with a calm event in between. After the first storm hits, the eye of the cyclone arrives, in which there is calm weather. Then the population thinks that the cyclone is over and goes outside their shelter to look at the damages caused by the first storm. However, afterwards the second storm of the typhoon hits and because many people are already outside, in unprotected areas, many causalities occur.

Lessons learned: It is important to have a good knowledge on the typhoon track and landfall location, and to inform well the population on how to act during a typhoon event.

Zero causalities competition

Displaying certain information such as the number of causalities of historic events might seem a sensitive topic. However, during the visit to the Operations Center it was observed that there might be a profitable side from it. Since the numbers on casualties are collected and shared within the neighbouring communities, a competition has been started. In this competition communities want to necessarily keep the number of causalities at zero. The *Zero Causalities Competition* results in an extremely pro-active behaviour within the communities.

The reaction of these communities features the early evacuation of especially endangered people in coastal zones. These are moved to evacuation points and are supplied with food, shelter and care. Although population that is not going to be affected is evacuated sometimes, the responsiveness on a call for evacuation is not at risk, since the general feeling on evacuations is positive due to the good services provided in the shelters.

The Lesson learned: The display of the number of causalities for historic events per community might lead to an increased responsiveness.

13 Final forecasting system

The final forecasting system represents the final product after all the steps previously mentioned to create the impact-based forecasting prototype have been fulfilled. This chapter presents a final overview of the forecasting prototype, according to the steps presented. To see the final maps created by the forecasting system, please see Appendix C.

The forecasting prototype is a tool that allows disaster managers to take better decisions through the prediction of the impact of storm surges in Manila Bay. After talking with disaster managers, the prototype has been designed according to their needs, in a simple and clear manner, with colour codes and icons as well as grids, when possible.

13.1 Interactive dashboard

The start of the forecasting system is done through the interactive dashboard, as mentioned in Chapter 10. This dashboard allows disaster managers to navigate through the Delft-FEWS system in a simpler and more understandable manner. The dashboard presents hazard information, such as the time to landfall and the maximum water depth and wind speeds. When clicking on the water depth and wind speeds data, it is possible to observe the time series of both parameters and to open the hazard maps on the Spatial Display. Furthermore, this dashboard allows the disaster managers to have an easy and clear overview of the impacts on the main assets for them: population, schools, roads and hospitals. For more information on the interactive dashboard please see Chapter 10.

13.2 Layers

The exposure information is static information and hence, in the final forecasting prototype it has been provided separated from forecasting information. Data on population density, strong walls and roofs, vulnerability scores and the location of important infrastructures can be toggled in the Layers tab of Delft-FEWS. This allows disaster managers to overlap forecasted and static information, which is helpful when making decisions. More information about the usefulness of static information can be found in Chapter 12.

13.3 Hazard

The hazard dimension of the final forecasting prototype provides the following information:

- Cyclone tracks: it provides the two tracks with the highest probability of occurrence as well as the two tracks with the lowest probability of occurrence and the best track obtained from the JTWC.
- Distance of each municipality to the cyclone: it provides the distance of every municipality to the cyclone, in each time step.
- Wind grids: it provides the wind grids of the cyclone.
- Water depth: provides the water depth in Eduard Folayang units, giving to the water depth a human dimension that can be more understandable for emergency responders and the population.
- Currents: provides the water speeds and directions.

For more information in the final hazard information and the reasons chosen to provide this kind of information, please go to Chapter 12.

13.4 Impact

The impact dimension of the final forecasting prototype provides the following information:

- A grid map with the number of affected vulnerable people per grid (50x50m).
- A colour code warning map at barangay level based on the number of affected vulnerable population.
- A map with coloured icons that provide information on the number of beds affected in each health facility.
- A colour code warning map at barangay level based on the number of beds affected in each health facility.
- A map of the major roads affected, classified into not flooded, flooded and not passable.
- A colour code warning map at barangay level based on the affected classification of the roads.
- A map with coloured icons that provide information on the economic damage in each elementary school.
- A colour code map at barangay level based on the economic damage in each elementary school.

More information on the forecasted impacts can be obtained in Chapters 8, 9 and 12.

13.5 Dashboard to observe all impacts together

After talking with disaster managers in the Philippines, it was understood the need of having a forecasting system that provides all the information in one screen, due to the fast response required in emergency situations.

Delft-FEWS though, does not allow yet to display different impacts output from Delft-FIAT in the same map. However, a tool called Dashboard in FEWS permits the user to combine several screens in one. Therefore, in this forecasting prototype a dashboard has been predetermined in order to display the different impacts mentioned in the previous section in one screen. Furthermore, disaster managers highlighted the preference of categorising the impacts according to municipalities/provinces instead of doing so based on assets. Therefore, within this dashboard it is possible to select the desired municipality in order to pay closer attention to the impacts in a specific area. More information about the usefulness of static information can be found in Chapter 12.

13.6 Importance of vulnerability

After talking with disaster managers, it has been highlighted the importance of vulnerability in decision making. Usually, the forecast of areas affected by only considering the hazard and the exposure are too large, and do not help on the priorisation of the actions. Therefore, in this thesis the vulnerability dimension has been added to the disaster risk forecast, in order to provide a fairer and more useful forecast.

Figure 13.1 compares the affected population maps with and without considering vulnerability. The left image depicts the affected population in Manila Bay without considering vulnerability. The white square indicates the area of Metro Manila. It can be observed that all Metro Manila is largely affected, without being able to distinguish among which areas or neighbourhoods require most help. The image in the middle provides the percentage of vulnerable population extracted from the *510 dashboard.* This information shows that there are some zones within Metro Manila with larger vulnerability than others. On the right image, the affected population and the vulnerability have been combined, and depict more clearly which parts of Metro Manila should be prioritised by the disaster managers. Therefore, the implementation of vulnerability within impact-based forecasting helps decision-makers to prioritise the areas where actions should take place, which can improve the response time during emergencies.

As it was mentioned in Chapter 12, the Operations Center of the Philippine Red Cross agreed on the results of this forecasting system and pointed out that the red area of the right map corresponds to Tondo, an area where they usually need to pay special attention to due to the large vulnerability of that district.

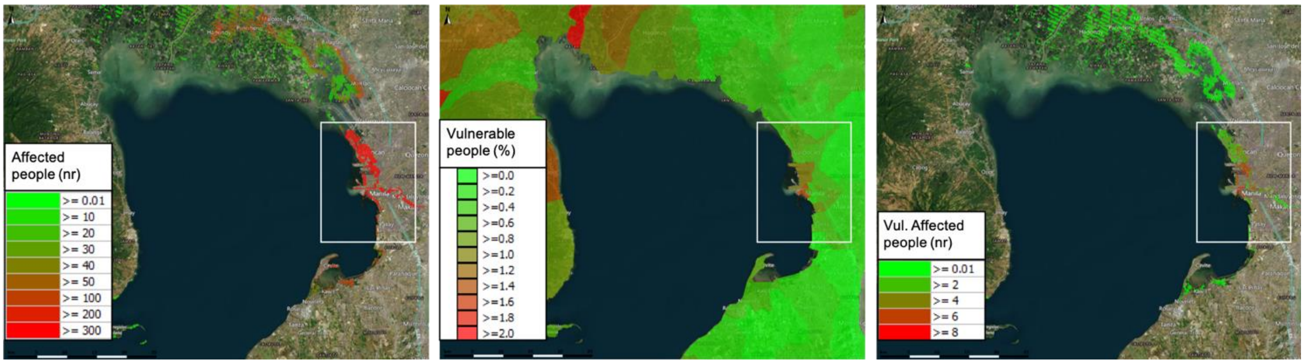


Figure 13.1.Left: affected population; Middle: Percentage of vulnerable population; Right: affected vulnerable population. The white square indicates the area of Metro Manila.

14 Discussion

In this thesis, an impact-based forecasting prototype has been developed in cooperation with disaster managers and vulnerability has been implemented into the system. However, the research approach followed in this study has its limitations due to assumptions and strategies followed as well as due to the constraints of the forecasting system itself. Therefore, this chapter has been structured into three sections that explain the limitations of the thesis approach, of the forecasting system and of Delft-FEWS.

14.1 Limitation of the qualitative research approach

During the research followed for this thesis, interviews to disaster managers have been carried out in order to understand their information and display needs. Once the forecasting system has been designed, feedback interviews have been carried out and the prototype has been updated towards a disaster manager-based forecast. However, more feedback-forecast update iterations would have been preferred during the creation of the system, in order to create a more tailor-based forecasting prototype for disaster managers acting in Manila Bay.

Furthermore, the first interviews to disaster managers were done in a structured manner, which led to too wide answers that did not provide all the necessary information required for the research. Nevertheless, the following interviews in this thesis followed a semi-structured approach, which led to qualitative and meaningful results.

Although impact-based forecasting is rising adepts within the disaster management field, most disaster managers have not worked with this kind of forecasts yet. The lack of experience with this type of systems made it difficult for disaster managers to actually imagine how an impact-based forecasting system would look like and the benefits that this system might provide in comparison to weather forecasts. Nonetheless, decision makers agreed on the usefulness of impact prediction rather than just forecasting the physical parameters of a disaster.

Moreover, an inconsistency was observed regarding the understanding of the terms impact and vulnerability. Whereas impact was sometimes considered by disaster managers as hazard, vulnerability had different meanings among the interviewees. This meant that when analysing the interviews, assumptions had to be made, in which the interpretations of impact and vulnerability were adapted to the terms used in this thesis. It has to be noticed that this inconsistency regarding the term vulnerability can be observed as well in literature, in which different studies define it in a different manner, due to the subjective and wide character of the concept.

Finally, when visiting the Philippine Red Cross, the forecasting system was shown to disaster managers. When the impact maps of the forecasting system were provided without previously presenting the dashboard, the information was considered difficult to understand at first sight. However, when the dashboard was used as a guide through the prototype, the information of the forecasting system was better understood. Nevertheless, the usefulness of the dashboard might depend on the technical knowledge of the users of the forecasting system. Depending on the background of decision makers, the complexity of the dashboard will be different, as well as the understanding of the forecasting system with or without the dashboard. Therefore, in order to determine the general relevance of a dashboard within a forecasting system, more decision makers with different background should be interviewed.

14.2 Limitations of the impact-based forecasting system

14.2.1 Limitations of the content

During the course of this thesis, the components a forecasting system requires to allow disaster managers make sounds decisions have been studied. Among those components, it is important to determine a useful forecasting scale, as well as to know the right variables the forecast should provide, their units, and how those should be depicted. In the forecasting system developed in this thesis, the predictions have been made at a local scale. The interviews with disaster managers have shown that, for countries such as the Philippines, which have a large geographical heterogeneity, it is useful to focus in specific areas in a larger level of detail. The area chosen for this research has been Manila Bay, due to its storm surge prone location and its large density population.

The required variables for the forecasting system developed have been chosen according to the information provided by the disaster managers. The outcomes of the Skype interviews and the visit to Manila Bay indicate a distinction in the forecast requirements according to the decision level of its user.

Regarding the hazard dimension, the physical properties of the typhoon of importance for local level decision makers have been implemented into the system developed in this thesis. Disaster managers pointed out as well the need for a better lead time – probability ratio in the pre-disaster phase of a typhoon event. However, this characteristic could not be improved in this research. Nowadays, the Philippine Red Cross relies on 3-days forecasts, which have a probability around 60-70%. Although with a 3-days forecast the typhoon might not be extremely accurate, early actions need to be taken. Softer actions are taken when the probability of occurrence is low. For example, house strengthening kits are distributed among vulnerable houses that might get hit by the typhoon. Finally, if the typhoon does not have impact in that location, the kits can still be used to reinforce vulnerable houses. On the other hand, more drastic actions, such as population evacuation, are taken the last day before landfall, when the probability is larger. Therefore, a cost-loss study is used by disaster managers to analyse whether and which actions should be taken, and when.

Regarding the exposure elements of interest for disaster managers, affected population and critical infrastructures are predicted by the forecasting system developed. However, although the impact on livelihoods and households is of importance as well for decision makers, it has not been included in this prototype. Livelihoods in the Philippines are based on agriculture. Its impact prediction is of big complexity due to the large dependency on factors such as soil moisture, crop season among others. Therefore, it has been recommended to study the impact on crops in future research. Relevant household damage maps could have been predicted with a finer DEM and vulnerability data.

Nevertheless, to provide a useful forecasting system it is not only required to deliver the necessary information. This information should be expressed in an understandable scale for their users. Therefore, in this system the water depth as well as the impact units have been adapted to a comprehensible language for disaster managers.

Moreover, the output of the forecasting system should also be depicted in a relevant format, in order to be easily and quickly understood. In this thesis, the manner in which the information should be presented has been studied. One of the outcomes of this research has been the usefulness of colour coded maps and icons. The colours of the barangays and icons change when certain threshold levels have been exceeded. Unfortunately, the threshold levels for schools and hospitals affected have not been studied in this research. Only the threshold level of roads has been related to the functionality of the roads, which is associated to water depth thresholds from a study made by Pregnolato, Ford, Wilkinson, & Dawson (2017). Therefore, an in-depth study on the threshold levels for each asset could be done in further research.

The importance of designing tailor-based forecasts for disaster managers, according to their agency and level of decision making, has been mentioned throughout this report. The forecasting system in this thesis has been developed for a local scale and especially for Red Cross disaster managers. However, under similar circumstances, the prototype could be generic. If the user of the prototype and the study area had similar conditions, the recommendations on the information and display needs of disaster managers could be extrapolated. Red Cross branches and NGOs usually require clear and simple information that allows to take relevant decisions quickly. However, if the user of the forecasting system would have a deeper technical background and would require more specific information in a certain aspect, the information should be delivered in a different manner with, for example, grids instead of colour coded maps. Furthermore, the assets of importance differ depending on the organisational level as well. Whereas at national level affected population might be more relevant, at regional level critical infrastructures might provide more useful information. Besides, the hydrodynamic model developed for Manila Bay has fine resolution, but it is expensive to develop. For larger areas or national models, other methodologies, such as data-driven models might be more cost-loss effective, due to the fact that coarser data can help as well for sound decisions at this level.

14.2.2 Limitations of the calculations

Regarding the limitations of the calculations of the impact-based forecasting prototype, several assumptions had to be made in order to predict the impact maps and incorporate vulnerability into the system.

The first assumption is related to the damage curves used to predict the impacts on critical infrastructures. The damage curves employed in this thesis were derived by the Joint Research Centre and are categorised per continent and land use. Damage curves for Asia and for commerce and infrastructure land uses have been used in this prototype for predicting the impact on schools, hospitals and roads. However, these functions for all Asia might not be representative for Manila Bay specifically. Ulisse Parodi (2019) performed a study on the most important inputs that drive uncertainties in coastal flood risk assessment. The outcome of this research showed that damage functions are the main contributors to uncertainty in coastal flooding models. In order to analyse the sensitivity of the model developed in this thesis to the depth-damage curves, the output of the prototype has been compared for four functions, which are presented in the following lines and can be observed in Figure 14.1:

- Damage curve of the Joint Research Centre, for commerce in Asia. This is the curve that has been used in this prototype to predict the impact on hospitals and schools.
- Damage curve from Hinkel et al. (2014). This curve provides a global scale logistic depth-damage function that relates 1-meter water depth with 50% of the assets being affected.
- Damage curve from Kok, Huizinga, Vrouwenvelder, & Barendregt (2005). This damage curve is used in the Netherlands for river flooding estimations. Although the forecast of this thesis predicts coastal flooding, this curve has been used to observe the sensitivity of the model to the depth-damage functions.
- Damage curve from Suppasri, Koshimura, & Imamura (2011). This damage curve is used to assess tsunami damages to buildings in Thailand. Although the forecast of this thesis does not consider the flooding due to tsunamis, this curve has been used to observe the sensitivity of the model to the depth-damage functions.

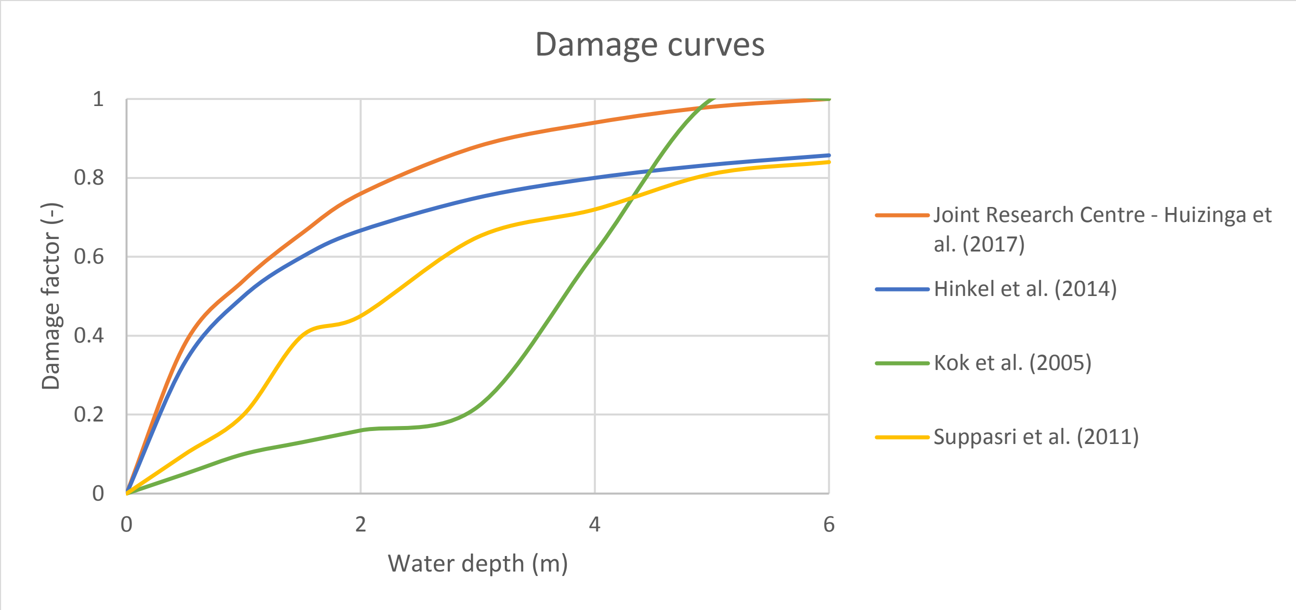


Figure 14.1. Damage curves from different studies, that have been used in this discussion to analyse the sensitivity of the forecasting system.

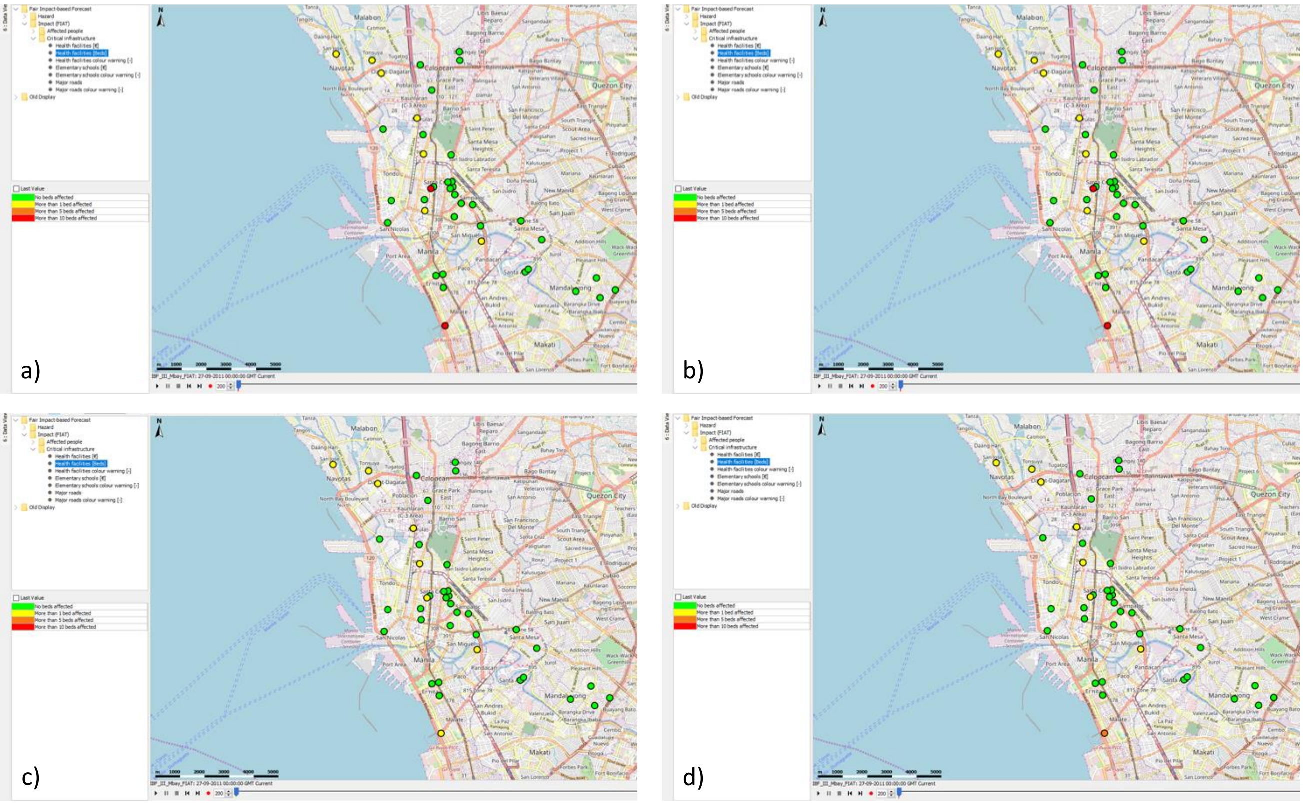


Figure 14.2. Impact maps of the hospitals in Metro Manila, for different damage curves: a) Impact map produced with the damage curve of JRC; b) Impact map produced with the damage curve of Hinkel et al. (2014); c) Impact map produced with the damage curve of Kok, Huizinga, Vrouwenvelder, & Barendregt (2005); d) Impact map produced with the damage curve of Suppasri, Koshimura, & Imamura (2011).

Figure 14.2 depicts the health facilities' impact maps produced with the four damage curves mentioned above. It can be observed that the maps predicted with JRC and Hinkel et al. (2014) functions provide same results. These results might be the same due to the small differences in the damage factor for low water depth values. However, when the flooding is larger, differences might be appreciated in the system. Differences can be observed among these two maps when compared to the impact maps produced with the other depth-damage functions. The reason for this change might lie on the big differences of the damage factors for low water depth values. Therefore, the forecasting system is sensitive to the damage curves used to predict the impact. This observation shows the significance of accurate damage curves to predict relevant impacts on the assets of importance for disaster managers. As it has been mentioned before, the JRC damage curves for all Asia might not be representative for a small area such as Manila Bay. More location specific depth-damage curves would be preferred, in order to provide more accurate vulnerability of the area and its critical infrastructures. Unfortunately, nowadays damage curves at national level for the Philippines do not exist, and therefore the curves at continental level of JRC had to be used.

According to Ulisse Parodi (2019), the second component that incorporates more uncertainty into coastal flooding risk assessment are the digital elevation maps. The impact prediction on roads of this forecasting system might have its limitations as well, due to the fact that the road depth might not be well defined by the digital elevation map, which has a grid of 300x300meters. The coarseness of the grid might lead to an over- or underestimation of the flood depth in the system, where roads are located. Therefore, a DEM with better resolution would provide a more accurate outcome of the forecast. Furthermore, regarding the impact maps of roads, an assumption has been made when classifying the impact according to its functionality. A threshold has been established based on the research of Pregnolato, Ford, Wilkinson, & Dawson (2017), in which roads with a water depth of more than 30cm were considered non-passable for 2-wheel drive cars. However, this study did not include research on trucks or 4-wheel drive cars, which might still be able to pass through 30cm of water depth. The classification made in this forecasting system for roads impact is thus, based only on 2-wheel drive cars. Nevertheless, because the non-passable threshold would only increase when considering trucks or 4-wheel drive cars, the road classification has been done following a conservative approach.

Apart from the impact maps, the implementation of vulnerability into the system has its limitations as well. The vulnerability dimension has been incorporated into the system through a postprocess of the impact data (in a transformation module of Delft-FEWS), instead of being incorporated in Delft-FIAT. The reason not to implement it directly into Delft-FIAT is due to the fact that the netCDFs created as an output from Delft-FIAT do not fulfil the netCDFs input requirements for which Delft-FIAT runs.

Moreover, in the course of this thesis no validation of the results of the forecasting system has been done, given the fact that the main objective of this research was to create a forecasting system considering the information needs of disaster managers, rather than creating an operational forecasting system. Therefore, future comparison with other forecasting systems is essential to understand the reliability of the prototype.

14.3 Limitations of Delft-FEWS

When implementing the information needs of disaster managers and the display of those needs, some limitations have been encountered with the data handling platform Delft-FEWS. Certain tasks had to be fulfilled in an alternative manner in order to provide the information according to decision makers' needs. Some of those limitations are explained in the following lines.

14.3.1 Limitations of the data generation

Regarding the hazard dimension of the forecasting system, limitations have been encountered when calculating the distance of each municipality to the typhoon. The coordinates of the typhoon track must be projected. However, it is not possible to project coordinates in Delft-FEWS. Therefore, the projected coordinates have had to be calculated using a look-up table, which produces an error of about one kilometre.

Furthermore, regarding the impact dimension of the forecasting system, only the maximum impact throughout all the time series has been predicted for each asset. Delft-FIAT can only use netCDF files with one time-step and therefore, the impact predicted cannot vary throughout time.

14.3.2 Limitations regarding the display of information

The forecasted information must be delivered to disaster managers in the correct format, to be understandable and easily accessible during an emergency event. Nevertheless, some limitations have been faced when intending to display the information in an adequate manner.

First of all, difficulties have been encountered when displaying the typhoon tracks. For disaster managers it would have been helpful the display of the typhoon track lines depicted with different patterns or thicknesses, that indicate the probability of each track. However, this feature is not possible yet for tracks in Delft-FEWS. Moreover, the creation of a shadowed area between tracks that indicates the cone of uncertainty of the typhoon would allow disaster managers to decide where actions should be taken. However, no features exist yet in Delft-FEWS that allow to display uncertainty in this format. Besides, in Delft-FEWS it is not possible yet to show each track ensemble in Thumbnails, which would allow to observe in several screens each of the possible typhoon tracks.

When considering the display of affected assets, disaster managers at local level have indicated their preference in using colour coded icons. Unfortunately, in the data handling platform colour coded icons cannot be associated to an affected asset. Instead, in the current system the impact of each hospital and school has been interpolated to a point and depicted as a colour coded circle.

Finally, when a disaster event occurs, it is necessary to take fast and relevant decisions and having to switch screens might imply losing a precious time. Therefore, having all the affected assets represented in the same maps is of special importance for disaster management. Unfortunately, in the forecasting system it is not possible yet to depict more than one affected asset per map. Each output from Delft-FIAT requires the creation of a new map in the Spatial Display. However, several Spatial Display maps can be depicted in the same forecasting screen thanks to the Dashboard Tool of Delft-FEWS. This allows to see at the same time different assets affected in one screen, although in different maps.

15 Conclusions and recommendations

The purpose of this thesis was to develop a fair impact-based forecasting prototype that integrates the information needs of crisis managers, in order to improve forecast-based emergency management.

To fulfil the purpose of this thesis, an approach following four steps has been performed:

1. Input: Interviews to disaster managers have been done in order to understand their information and display needs.
2. Model: The development of the forecasting prototype considering the input provided by the disaster managers.
3. Output: A dashboard has been designed in order to simplify and provide cohesion to the system.
4. Feedback: Interview to disaster managers in the Philippines have been carried out to get feedback of the prototype, in order to improve it afterwards.

Once all the steps have been done, the final impact-based forecasting prototype has been designed. The conclusions obtained from this research can be divided into conclusions regarding the information needs and the display needs of disaster managers.

15.1 Information needs

During disaster events, decision makers need to rapidly decide and take actions. Therefore, having the relevant information available is extremely important. After having talked with disaster managers, it has been comprehended the information a forecasting system must provide to take actions against an upcoming event.

Regarding the hazard information, it is important not only to have the physical parameters of the event, but also to provide them in an understandable manner, with, for example, water depth units that can easily be understood by emergency responders and the population. Furthermore, the track accuracy is of importance, especially in archipelagos and islands, in which a slight variation of the track could mean completely different effects into the country. Besides, the lead time required in the case of cyclones should be slightly longer than it is currently to allow disaster managers take more and more effective early action.

Concerning the assets of interest for disaster managers, in the case of disaster management in Manila Bay, the main assets of interest are population and critical infrastructures. Population and its livelihoods are priority. After population, the critical infrastructures start to matter. Road impact predictions are important because humanitarian aid is deployed by road. Damaged hospital predictions are important in order to know if health facilities will be available for the affected people and whether patients should be moved. Finally, elementary schools are of concern because these buildings are used as shelter by the population. The forecast impact on these assets should indicate the functionality of the infrastructures rather than providing economic impact. In the pre-disaster phase of an event it is more necessary to know which facilities will be accessible and in use. Economic damages are more important in the aftermath phase of typhoons, in which assessment of the disaster is done.

Moreover, during this thesis it has been pointed out as well the importance of considering not only the hazard and exposure, but vulnerability as well when predicting impacts. Vulnerability plays a key role for disaster managers when prioritising actions and therefore, this one should be included as well in forecasting systems in order to save time to decision makers.

15.2 Display needs

Providing the correct information is a key objective of a good forecasting system. However, if this information is not provided in a useful and understandable manner for disaster managers, the forecasting system cannot be used in its full capacity.

When interviewing disaster managers in this research, it has been a consensus that forecasts should provide simple and clear information. However, the level of detail of the information required by disaster managers varies depending on the organisational level and the agency for which the decision makers works for. While when talking about local and national level graphs, icons and colour codes are prevalent, when talking about regional level grids get more important. Furthermore, for Red Cross branches it has been preferred to have displays similar to those at local level.

Because this forecasting system prototype predicts the impacts at local level and the interviews have been carried out to Red Cross disaster managers, the information has been provided in icons, colour codes and graphs. However, when displaying the population impacts, grids have been created as well for a better representation of the data. Furthermore, icons have been chosen to represent impacts on critical infrastructures over grids also because due to the fine grid of the forecast, the data is not easily visible otherwise.

Besides, a good organisation of the forecasting system screen is necessary. A clear distinction between the data that is forecasted and the static data, such as population density, provides an easier overview of the system and allows to overlap different kinds of information. During emergencies, decision makers need to take fast decisions and hence, looking at different screens can make responders loose valuable time. Therefore, it is important to organise the forecasting system according to municipalities instead of assets. Disaster managers take decisions based on municipalities and it is necessary for them to see all the affected assets of a certain municipality in one specific map.

15.3 Recommendations

The forecasting system designed in this thesis has been developed with the purpose of fulfilling the disaster managers' information needs. Therefore, the aim of this thesis was not to provide a perfect numerical model, but to provide a prototype that guides on how a forecasting system that could be used by disaster managers would be. Because of that, more improvement should be done in the forecast before being able to use it operationally.

First of all, the impact-based forecasting model should be validated or compared with other forecasting system, in order to assess the reliability of the system. During the field visit to the Philippines, the German Red Cross proposed that the forecasting system might be sent to the Philippines in a future cyclone event in order to evaluate its outcome. This would allow for a better understanding of the system performance and possible improvement.

Furthermore, the present forecasting system considers the impact on population and critical infrastructures due to water depth only. However, water speeds have influence as well on the damages produced by storm surge. Therefore, a forecasting system that predicts the impact due to the combined water depth and currents would provide more complete information.

Besides, the impact-based forecasting system predicts the damage due to storm surge. However, during a typhoon the wind speeds can have a large destroying effect as well in coastal areas. A multi-hazard system that provides impact from both phenomena would predict a more accurate reality.

Moreover, regarding the precision of the prototype, nowadays the digital elevation map (DEM) used to forecast the water depth has a resolution of 300 x 300 meters, subdivided in cells of 50 x 50 meters. A larger precision in the DEM would provide more accurate predictions of the impacts. Apart from that, it has been remarked by disaster managers that the damage of housing is of relevance as well in order to determine the actions to be taken in an event. A more accurate DEM would allow to predict household impact at a more meaningful resolution. In order to predict impact at household level vulnerability at this level would also be required. However, this data is difficult to gather.

Finally, during this thesis it was also intended to perform a CIrcle (Critical Infrastructures: Relations and Consequences for Life and Environment) workshop, which is a workshop designed by Deltares that gathers stakeholders from several critical infrastructures of a certain location together. In this workshop, the cascading effects of critical infrastructures during a hazard event are better understood. The forecasting prototype can only predict the impact on infrastructures that are flooded. However, with the information gathered from this workshop infrastructures that are indirectly affected could be included as well. Moreover, the water depth at which infrastructures fail can also be registered thanks to the expertise of stakeholders. This would allow to obtain more accurate data to define damage curves that would help to design more location specific damage curves. Unfortunately, this workshop could not be done in the Philippines. However, a Circle workshop might provide insightful information that could eventually be implemented in the Delft-FEWS system as it can be observed in the mock-ups presented in Section 7.2.2.

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17 Appendices

A. Semi-structured interview summaries to disaster managers (Input)

A.1. Interviewee 1

General information

I work in *510 an initiative of the Netherlands Red Cross* and I am the lead of an FbF project called Innovative Approaches to Responsive Preparedness. Previously I have worked for few months in an FbF project in Malawi and in projects in Kenia, Ethiopia and Uganda.

Forecast information

The natural hazards experienced in my project areas are usually floods and droughts.

Display information

If I could design a forecasting system, I would like to display the data in numbers or graph format. The graphs would show the number of people affected and how many houses, how many agricultural fields and infrastructures are affected. It would also have, for example, a map of the country with warning colour system for particular areas that, when pressing, shows immediately a graph with the forecasted impacts, or maybe the graph would already be there.

Information needs

The hazard information that triggers my actions is the forecast, the lead time, and the risk of flooding. The impact data that triggers my actions is the kind of impact, the affected people, the people in most need, household data and poverty data.

Until now, the projects I have worked at did not use probabilities. Instead, we used threshold levels that triggered out actions.

Closing

Tips: Present a basic prototype to show before the interview. Although this depends on the interviewer. Some people prefer to have the topic really open while other like to have to show something beforehand.

A.2. Interviewee 2

General information

I work in the regional integrated risk management team for East Africa region and in the Innovative Approach for Response and Preparedness project in Ethiopia. My job focusses in supporting and integrating risk management at regional level for the *Netherlands Red Cross*.

Forecast information

In East Africa region, the most common hazard are droughts, flooding and epidemic diseases (human and animal diseases).
What I find relevant from forecasting systems and what I would change from the ones I have used is the following:

1. Most important part of the forecast is the accuracy. Therefore, forecasts should be accurate.
2. Forecast needs to be local specific for a certain area.
3. Sometimes there is contradictory information between forecasts. There should be consistency.
4. Information provided needs to be clear.
5. The forecasting system should give advisory information: this forecast is coming, this could be the potential impact, so for early action do this.

Display information

The forecasting system should be visual, with concrete figures. It should contain quantitative information, specific, simple, very clear and visualised in terms of a map. Not too much narration or description. It should present what is going to happen, what the potential impact is and the actions to be taken. The map should show where the hazard meets the vulnerability to show the risk level. Furthermore, it should have graphs indicating where the vulnerability and the hazard overlap, and where the coping capacity is low. Also, indication of how many people are potentially being affected should be shown. Maps should be mixed with bar or pie graphs.

Information needs

When a hazard is approaching, it is important to know the following:

1. When, how long and intensity of the hazard;
2. The lead time;
3. Where will the hazard occur;
4. Information about the people living in the area and about the affected people (segregated data is important: gender and age group, for example), which livelihoods people are using, and the housing affected;

5. coping strategies available in the area (i.e. resources available, such as drinking water and food);
6. Emergency items available (food stock, infrastructures, road access, health facilities, shelter, alarming system).
7. Whether there is a strong social structure, in which the community will help each other if necessary.

Once the hazard is approaching, probability is used as a trigger point to start action. However, there is no clear probability in which action is taken, as governments prefer not to act until the probability of occurrence of the hazard is 100%. However, if the probability is 100%, there is no time for early action as the hazard is already occurring.

When talking about vulnerability, there are different dimensions that prioritise my actions:

1. Human life in terms of people: number of people that will be vulnerable;
2. Number of houses that could be flooded/demolished and food and water supplies affected;
3. Livelihoods: livelihoods affected and how many people's livelihood will be affected;
4. Infrastructures affected such as health and water facilities.

Closing

Tips: it might be interesting for this research to capture the aspect that many decision makers are still reluctant to take measures based on probability.

A.3. Interviewee 3

General information

I am a climate science advisor for the *Red Cross Red Crescent Climate Centre.* My work focusses in the Philippines, Ecuador and Peru.

Forecast information

The hazards I work with in the Philippines are cyclones.

Display information

From my point of view, I think it depends on who your public receiver is. For disaster management, perhaps it is necessary map grid information, but for the Red Cross branch simple graphics would be enough.

The forecasting system I would like to use would be probabilistic, with good verification, in grid format or shapefile and with high resolution.

Information needs

At first, the most important data is the vulnerability and exposure dataset, although this is depending on the kind of hazard analysing. Secondly, the forecast system is important because it will decide where it is possible to act. Therefore, it is necessary to know the intensity of the hazard and the lead time, in order to be able to take a better decision. Usually the actions we take are triggered when the forecast exceeds a certain threshold, usually related to an impact or danger level.

In my job, if we have a probabilistic forecast available, we use it. Therefore, when possible we consider probabilities.

Closing

DK/DA.

A.4. Interviewee 4

General information

I work for the *Croix-Rouge Française,* on the *Plateforme d'intervention Régionale Océan Indien.* We work at regional level, in the South-Western Indian Ocean Islands (Comoros, Madagascar, Mauritius, Seychelles, Réunion, Mayotte, Mozambique and Tanzania).

Forecast information

In the South-Western Indian Ocean Islands, we suffer from floods, volcanic eruptions and other hazards. However, the most dangerous hazard are cyclones.

Display information

If I could design a program to help during disaster management, it would be graphical, with maps, and clear without too much information. With a colour system or icons. Maybe a map in two versions: one version more graphical and one version more detailed.

Usually it is necessary to have a very quick and simple understanding of the information, and for that the graphical map would be useful. However, some information may not be clear graphically and therefore, additional elements are required with, for example, tables. The manner in which the forecast is displayed also depends towards who the forecast is aiming to.

Information needs

The information needs depend at which level you want to look at (national, regional, local). It is necessary to know the track of the system forecasted and the intensity of the system (strong storm or cyclone) as well as the confidence/uncertainty regarding the track. For small islands is very difficult to take actions based on the confidence of the track, because if it has landfall 50km further or nearer it makes a huge difference. Also, infrastructure is very important to know (for example, unusable roads).

Besides, it is necessary to have a very clear probability factor, reliable. It is necessary to know the confidence/uncertainty regarding the track, and when there is a possible impact on the population there should be action taken.

Furthermore, flooding and wind might not necessarily cause the same humanitarian needs. Wind mainly affects the houses, and therefore, shelter response will probably be required. Instead, flooding can affect the houses, the households, the buildings but also the drinking water sources. Therefore, it would be interesting to be able to see the differences on wind impacts and flooding impacts.

Closing

What needs to improve the most are the disaster management procedures. We can have a very nice impact forecast but if we do not understand or follow the procedures, it is not useful.

A.5. Interviewee 5

General information

I work for the *German Red Cross*, but I have close cooperation with the *Philippines Red Cross*, the *510 an initiative of the Netherlands Red Cross*, the *International Federation of Red Cross and Red Crescent Societies*, the *Red Cross Red Crescent Climate Centre* and other *Red Cross* partners. My job focusses on implementing FbF in the Philippines. However, I also cooperate with other projects of the *German Red Cross.*

In my job I work mainly with the laptop and the phone, and we rely a lot on the internet. We used these devices to check the rainfall and typhoon forecasts. Moreover, for flooding we also look at GloFAS (Global Flood Awareness System) from the European Union.

Forecast information

In the Philippines we experience typhoons, floods and droughts. In my job, we are more interested in typhoons. The last one I experienced was Yutu (Rosita) in October. After that one, there was last month a tropical depression which produced a huge rainfall and was more impactful than typhoon Ompong (Mangkhut). In 2018 we had 21 tropical cyclones, among which 8 were typhoons and 2 made landfall. For Mangkhut we had 6 days of forecast available, which means on Sunday 9th September we saw a typhoon was approaching the Philippines. Monday 10th September the forecast was predicting a landfall on Saturday morning. This was a good forecast. It did landfall on Saturday morning. Before the typhoon landfall we had to decide whether the typhoon was reaching our trigger. We decided to act based on the 3 days forecast. When we decide to act, we should start sending messages to the chapters to say there is a typhoon coming, and they should start early house strengthening and maybe early pre-harvesting. This should last 2 days because, last day is left for evacuation in theory.

Display information

A forecasting system with colour classification from lower to higher damage is quite good already. As part of our process we want to which percentage of houses will be destroyed at municipality level, and we would base our decision on this colour coding. The more impact forecast we are able to access in the future, the more type of visualisation will be needed.

Nowadays we use the *510* dashboard, which is quite good and comprehensive. What we might want to do with *510* is a combination of the forecast impact with the vulnerabilities. During typhoon Mangkhut (15th September 2018) *510* were able to give us the impact forecast for housing at municipal level 3 days in advance based, on the statistical analysis of 13 past typhoons in the country. If we would be able to overlay the impact and vulnerabilities, it would provide a good indication on where to act in the anticipation phase of a typhoon. In the past typhoon *510* shared a map of impact and an excel of vulnerability data. That would tell which municipality is probably the most impacted and where the vulnerability of the elements at risk would be the highest.

Information needs

The most crucial information required for typhoons is the following:

1. Regarding the hazard: the track, date of landfall, windspeed and rainfall predictions.
2. Regarding the impact of the typhoon: the main impact of typhoons is agriculture (standing crops) and the second is infrastructure (until know the *Red* Cross can only anticipate the impact on housing, but it is not possible yet to anticipate the impact on the main roads or bridges, for example). Regarding impact on housing, we have the *510* statistical model that can tell the percentage of houses being damage based on windspeed, when and where. At the time being we have no information on the impact on crops. Impact on crops is complicated because it also depends on rainfall levels. Impacts in housing is better nowadays

because it mainly focusses on wind speed forecast, which is more reliable than rainfall forecast.

In order to start our early actions, we decide to act when the prediction on housing being destroyed reaches 10% in at least three municipalities. The typhoon early actions we do are strengthening weak shelter, distribution of lumber and nails and pre-harvesting of crops (rice, corn and abaca). The *Red Cross* relies on provincial *RC* branches (Chapters), in order to perform the early actions. They are the ones having the stocks for house strengthening and the cash to give to the farmers for pre-harvesting. We do not send people to the field from Manila. People from the *RC Chapters* are already there. They are trained and will be the best responders. The headquarters will be able to go to the field only if the forecast is good enough and there is enough time to take a flight. It is necessary to rely and depend on the local chapters.

When deciding when are where to act, we do not rely on information that has low probability. Five days forecast has too low probability. Three days forecast has probability around 60-70%. The track movement three days in advance is important, to know because three days in advance we would be able to pin point which province is at most risk. The track at five days we know is not going to be extremely accurate but at three days we would take the risk of deciding where to go. If we distribute for example a reinforcing kit for the houses, even though the event does not end up hitting there, it will have a use, as long as we deliver it to the most vulnerable houses, because the kit will be used anyway to reinforce the houses. In FbF we have to accept the fact that in some occasions we will act in the wrong place, or not in the most affected place.

Regarding vulnerability information, we have the general information about farmers, but we need to know which farmer has less than one hectare, and which farmer is has irrigation or relying on rain fed crops. Rain fed farmers are a bit more vulnerable. The vulnerable specifics are only available at local level. We are asking our *Red Cross Chapters* to collect this information as much as possible in advance. Would be interesting to know in advance which farmers are the most vulnerable. We need to know information in farmers short in advance (three days for typhoons).

Closing

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A.6. Interviewee 6

General information

I work for the *Zambia Red Cross Society* as a disaster manager. The decision-making scale I work at is at national level.

Forecast information

In Zambia, most of the disasters I work with are weather-related, such as droughts and floods.

When a devastating event is approaching, it is necessary to have the adequate ground information. For example, once a flood occurred in one of the districts over 900km from Lusaka, but I had no details on the vulnerabilities and households/populations in danger and therefore, I could not estimate the potential economic losses or food needs, shelter, health and water needs. Besides, the short-term forecast did not work because the meteorological office could only forecast rainfall falling upstream while floods occurred downstream.

Display information

In a forecasting system, hazards should appear in relation to the possible consequences of their occurrences. For example, when taking drought as a hazard we can proceed to project its impacts in several environmental dimensions, such as in the economic environment, food security, livelihood (i.e. power generation may be affected when water reservoirs dry up and this affects the entire economy) and the type of Society to be affected (farmers, for example).

Basically, a combination of displays would be desirable to project multiple scenarios from the same viewpoint. The system should be able to facilitate the tracking of an event from its parent trigger through its evolution to offspring events that produce impacts, including lead time from the point of forecast release to event of occurrence. For example, if above normal rainfall is to be recorded at place X on day one at 10:00AM, when will the consequent flood be experienced at place Y and by what time? and if this happens what will be the likely impacts of this flooding at place Y?

Information needs

From the perspective of weather-related events that are highly predictable, the information of most importance to me is the following:

1. Early warning (forecast) at different time scales ranging from seasonal down to 7-day forecast;
2. Reliable lead time to be established;
3. The magnitude/intensity of the event;

4. The ground characteristics: land cover dynamics, general features of the cultural landscape and built environment and the ecological sensitivity of the natural landscape and ecological functions to be drastically affected and how they are likely to impact on human livelihoods;
5. The exposed population: number of households affected by character (for example, built of permanent material, semi-permanent and temporary materials), socio-economic activities/livelihoods to be affected, water and sanitation/water points and latrines, farmlands, communication networks/core-road network and access bottlenecks to be established (bridges, culverts, weirs);
6. Accessibility: usable routes and evacuation routes, temporary safe havens for relocation, transport systems.

In order to take actions, there is certain information that triggers us:

1. Number of populations affected;
2. The intensity of the forecast event. For example, if above normal rainfall is expected, a high flood could be expected as well;
3. Prepositioned stock or lack of thereof.

Probabilities are considered as a preliminary step towards an informed disaster preparedness, response and mitigation strategy.

When considering vulnerabilities, the following are the ones that prioritise our actions:

1. When life is threatened;
2. When assets/property are/is under threat;
3. When the environment faces degradation of any kind;
4. The possible implications of asset and environmental damage on human welfare would incentivise response any time;

Multi-hazard forecasting is vital, because certain hazards are a function of other events. For example, above normal rainfall in a built-up area with poor drainage systems may induce flooding, that coupled with unsound waste management and bad sanitation systems my result in epidemics. Therefore, a transition would occur from a meteorological hazard to a biological hazard. This occurs with, for instance, cholera outbreaks. Hence, linking meteorological forecasting systems to hydrological would help assess potential impacts when interfaced with the cultural landscape.

Closing

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A.7. Interviewee 7

General information

I work in the headquarters of the *Philippines Red Cross*, in the disaster preparedness and risk reduction team, at national level. My job focusses on the Philippines. The *Philippines Red Cross* works in the Philippines. However, we support other countries within Asia-Pacific, and we cooperate with sister national societies such as Malaysia, Mongolia, Bangladesh or islands of the Pacific.

For our preparedness work we use our laptops and tablets, and when we do our digital mapping at the community level, we also use our GPS devices. And the rest are the typical stationaries. In the field we use tablets instead of the phone. It is better for our community mapping exercises and also for data collection. I use my personal phone for work, to contact my colleagues, because we have limited mobile phone devices in the office officially provided.

In the laptop usually we use Microsoft Office for the day to day work. Besides, more specialised programs are used by some of my colleagues, such as ArcGIS and QGIS. For other scientific information such as hazard or vulnerability profiles we use open data sources. We use the tablet in order to do our community-based risk mapping, which also uses ArcGIS. This tool digitalises community data information gathered in the ground, for planning purposes. Furthermore, to communicate between colleagues we use several applications in the phone, such as Messenger, Skype, WhatsApp, Viber and Facebook.

Forecast information

Recently we had a tropical depression. It was during the holidays and it affected the eastern part of our country. It brought a lot of rain, flash floods and landslides.

If I could improve forecasting systems, this would be mostly related to the impact. I would also include data on exposure data and vulnerabilities. It is also necessary to have a better lead time. Now we receive a good forecast hours before the actual event, but that is not enough time to act. We want a slightly longer lead time to allow actions. We would like to have three days with a probability of 60-70%. Sometimes having it two days in advance is enough but for big typhoons or flooding three days are necessary.

Display information

In the forecasting system we want to see the impact. Because typically what we see in our government sources or forecasting agencies is that they show us the data on wind speed, the path of the typhoon or the area affected, but we want to know the impact in a specific location, more than the weather. Will it blow away roofs? will it uproot trees?

Regarding the display format, for decision makers and practitioners, grids and graphs would be better because it would provide us of the information we need to make our response plans. However, for community level, maps or something more visual and simpler would be easier to understand. I would like it with colour coding and icons.

Information needs

The information I would be more interested in are:

1. Vulnerabilities in a specific area (what are the facilities that would be more likely to be damaged or destroyed: hospitals, houses, markets, water, electricity, communications and main access points like the major roads and bridges, the airports, the land terminals, the sea ports);
2. Exposure data (affected people and the livelihood);
3. What the local capacity of people is (which area has a big evacuation centre? Shelter? Equipment? Emergency communication? Debris clearing? Do they have enough food items? Water?).

It is really important for us vulnerability, exposure and capacity data to then match it with the hazard that is coming. I would show this information of vulnerability, exposure and capacity data in different layers that we can toggle to see them when necessary, in order to be able to overlap them. Then, with icons it should be possible to see the specifics of certain data. Have different icons for vulnerability, exposure and coping capacity, but constant. Too many icons would be confusing. Besides vulnerability, exposure and capacity (which are the main information we need), it would also be helpful the human resources capacity. We are now mapping our volunteers to know where they are. We have a map that says where the doctors are and the volunteers.

We take early actions based on a trigger. However, this trigger it is not definite and it depends on the characteristics of the hazard. Once the local weather bureau forecast informs the typhoon will make landfall, that triggers our actions. Once the community decides there is a clear track or risk, then they propose activities. If it is a small area, we do not need to deploy our resources. The Chapters can handle it. For now, we focus our trigger on the hazard because there is no good forecast on impact yet.

Based on our previous response, the early actions are taken prioritising the areas that will be first directly affected. Usually we have a colour coding (red, orange and yellow) that indicates the critical areas based on wind speeds. We prioritise those areas as a basis for planning. But when there is a report of actual impact or actual damages then we go to the areas that have not received yet humanitarian assistance or those areas that were partially provided with assistance. For example, if in one community they have received food but there is still need for shelter, then we go there.

When a cyclone is going to occur, we consider the impact of both the storm surge impact as well as the wind impact. We have historical data of both hazards. We prefer the impact of wind and storm surge separated, because they affect different and have different exposures. For wind, usually the houses made for some materials or trees are the most damaged. And storm surges instead affect more those areas in the coastal communities. We rather have it different because also sometimes have different response requirement. When you have the impacts separated, it is easy to compare them.

Closing

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A.8. Interviewee 8

General information

I have been working for four years for the *Red Cross Red Crescent Climate Centre* as a technical advisor. Before, I worked in Ethiopia, Sudan and Egypt as part of the World Bank. The work I do now for the *Red Cross* is mainly focussed in Bangladesh, although I am also doing a feasibility study in Nepal on FbF for the *Danish Red Cross.* I also help the Philippines on setting up a trigger for early action based on FbF. My work is basically focussed at national and regional level.

For my work I use a phone and a laptop. The phone I use at work is private, and the laptop is partly private and partly from work. I use ArcGIS modelling for vulnerability assessment indexing and risk assessment. I also use Microsoft Office, and to communicate I do it through mail, WhatsApp and Viber.

Forecast information

The most recent disaster I have experienced was a flood in 2017, in Bangladesh. I worked on it using FbF to give early support before the event happened. Other kinds of hazards I have experienced are cyclones, river erosion, flooding, drought, malaria, cholera, landslides, earthquakes among others.

In the 80s – 90s I changed the forecasting system in Bangladesh. I changed several things:

1. I introduced the community-based early warning systems and flood early warning system in the community level. This was necessary because information generated by scientifics is not easily understandable to the community, who does not understand the numbers and/or language. It is necessary to convert everything to an understandable language and symbols. I used a +/- sign in a participatory approach, working with the community;
2. I changed FbF into the shortest possible time, so that people can take early actions to safe their assets and lives.

Things need to be changed now in forecasting systems: people need different units than the scientific. Whether water will increase or not and if it increases, how much in terms of impact.

Display information

The forecasting system should be simple, easy to understand and self-explanatory. By looking you should understand what is showing. People do not understand hydrographs. However, people understand colours. We need impact-based forecast, more than hazard forecast. It is more necessary to know whether my house will be flooded rather than how much will the water increase. Nevertheless, it is also important to show the hazard, because it is necessary to know the reason why there is an impact.

Therefore, the forecasting system should be colour coded. Buildings with colour code or rice with colour code, roads with colour code, market with colour code. It should be better simple than in a grid. Visual displays have three different levels of users: one is policy makers or national level managers; one is local level managers or disaster managers and one is population. Each must have different view.

Information needs

The required information of the forecasting system should depend on the decision-making level. The national level wants to know a more gross and perspective of the impacts (people affected in each district). In regional level is more important when the flood will come, the lead time, infrastructure, people, livelihood, markets.

The trigger that determines the actions depends on the impact level, on the resilience of the society and on how long society needs to recover from the impact. If society can recover within five days, then there is no need to act. If it is more than that, we have to act, for example, by giving some money. Therefore, the most important aspect to look at is the potential impact in three points: on food, living comfort and the income (for example, if they are farmers and the flood destroys their crops, they cannot have income). Early action is usually taken based on impact forecast (for different exposure element we have different impact curve on their households, assets, income, affected population). We act when the trigger point is reached.

In Bangladesh, deterministic forecast is the more used than probabilistic forecast.

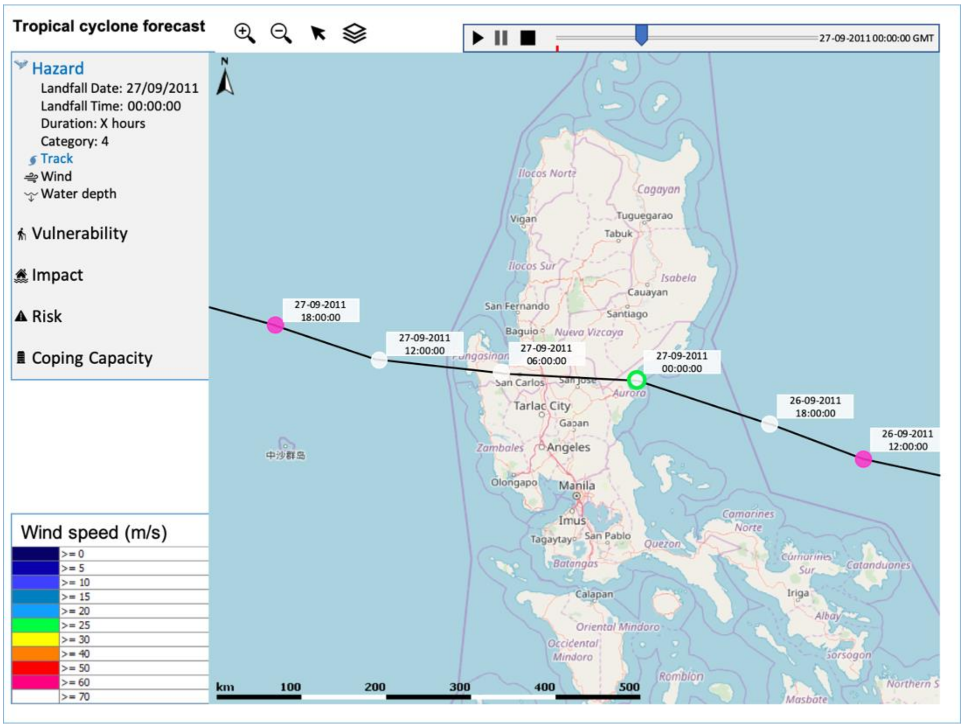
In order to consider vulnerability when taking decisions, we use the vulnerability index. There are different indicators that combined provide the vulnerability index. Some of those indicators are: poverty, number of people and specifics in a household (elderly people +60, children and disabled are more vulnerable), house type or structures and where people are living (exposure).

Closing

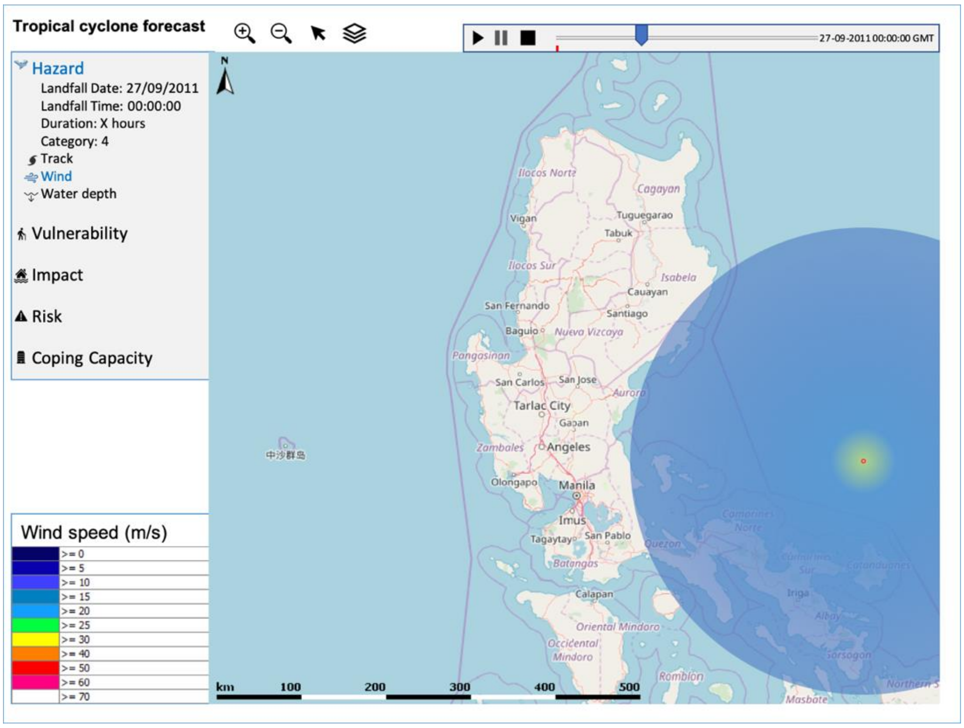
B. Impact-based forecasting mock-ups

B.1. Hazard mock-ups

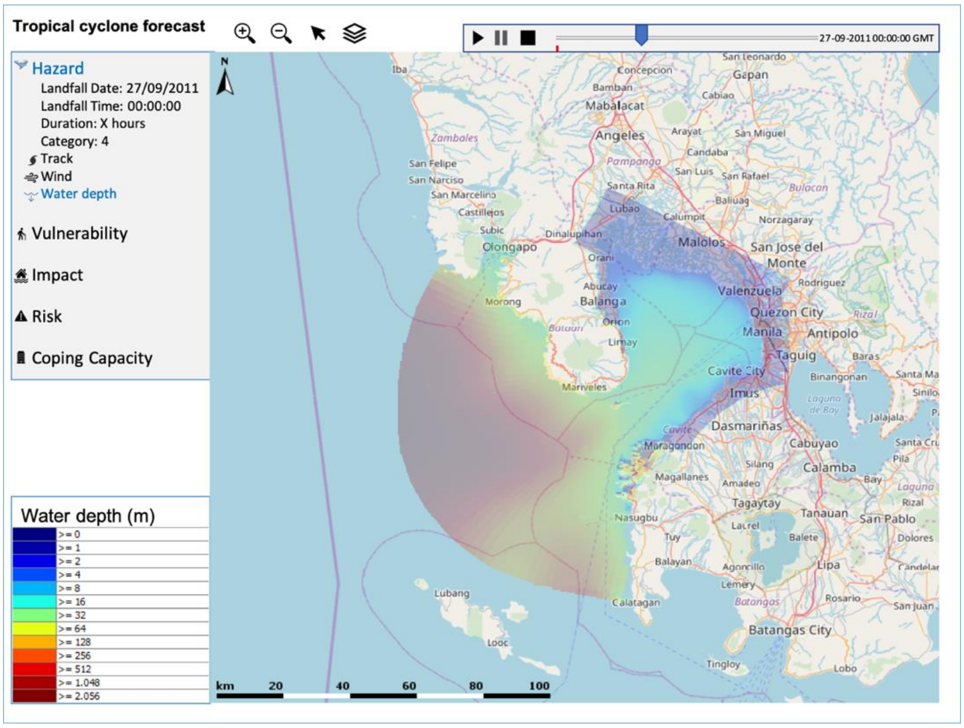
Typhoon track



Wind grid

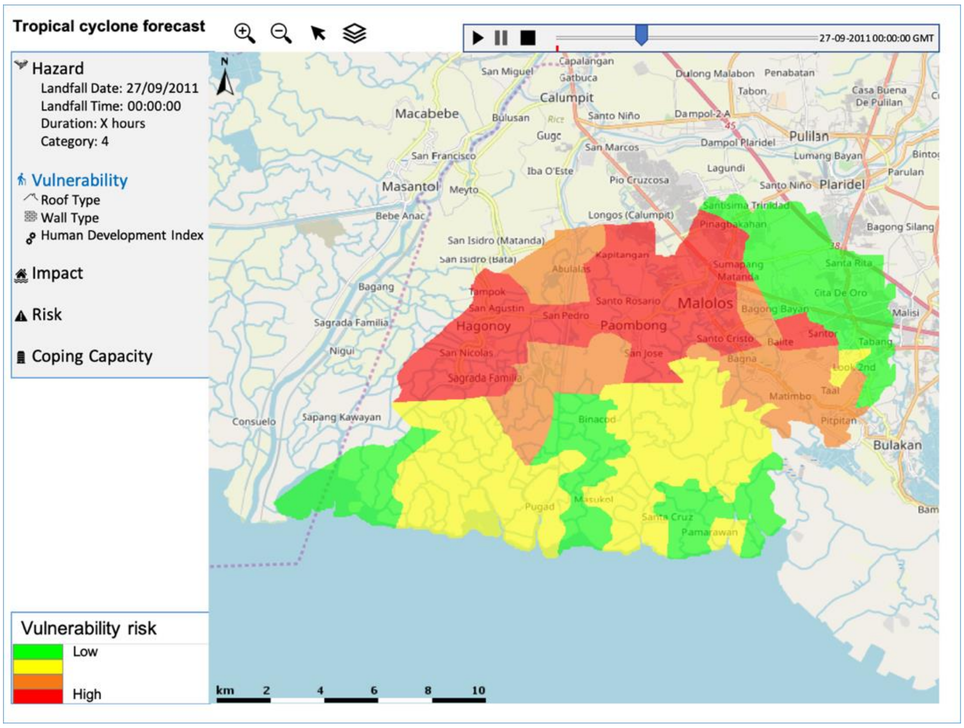


Water depth

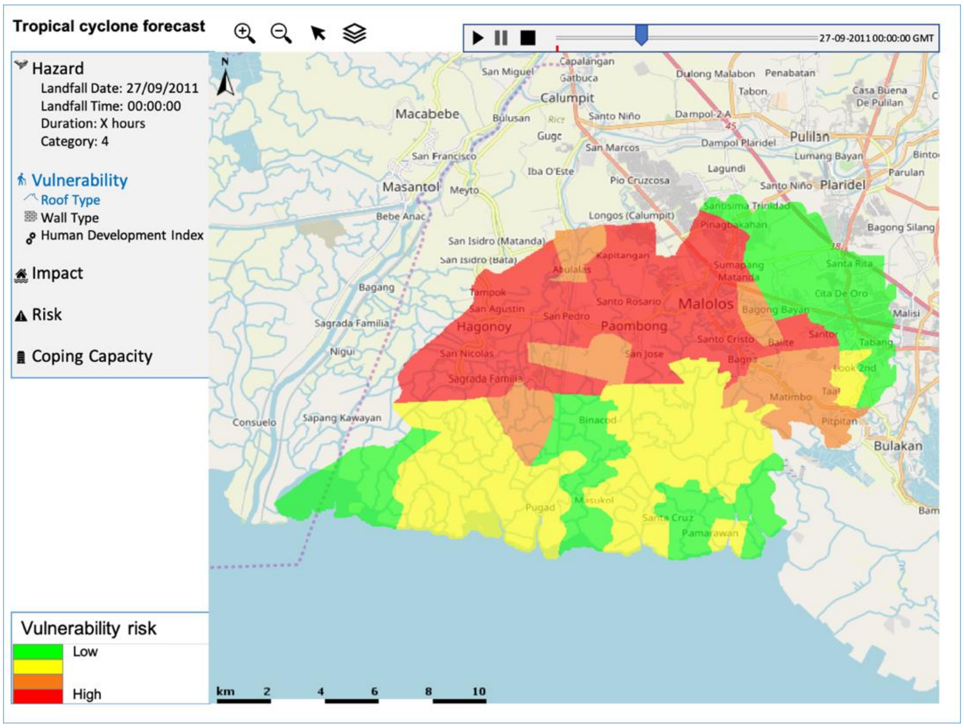


B.2. Vulnerability mock-ups

Vulnerability

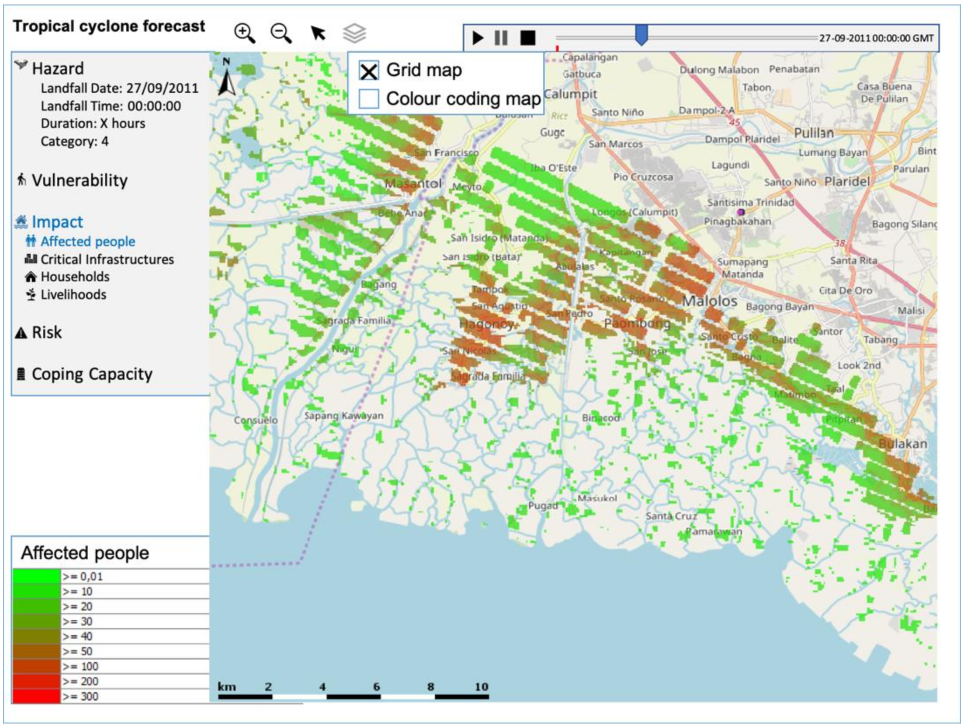


Roof type

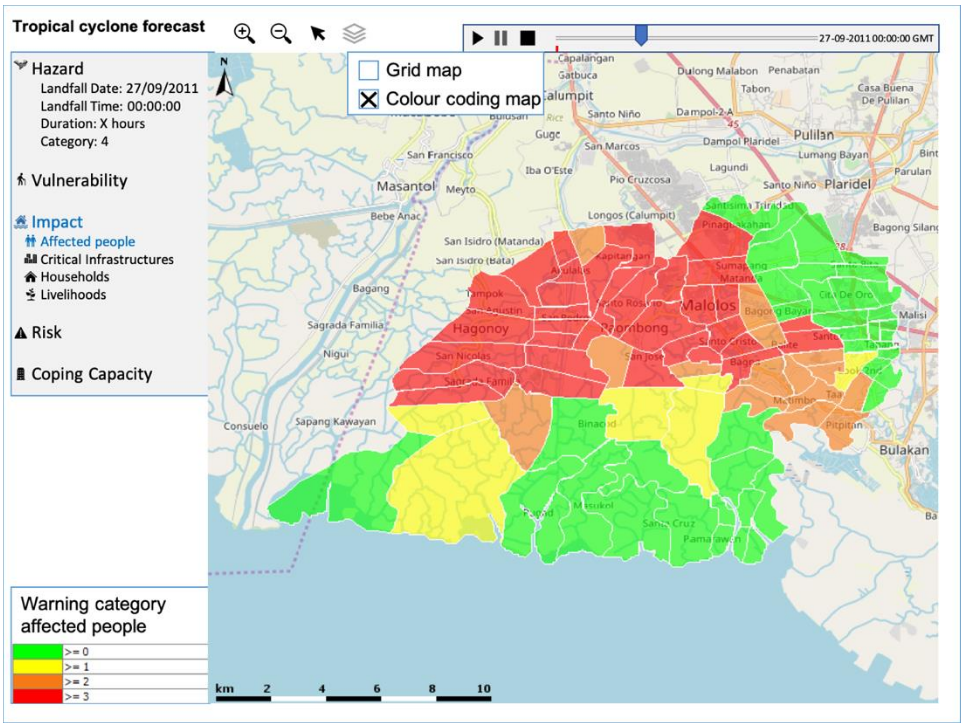


B.3. Impact mock-ups

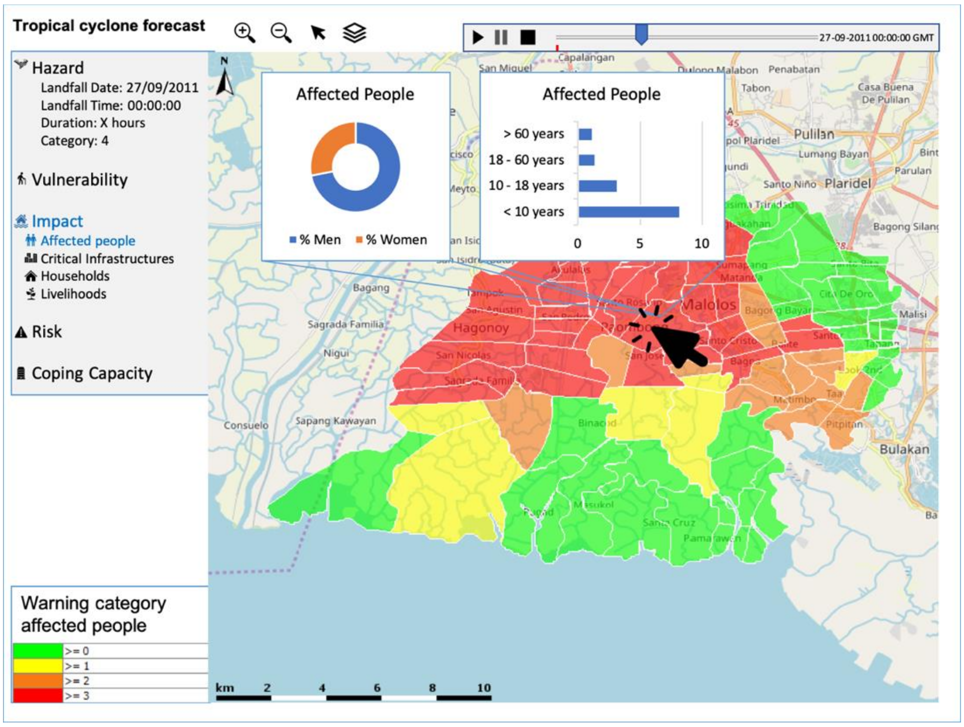
Affected people – grid



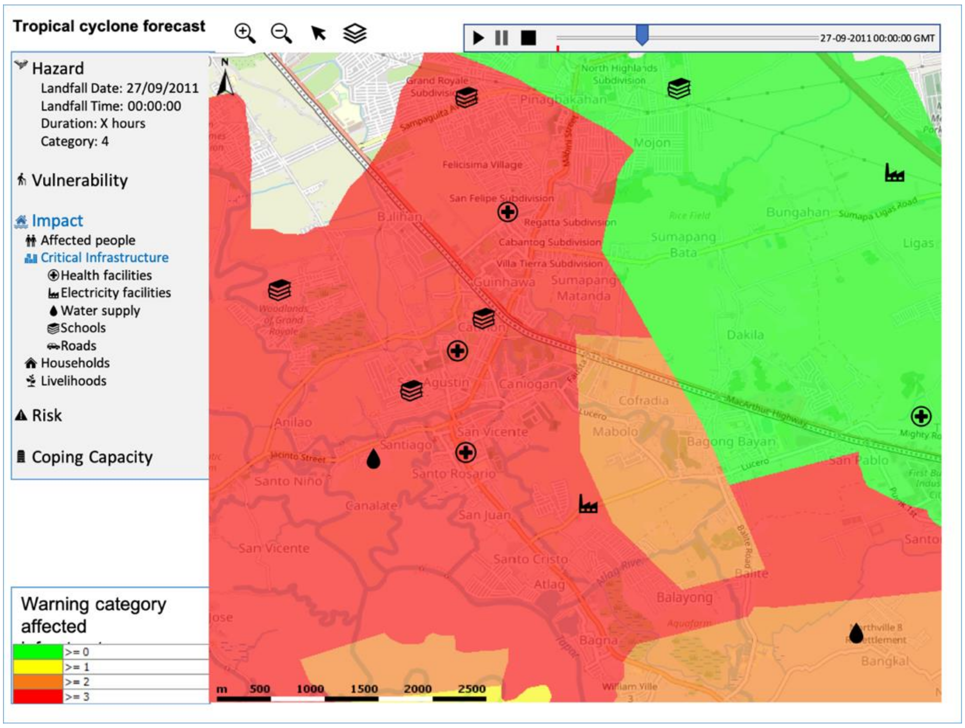
Affected people – colour code map



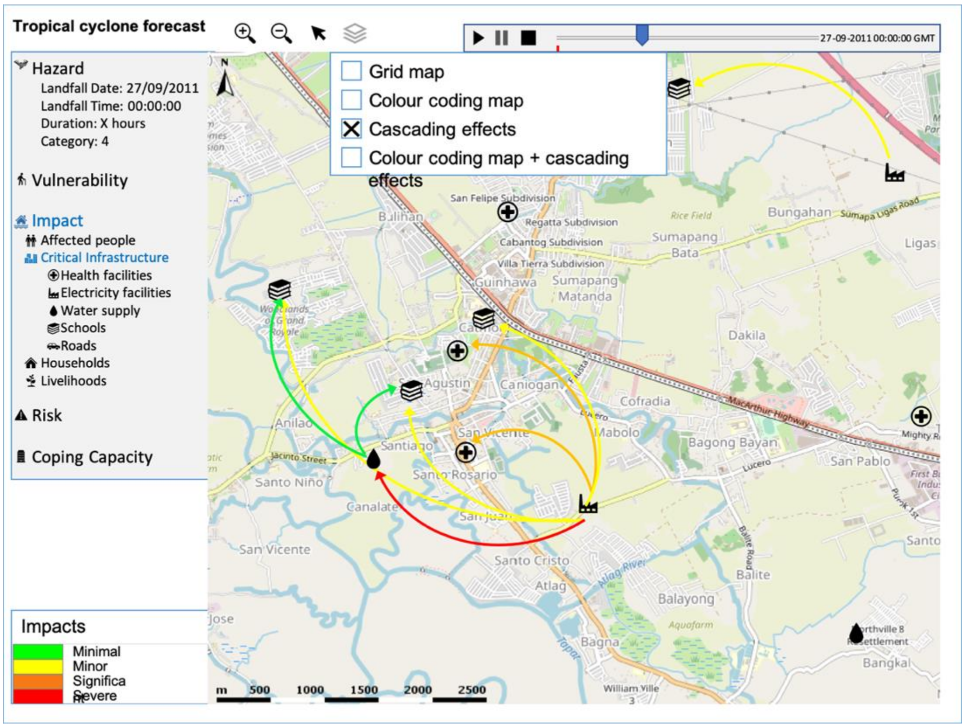
Affected people classified



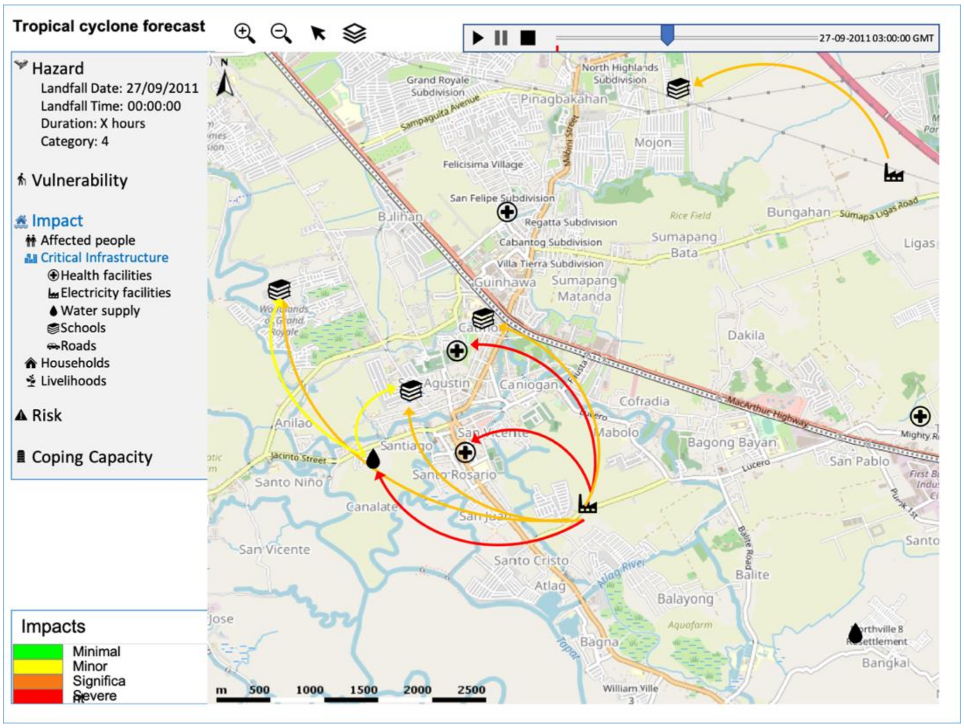
Affected critical infrastructures – colour map with icons of the infrastructures



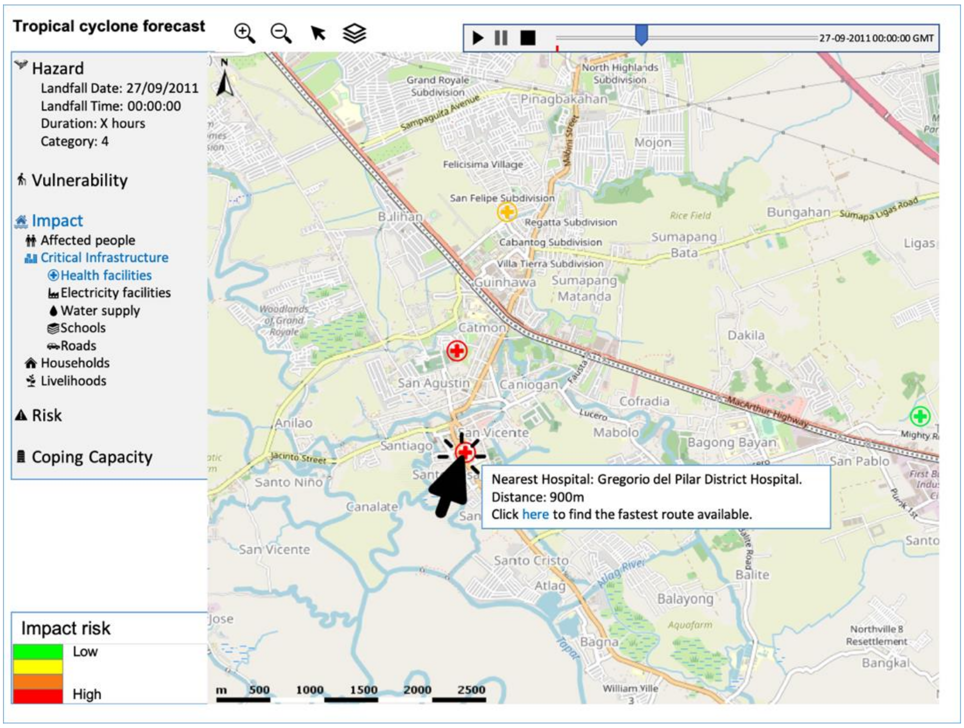
Affected critical infrastructures – cascading effects at 00:00GMT



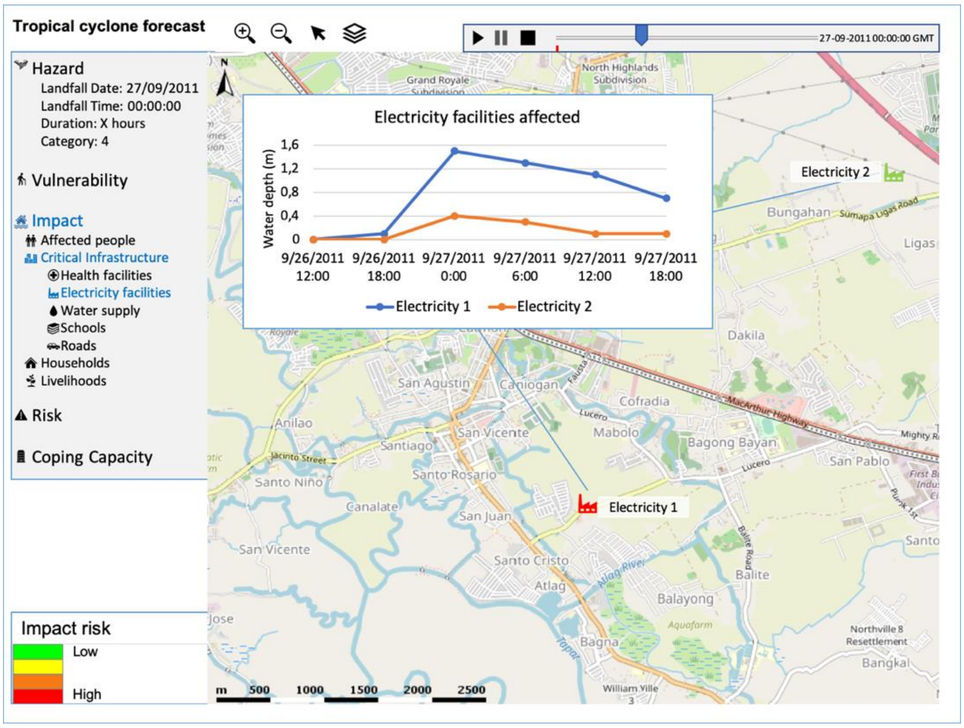
Affected critical infrastructures – cascading effects at 03:00GMT



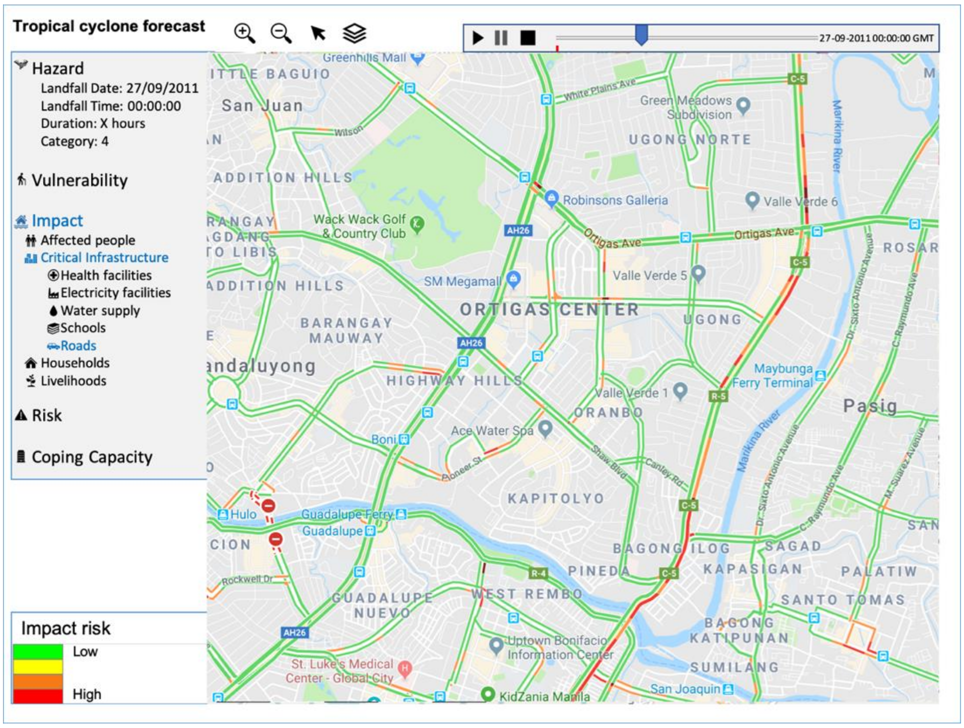
Affected critical infrastructures – Health facilities



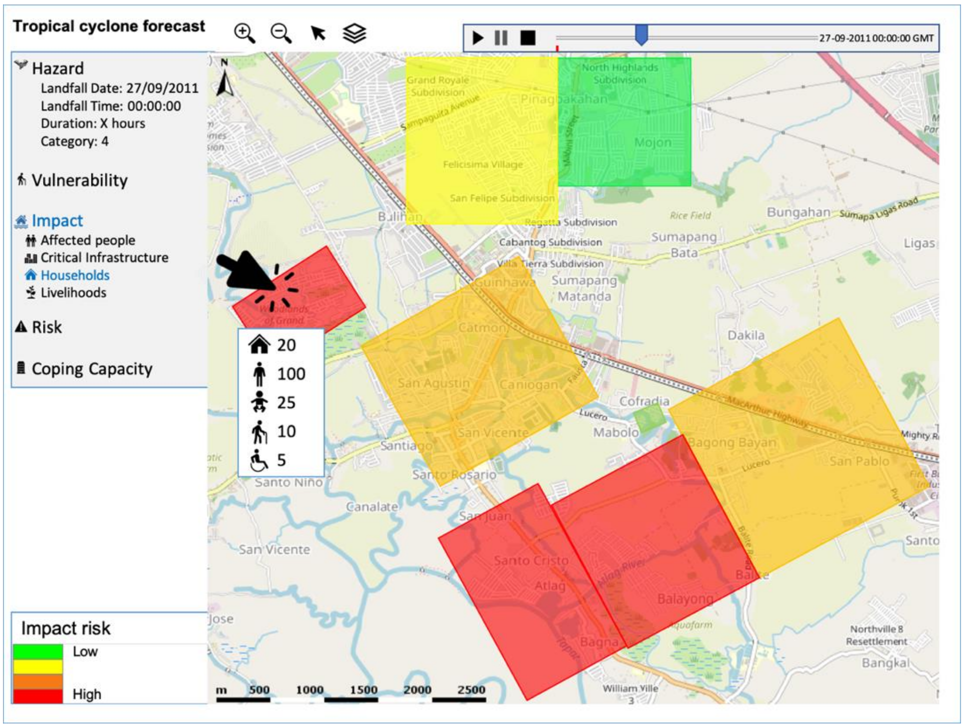
Affected critical infrastructures – Electricity facilities



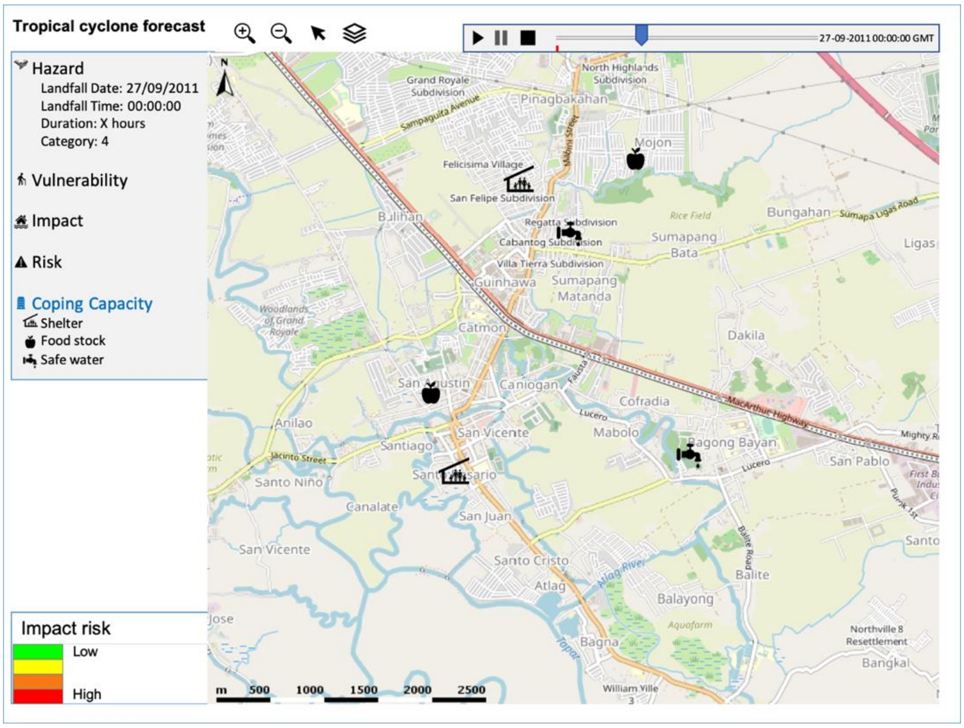
Affected critical infrastructures – Roads



Affected households

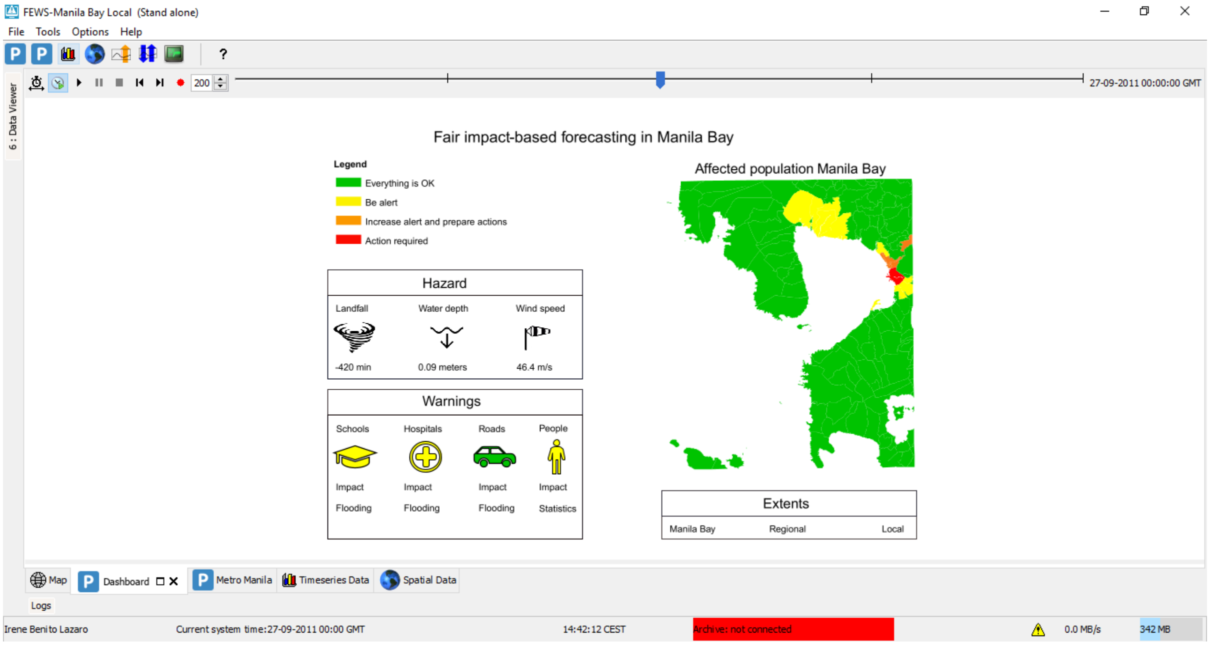


B.4. Coping capacity mock-up



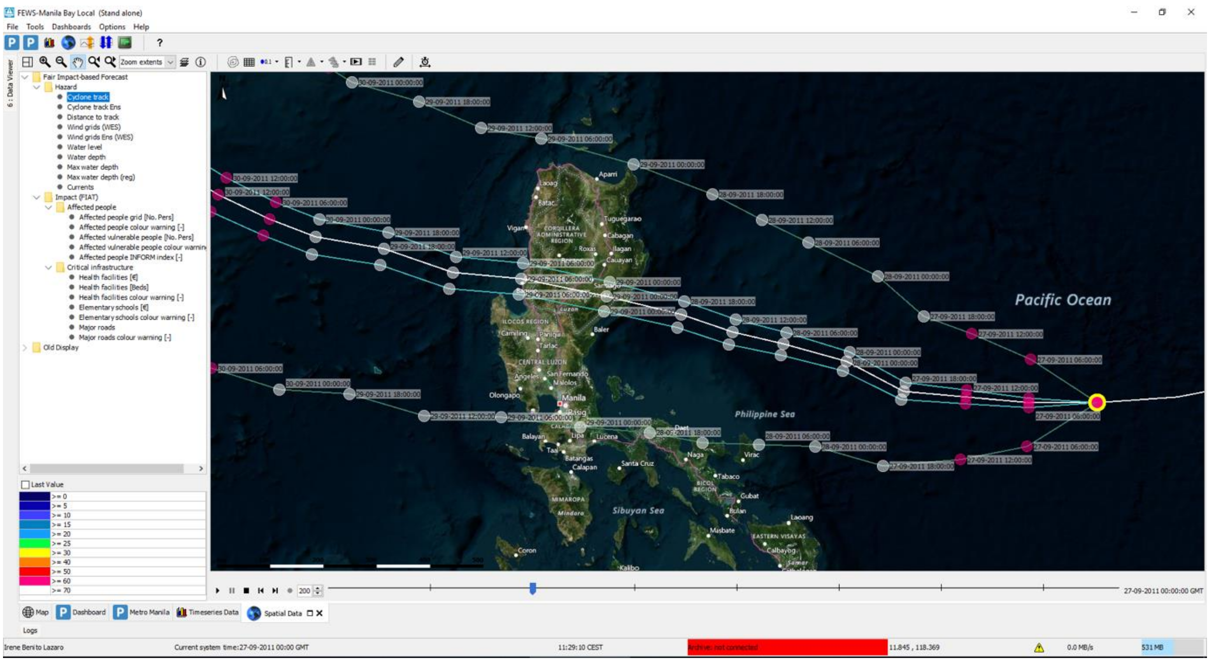
C. Final forecasting system

C.1. Dashboard

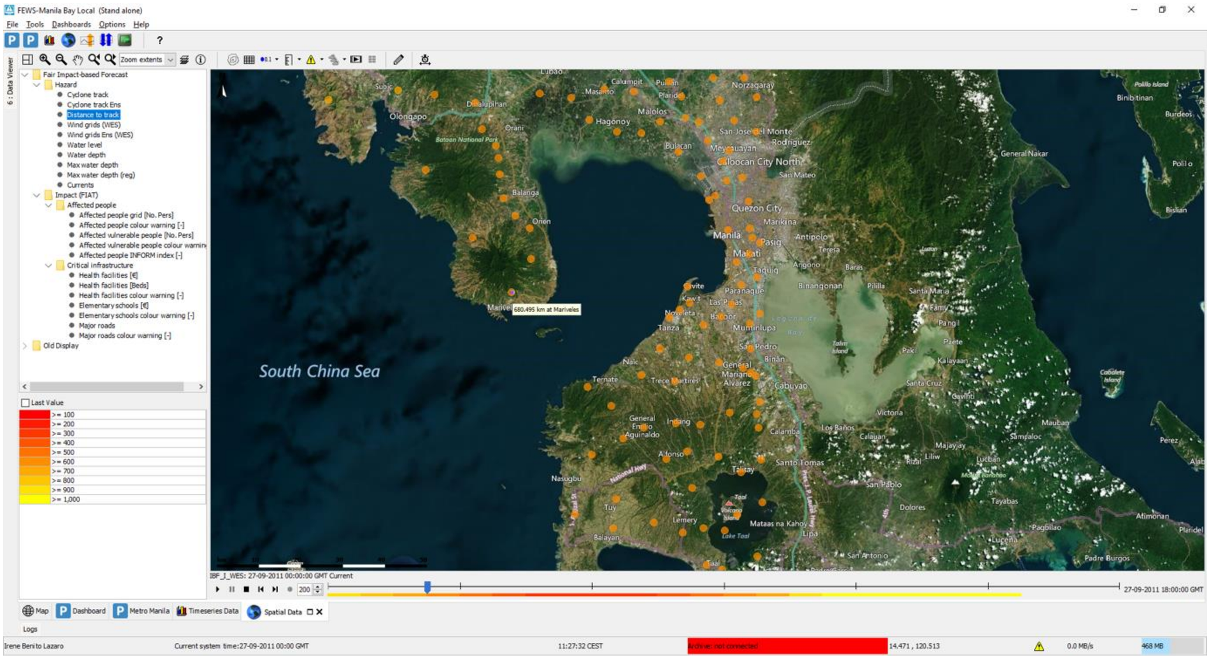


C.2. Hazard maps

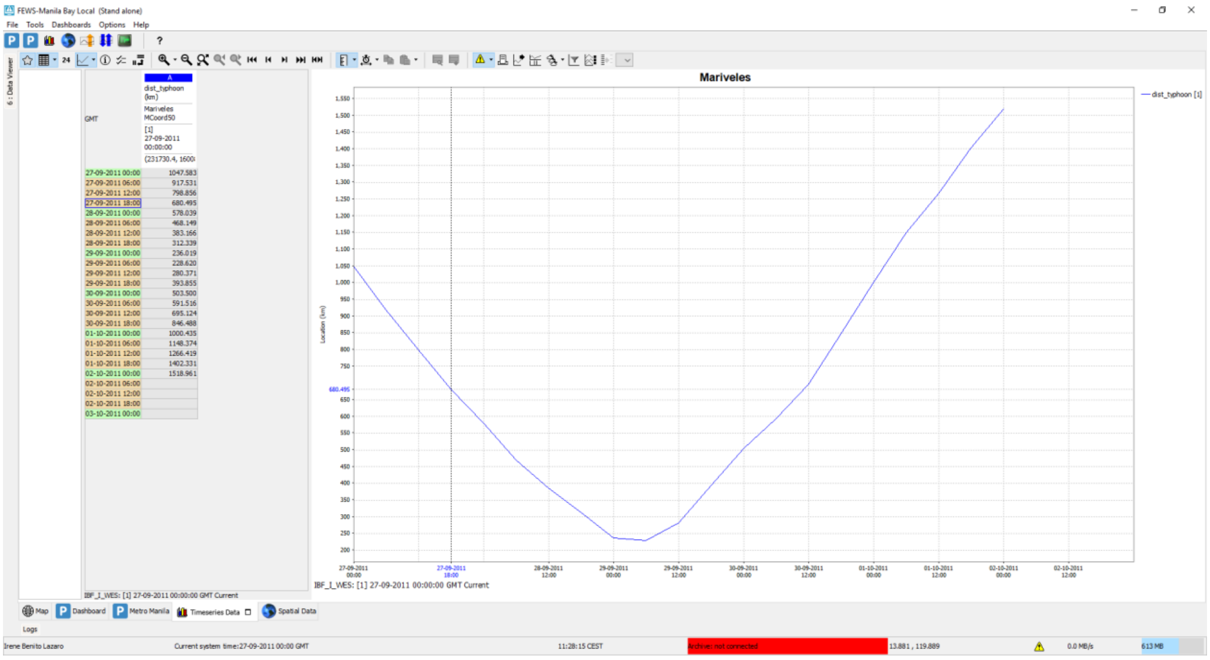
Cyclone track



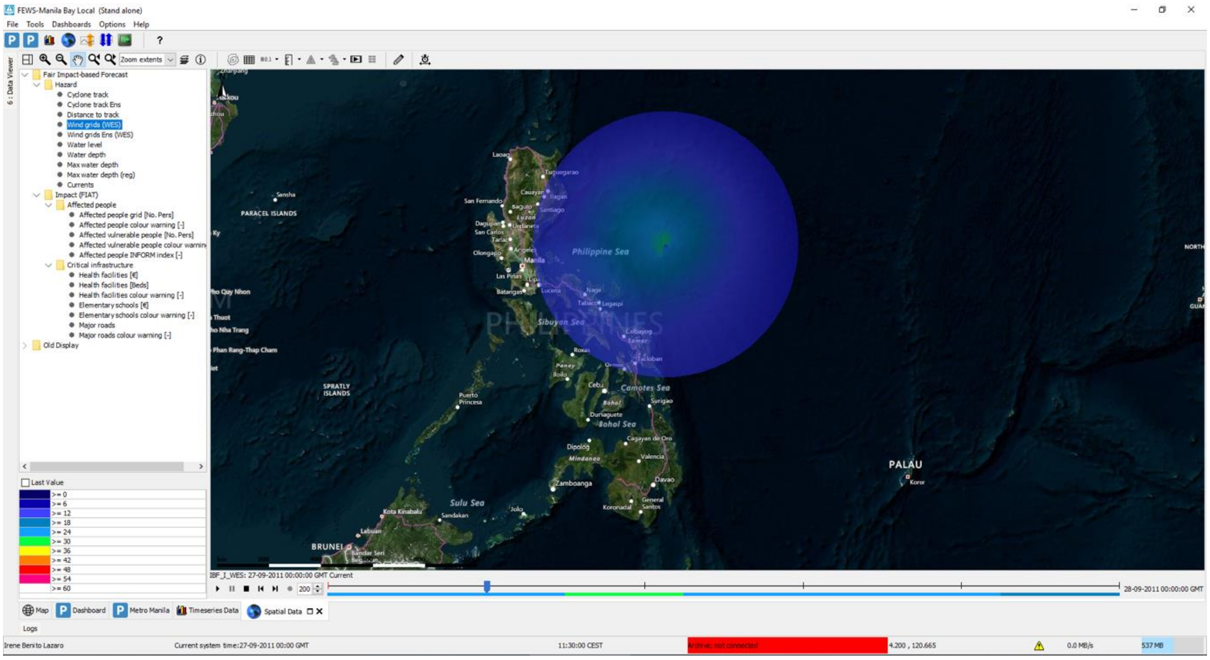
Distance to track



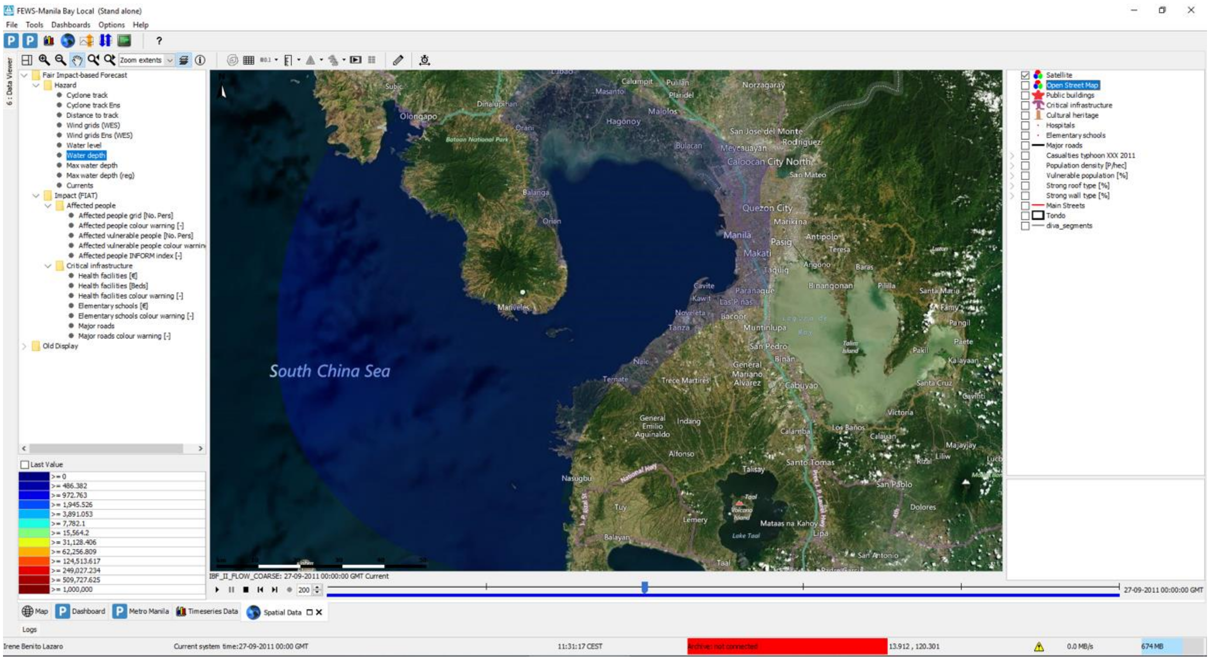
Distance to track – Time series



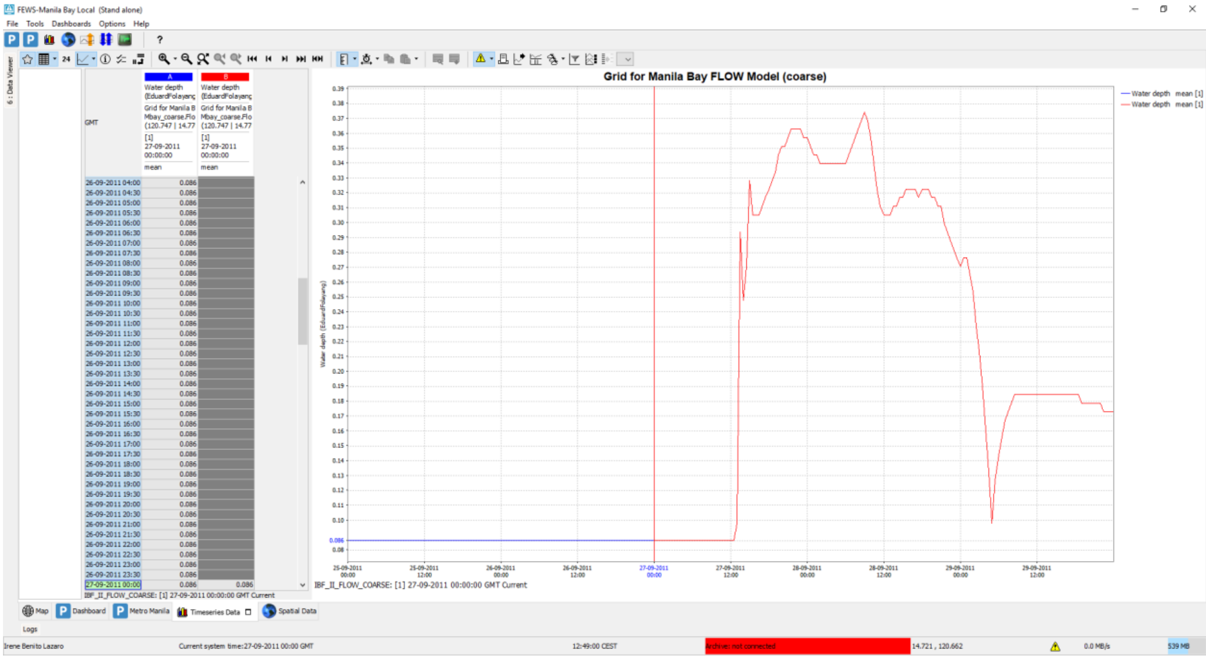
Wind grids



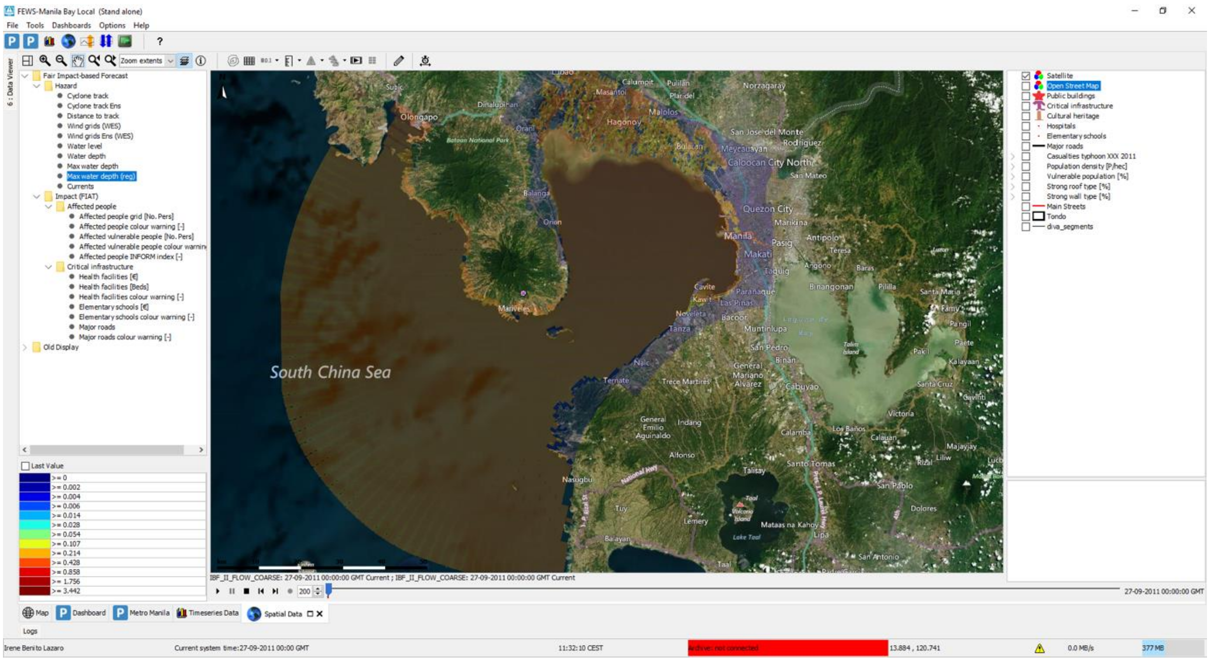
Water depth



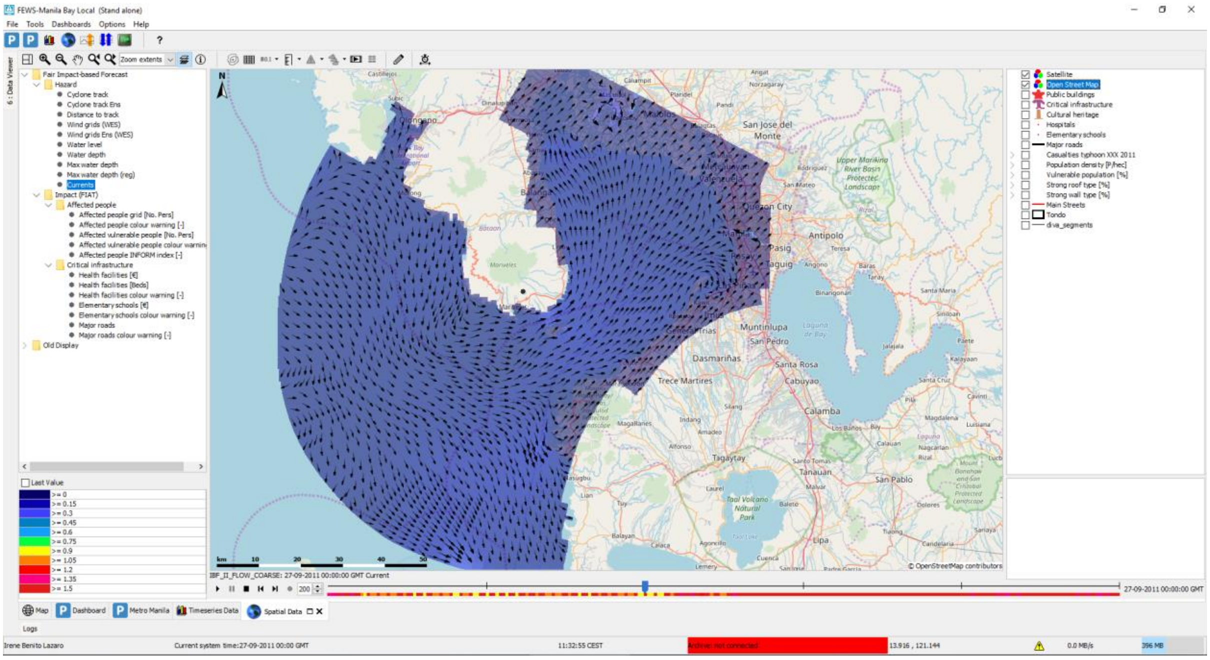
Water depth – Time series



Maximum water depth

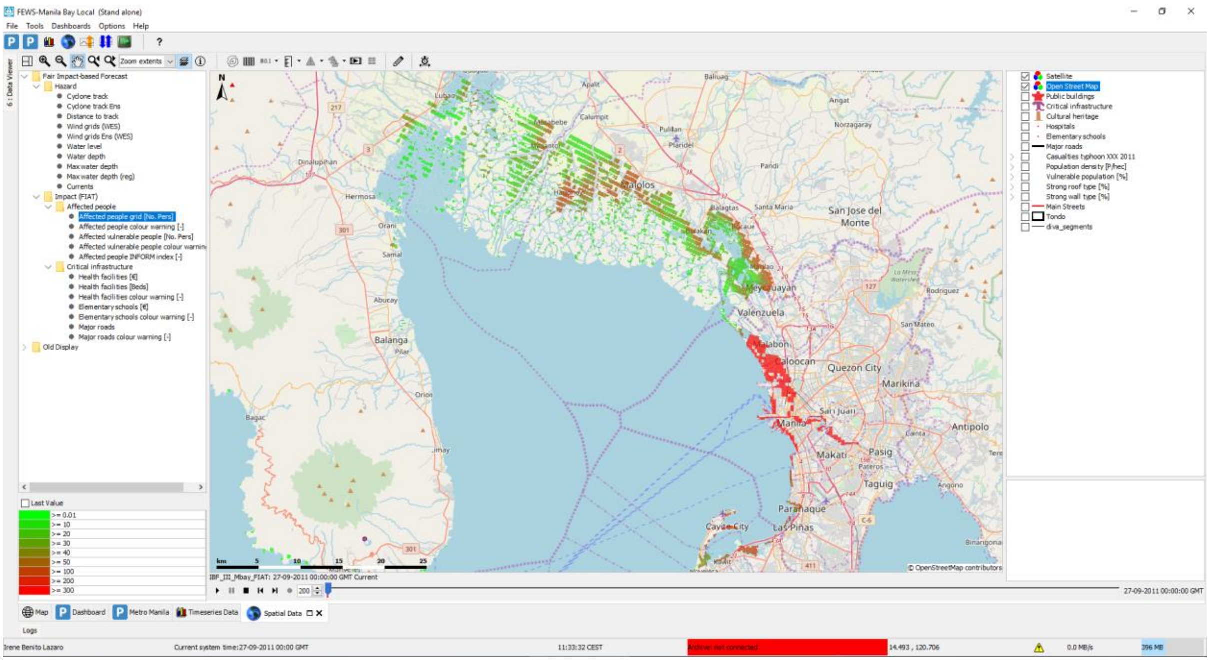


Currents

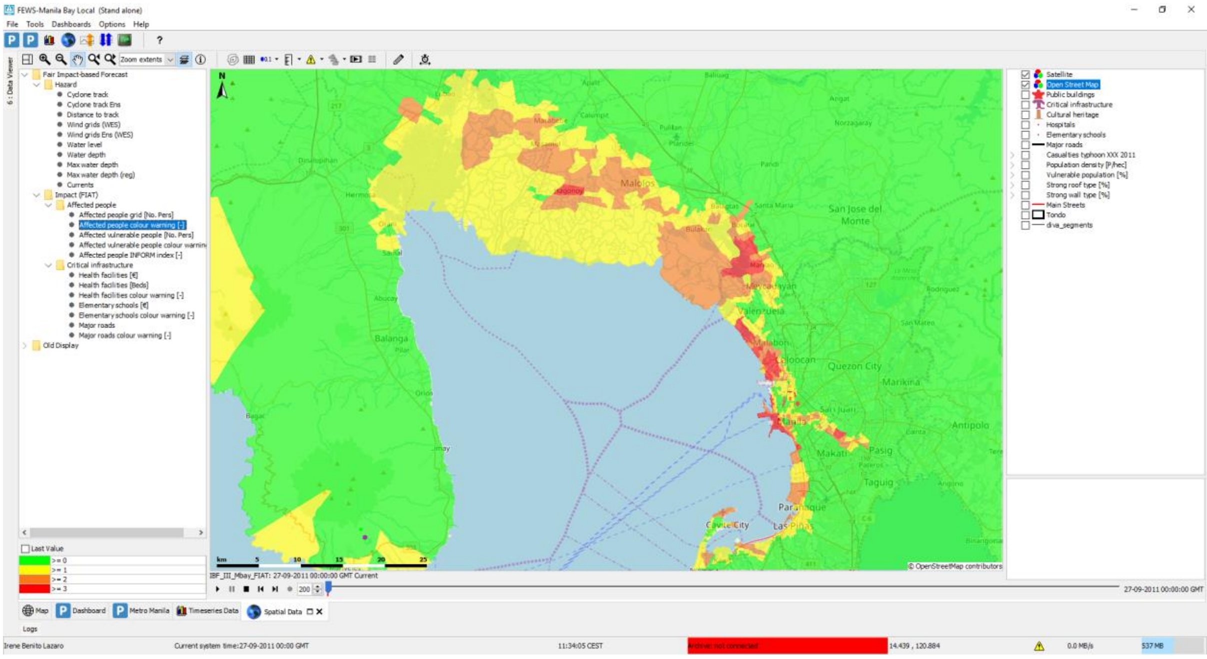


C.3. Impact maps

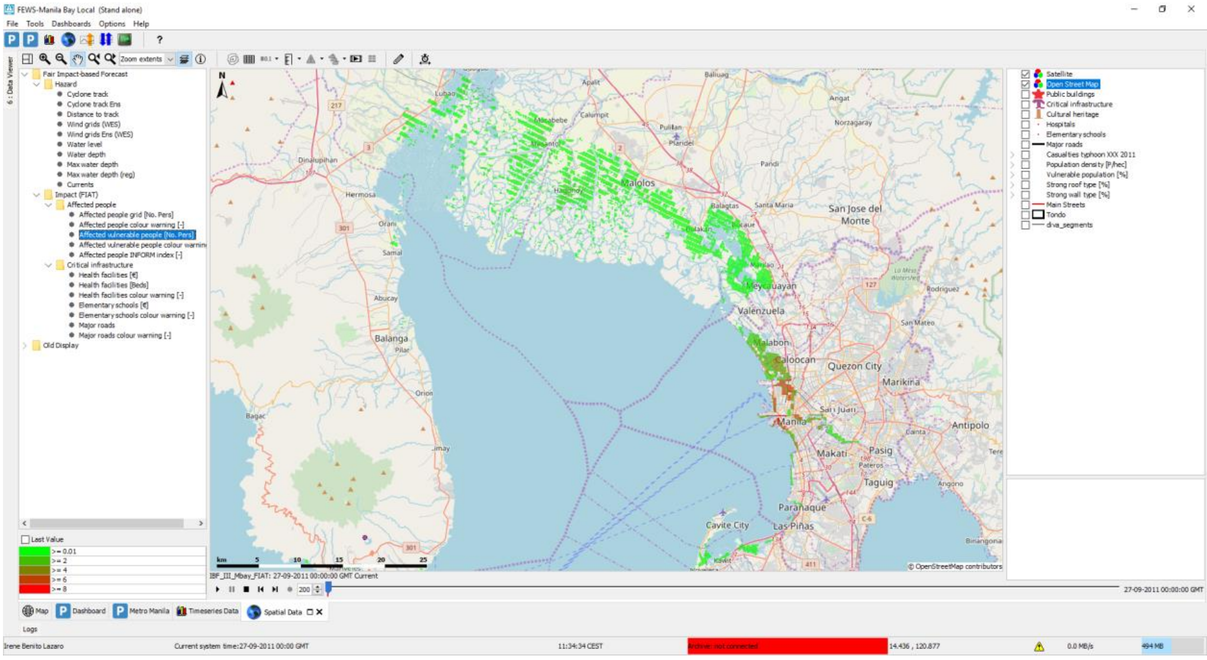
Affected people – Grid



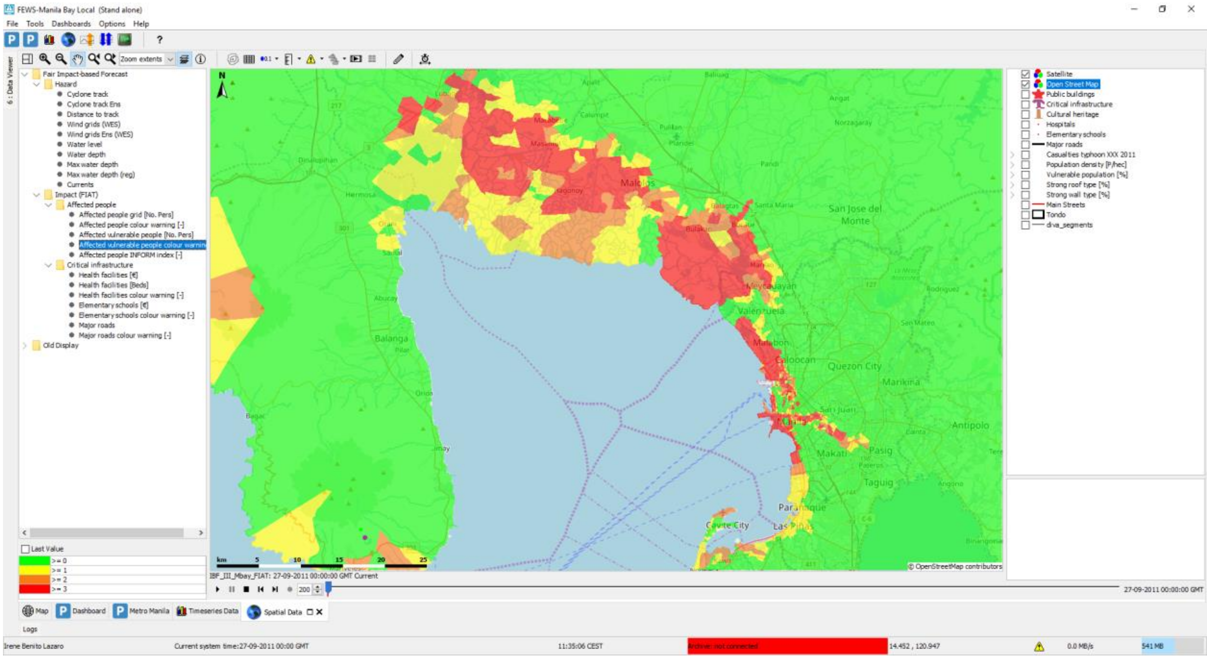
Affected people – Colour code warning



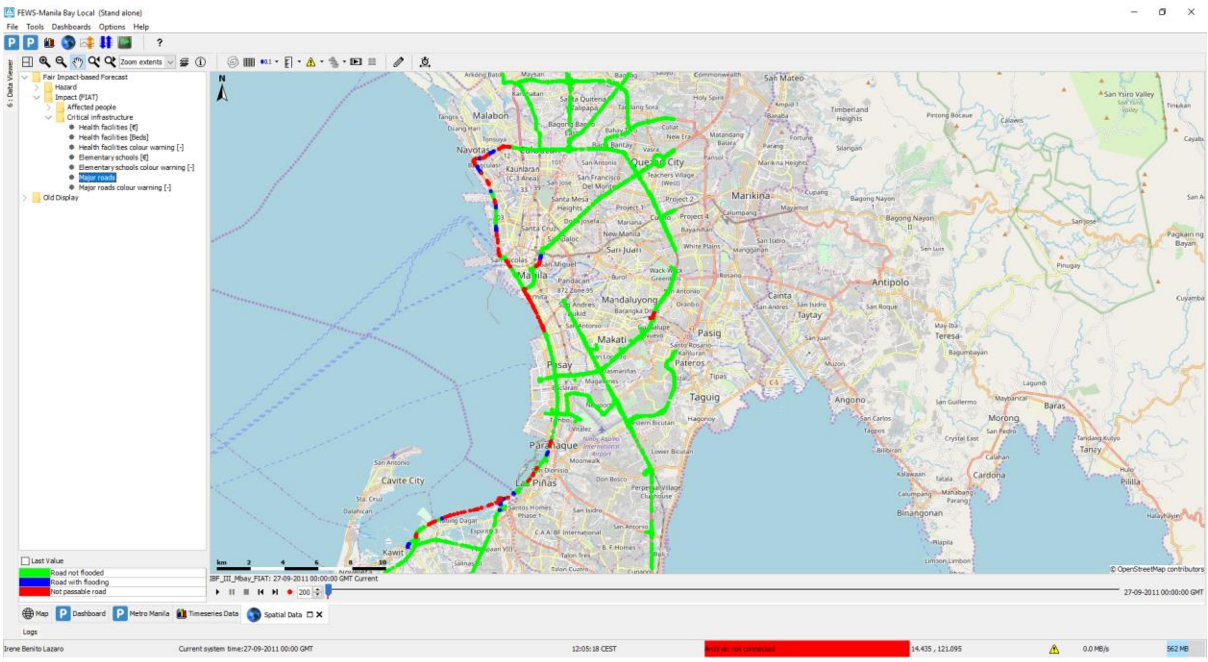
Affected vulnerable people – Grid



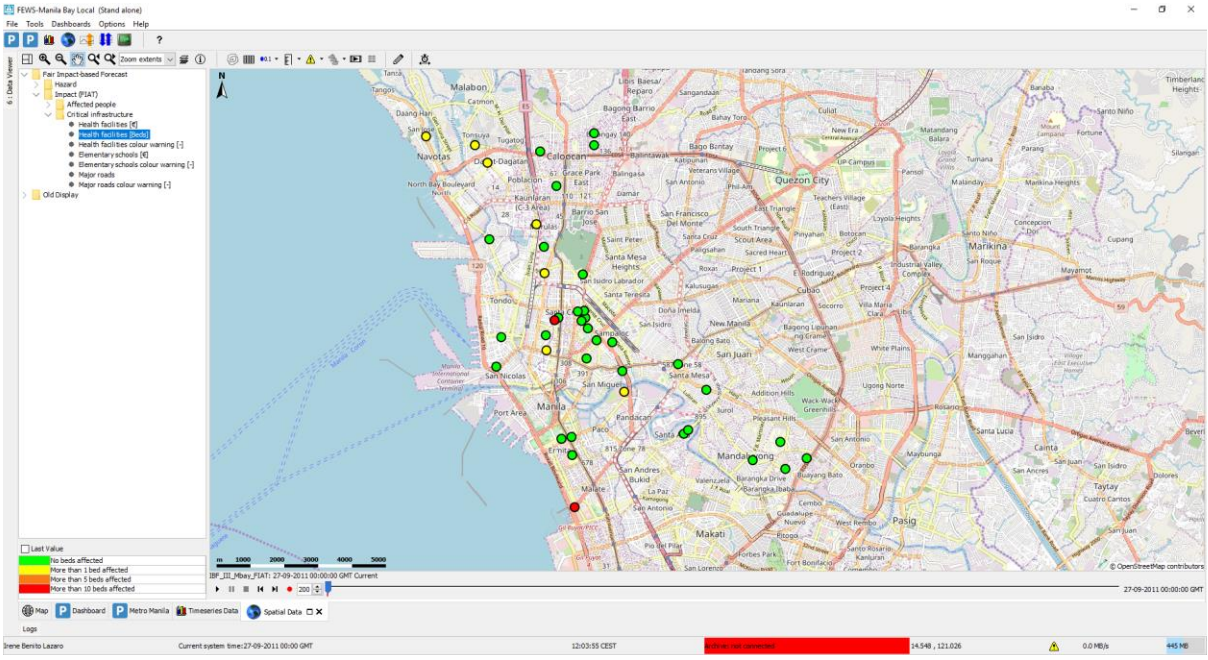
Affected vulnerable people – Colour code warning



Major roads



Health facilities



Elementary schools