Faculty of Spatial Sciences
Master Environmental and Infrastructure Planning

Master Thesis

Flood impact analysis using Geographic Information Systems: A case study, Quetzaltenango, Guatemala.

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Groningen, the Netherlands
July, 2015

DOCUMENTATION

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Abstract: *This thesis realizes an impact analysis focusing on mapping prone areas to flood events and assessing the vulnerability to flood of public schools and health care centres in the municipality of Quetzaltenango, Guatemala. The flood impact analysis is performed with official data provided from the Guatemalan National Institute of Geography and other public institutions dedicated to generate fist hand datasets. The method for analysing the impact of flood is based on map algebra techniques using Geographic Information Systems to assess variables such as land cover, slope, water flow, water accumulation and population density. The result consists of a set of maps showing the areas which are prone to be inundated within the ten sectors of the municipality; and the social facilities that can be negatively impacted in case of a flood event occurs. The discussion of the mapping products identify singular characteristics of each sector regarding social and environmental conditions related to the causes of floods. These findings allow posing for each sector, a set of tailored made measures aiming to be considered as a first proposal for discussion on how to deal with the flood risk profile of the municipality. In this work, measures for the short, middle and long term have been identified for all the sectors that comprise the municipality; such measures for flood risk management need the development of a collaborative planning model for governance, which suggests a transition from the current centralized-reactive approach towards a decentralized-proactive approach to develop an adaptive resilience profile in the municipality of Quetzaltenango.*

Keywords: Flood impact analysis, Impact analysis using GIS, Floods in Quetzaltenango, Floods in Guatemala, Flood risk management, Vulnerability to floods, Flood resilience, Weighted analysis, GIS analysis, Flood mitigation measures, Flood mapping

Título: Análisis de impacto de inundación mediante el uso de Sistemas de Información Geográfica, municipio de Quetzaltenango, Guatemala.

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Resumen *En esta tesis se realiza un análisis de impacto que se centra en la cartografía de zonas propensas a inundaciones y evaluación de la vulnerabilidad a inundación de escuelas públicas y centros de salud en el municipio de Quetzaltenango, Guatemala. El análisis del impacto de inundación se realizó con datos oficiales proporcionados por el Instituto Geográfico Nacional de Guatemala y otras instituciones públicas dedicadas a la generación de bases de datos de primer orden. El método para analizar el impacto a inundaciones se basa en técnicas de álgebra de mapas que se utilizan en Sistemas de Información Geográfica para evaluar variables como la cobertura del suelo, la pendiente, el flujo de agua, la acumulación de agua y la densidad poblacional. Los resultados se componen de un conjunto de mapas que muestran las áreas que son propensas a ser inundadas dentro de los diez sectores del municipio; asimismo las instalaciones que pueden verse afectadas negativamente en caso de inundación. El análisis de los productos cartográficos identifica características propias de cada sector en relación a las condiciones sociales y ambientales relacionadas con las causas de inundación. Estos hallazgos permiten proponer para cada sector, un conjunto de actividades para la discusión acerca de cómo abordar el perfil de riesgo a inundación del municipio. En este trabajo, se han identificado medidas a corto, medio y largo plazo para todos los sectores; las medidas de gestión del riesgo de inundación necesitan el desarrollo de un modelo de planificación colaborativa, lo cual sugiere una transición del enfoque centralizado actual, hacia un enfoque descentralizado y proactivo para desarrollar un perfil de adaptación y resiliencia en el municipio de Quetzaltenango.*

Palabras clave: Análisis de impacto de inundación, Análisis de impacto usando SIG, Inundación en Quetzaltenango, Inundación en Guatemala, Gestión del riesgo a inundación, Vulnerabilidad a inundación, Resiliencia a inundación, Análisis de ponderación, análisis de SIG, Medidas de mitigación para inundación, Mapeo de inundación

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1 CHAPTER ONE, INTRODUCTION

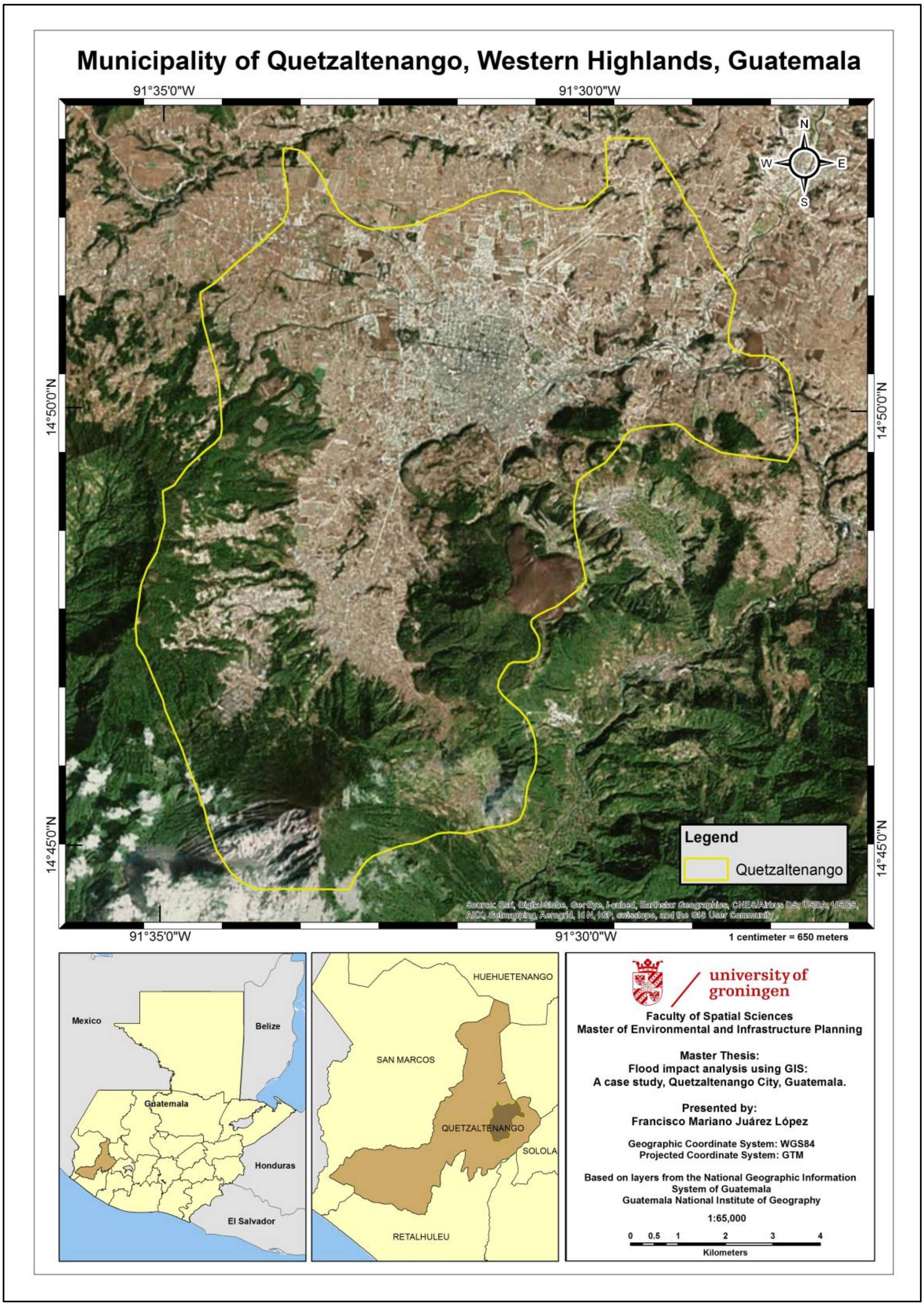
1.1 Background

Central America is considered as one of the most natural-phenomena exposed areas in the world due to its geographical location and orographic characteristics. Therefore, Guatemala which is located in the Central American isthmus, constantly faces disasters as an effect of the impacts of hydro meteorological events such as tropical storms and hurricanes. Climate changes also contribute to the increment of rainfall in the western part of Central American isthmus, (United Nations, 2010); this increment in volume of rain water has led to more recurrent and serious flood events in both floodplains of river basin and lowlands. Guatemala was ranked in 2005 as one of the most affected countries in the world due to the ongoing impact of natural threats (Harmeling, 2007).

Guatemala is located in the north-western side of the Central American isthmus, (see appendix, map 2) borders to the north with Mexico, to the south with Pacific Ocean, to the east with Belize, Honduras, El Salvador and the Caribbean Sea, and to the west with Mexico. It covers an area of 108,890 square kilometres and a total population of 15,073,375 inhabitants as of June 2012 (Instituto Nacional de Estadistica de Guatemala (INE), 2013). Guatemala has the highest population density in Central America -145/hab/sq km-, (see appendix, map 3) and one of the highest population growth rates in Latina America, (Comisión Económica para Amperica Latina y el Caribe (CEPAL), 2005) which rises up to 2.44% annually (Instituto Nacional de Estadistica de Guatemala (INE), 2013). In addition to these demographic characteristics, the impact of hydro meteorological phenomena is the most recurrent threat Guatemala constantly faces. This is the result of the combination of two main geographical characteristics. First, the country is located in equatorial latitude, having a tropical ecosystem. Second, the inland isthmus is narrow and exposed to two coastlines on both sides, whereas the Pacific Coast is more exposed to tropical storms and hurricanes. As a result of these natural phenomena, floods by rainfall, river mouths overflows and landslides become frequent events near the coastlines and river basins. The major cumulative impacts lays on agricultural production, household in urban areas and roads infrastructure which are greatly affected (Comisión Económica para América Latina y el Caribe (CEPAL), 2010).

The municipality of Quetzaltenango is the second most important economic region and the second largest city in Guatemala; it is located in the western highlands at 201 kilometres away from Guatemala City. The city lies in a mountain valley at 2,400 meters above sea level and is surrounded by mountains and the Santa Maria Volcano.

Figure 1, Municipal limits, Quetzaltenango



According to projections, it hosts a population of approximately 159,898 inhabitants by 2015 (Instituto Nacional de Estadistica de Guatemala (INE), 2013). As an important economic region in Guatemala, the city is rapidly growing and getting denser populated. In comparison with the surrounding municipalities, Quetzaltenango offers a wide variety of professional and educational services for the western region of Guatemala, causing a large amount of people to move to and from the city. It is usual that residents from other municipalities move to Quetzaltenango for studying purposes, temporary working offers or entrepreneurs which many of them end up moving permanently into the city. The parallel effect to this movement is a high demand of housing services within the city area, as long as putting pressure in new housing projects to be developed in the surrounding areas of the city.

The Municipality of Quetzaltenango covers an area of 126.83 square kilometres, however not all of this area is suitable for living because, as stated before, the city is surrounded by mountains and a volcano reaching its highest peak at 3,700 meters above sea level. Just by calculating the population density in rough numbers, the city has a minimum base rate of 1,261 inhabitants per square kilometre. With this ratio at the moment, the city itself does not have many options to keep growing other than sprawling into the neighbouring municipalities and/or grow vertically. The urban sprawling of Quetzaltenango City is putting more pressure to the surrounding environment, especially into natural resources, being the main cause of deforestation and forcing green areas and forest lands to convert into other land uses, such as urbanization, roads and agriculture. The relation between population growth and pressure to deforestation are considered to be so strong that have a direct link to environmental quality in a populated area (M. Cropper & C. Griffiths, 1994). This can be easily related to the fact that Quetzaltenango City is not an exception when it comes to facing disasters caused by natural phenomena, specially floods and earthquakes, being floods the most recurrent during the last decade. It affects social wellbeing and economic growth, as it is progressively becoming a more frequent event during the rainy season every year.

It is of great relevance to perform studies and research regarding flood impact in Quetzaltenango City, so that the municipal authorities will have a better understanding and view of the magnitude of the impact of flood events, its effects and consequences, especially those in the short term. It is necessary to identify the urban areas that are prone to be negatively impacted in case of a flood event. This will allow the local authorities and civil sector to develop immediate strategies for preparedness in case of disaster. The present work is the response to the need of having a first-hand research to start the debate regarding environmental and disaster risk management in Quetzaltenango City, Guatemala. It will bring a first overlook of areas that are in risk of flood, the potential damage that can be caused by a flood event at present time and the areas that could be impacted by flooding in the future, especially if no spatial planning strategy is developed and implemented in the city. Finally, it aims to be the first document that suggests mitigation measures that could be taken in the short term, to deal with future flood events, as long as to have a positive effect towards changing the current model in Quetzaltenango City regarding spatial planning.

1.2 Objectives

The research aims to carry out an impact analysis focusing on mapping prone areas to flood events, assessing social facilities at risk and identifying measures to develop a flood risk management approach in the municipality of Quetzaltenango, Guatemala.

The case study aims to provide the spatial information that can be used for linking the decision making processes that take place in the municipality, with a transition towards a flood risk management approach model for municipal policies and planning.

1.3 Research questions

In order to achieve the goals described in the objectives, a series of questions have been outlined. Responding to these inquiries is also the aim of this thesis work; one main question has been identified and two sub questions have been derived for the purpose of developing the present research. The questions are listed as follows:

<u>Main question:</u>
Which measures could implement the municipality of Quetzaltenango in order to deal with negative impacts due to flood events in zones which are prone to flooding in Quetzaltenango?

<u>Sub questions:</u>

1. Which areas are prone to flood events in the municipality of Quetzaltenango?
2. What social facilities will be negatively impacted in the municipality of Quetzaltenango in case of flood events?

1.4 Importance of the present work

The outcomes of this research could help to understand how flood events affect specific areas and neighbours of Quetzaltenango city. Besides that, the outcomes are valuable inputs that can be linked to the process of analysing the flood risk profile of the city, as long as for formulating municipal flood risk management strategies that will contribute to develop resilience in Quetzaltenango city against flood events in the future. Creating resilience cities is the most accurate approach to cope with inevitable hazards such as flooding (Dewan, 2013). Developing resilience capacities is crucial for Quetzaltenango city to reduce its vulnerability and exposure in the middle and long term. Building up a resilient community to natural disaster is best achieved by using an approach oriented towards sustainable development, while also including specific strategies that have been proven as useful for mitigating against natural hazards (Paton & Johnston, 2006). In the case of Quetzaltenango city, those strategies should involve issues in the social, technical, economic and political areas. The products generated in the present work can be used as a starting point to begin a process of analysis for formulating policies for Quetzaltenango city regarding environmental management and spatial planning.

In order to formulate such policies, municipal authorities need to analyse the current situation, and identify the conditions and factors that are increasing the vulnerability of the city regarding flood events. This kind of process ideally have to be carried out through a decision making process jointly with community leaders from vulnerable areas (Pelling, 2003). However, to start the process it is vital to have accurate information regarding which areas within the city are prone to be directly impacted and which areas have a potential to become vulnerable in the future. The recognition of such areas is the main contribution of this work. The present research is relevant for the city, as it positions itself as a first insight to start analysing the flood risk profile of the city. The research emphasizes in the actual prone-to-flood areas and identifies those that have potential to become prone-to-flood in the future. This research aims to be useful for municipal authorities and municipal technicians by contributing as described below:

1) It provides essential information related to identifying flood prone areas and determines areas that will be prone to flooding in the future, both in Quetzaltenango city.
2) It shows the public infrastructure and property at risk in Quetzaltenango city in case of a flood event.
3) It provides information as a starting point for determining short term mitigation measures in the prone areas to flood events in Quetzaltenango city.

2 CHAPTER TWO, THEORY

2.1 Flood hazard

Floods are present naturally as physical phenomena in several types of ecosystems; it is not considered as disaster itself. However, a flood event within a populated area becomes a serious cause of human harm, property damage and economical loss. In other words, a flood event frequently turns from natural phenomena into a hazard to human society when it occurs in a populated area of human beings. It may have an extended and recurrent negative impact and becomes especially harmful when local response and coping capacities of the population are surpassed by the flood event.

Globally, floods are the most frequent occurring destructive natural events, affecting both rural and urban settlements (Global Facility for Disaster Reduction and Recovery, 2012). Generally, floods events are the result of the combination of meteorological and hydrological extreme conditions in one place and time, for instance, extended rainfall and increase volume of runoff. Unfortunately, it is usual that the frequency and potential damage of flood are enhanced as a result of human activities such as the increment of urban density, unplanned growth of settlements and land use changes without environmental management criteria. The combination of natural extreme conditions and anthropogenic pressure on the environment in populated areas, make these areas to be characterized as element at risk and thus prone to flooding. Typical characteristics of flood hazards include area of inundation, flood depth, frequency, rainfall–runoff lag times, and geomorphological settings (Dewan, 2013). Populated areas that are elements at risk of flood events share common characteristics. For instance, they might be located at the riversides of large stream waterbodies, at the bottom of watershed floodplains or within a mountain river basin delta. In cases with one or the combination of these typical scenarios, the mayor hazard comes from river overflow during the rainy season, while sea level rise is for those populated areas located directly at costal zones.

2.2 Vulnerability to floods

When a population is exposed to hazards, the elements at risk, such as people and property are implicitly vulnerable. Vulnerability is a concept intrinsically linked to hazards when it comes to define prone areas; it makes reference to the characteristics of a specific area or element from the point of view of hazard management. One of the most known and widely accepted definitions of vulnerability was formulated by the International Strategy for Disaster Reduction of the United Nations, which defines vulnerability as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (United Nations Office for Disaster Risk Reduction, 2009). Vulnerability is relative from place to place and differs from specific circumstances from one place to another; however, in all cases, it corresponds with the understanding that vulnerability is primarily a human condition, not a natural condition. A population of human beings is vulnerable to the hazard “flood”, when it is at risk of being inundated by any reason. In other words, the natural phenomena rainfall, water runoff, sea level rise or others, become into hazards for human population because they cause human harm and material damages throughout flooding the city. The result is that the city itself is an element at risk of flood due to the combination of its location and human activities in the surrounding environment. These activities might include urban sprawling, deforestation, agriculture expansion and change of land use, among the most common. These particularities characterize a populated area as vulnerable to flood, and increase the probability to receive negative impact more frequently. Vulnerability of a population of human beings can be categorized in the following four types of impacts (Kingma, 2011):

1. Physical vulnerability: the potential for physical impact on the built environment and population.
2. Economic vulnerability: the potential impact of hazard on economic assets and processes.
3. Social vulnerability: the potential impacts of events on specific groups such as the poor, single parent households, the handicapped, children, and elderly.
4. Environmental vulnerability: the potential impacts of hazard on the environment.

2.3 Exposure and risk

Vulnerability and the coping capacities of the population manifest themselves once a vulnerable community is exposed to a hazardous event (United Nations University, 2006). For instance, a city that has never been flooded is not classified as vulnerable to floods; it will be, only after several years recurrently facing flood events that will be seen as vulnerable. At this point a community is clearly an element at risk, defining the term risk, as the product of the interaction between hazard and vulnerability in a certain area (Asian Disaster Reduction Center (ADRC), 2005).

Risk itself is defined as the expectation value of losses (deaths, injuries, property, etc.) that would be caused by a hazard (Asian Disaster Reduction Center (ADRC), 2005). Thus, risk itself is the outcome of bringing together the three factors: Hazard, vulnerability and exposure combined in a specific period of time and location. This combination explains whether such location has a risky or safety profile. An increasing exposure of people and infrastructure (the elements at risk) due to environmental degradation of surrounding natural areas, expansion of unplanned urbanization and inappropriate policies to reduce vulnerability, evolve into a larger number of disasters caused mainly by flood, and secondary by other related natural hazards. The risky profile of a populated area of human beings can be pictured as a function of hazard (extended rainfall and water runoff), exposure (people and infrastructure) and vulnerability (location, policies and environmental conditions). The combination of the factors hazard, vulnerability and exposure in a specific period of time and location define the disaster risk profile of that indicated location. Disaster risk can be described as the potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period (United Nations Office for Disaster Risk Reduction, 2009). The idea of disaster risk implies a permanent condition in which the factors hazard, vulnerability and exposure are combined, thus generating constant risk conditions. Disaster risk involves the potential to suffer losses of different kinds; for instance, from invaluable human lives, to agriculture damage, deterioration of public infrastructure and inhabitation of household among the most common and important. The comprehension of vulnerability and exposure to natural hazards has considerable implications for communities and cities regarding understand the disaster risk profile. In other words, understanding of exposure, vulnerability and hazards of a certain location, can extensively contribute to develop a set of mitigation measures for disaster risk reduction of that location (Dewan, 2013). In Addition, the knowledge of the interaction of those elements promote the development of a disaster-resilient community.

2.4 Flood risk management

Communities or cities which have a disaster risk profile without a disaster risk management approach are subject to be severely impacted when facing the hazard they are vulnerable to. To address the problem and minimize the negative effects of flood events, a flood risk management approach is needed. In recent years, a paradigm shift in flood policy has been evident across the world, that is, flood risk management has become the focus rather than the traditional concept of flood protection (Dewan, 2013). Flood risk management comprises a systematic process of using a combination of administrative directives, smart organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of flood events and thus reduce the possibility of disaster (United Nations Office for Disaster Risk Reduction, 2009).

Flood risk management can be develop and implemented by different means that include a combination of policies, capacity building processes and engineering techniques. Local consensus and level of investment are variables to take into account when choosing an approach and designing strategies for flood risk management. Three different strategies of flood risk management are identified (Meijerink & Dicke, 2008). In the following chart, the strategies and their approach are summarized.

Table 1, Different strategies for flood risk management

No.	Strategy	Approach	Measures	Focused on
1	Reduce probability of flood	Technical, spatial (Reactive)	Dams, dykes, levees, storm surge barriers and other civil engineering.	Hazard control

No.	Strategy	Approach	Measures	Focused on
2	Reduce impact of flood	Communicative, social (Proactive)	Early warning systems, planning of evacuation routes, adjustments to houses and infrastructure	Vulnerability control
3	Reduce exposure to flood	Communicative, social (Proactive)	Relocating properties, inhibiting new developments in flood prone areas.	Exposure control

Flood risk management can be seen as a collective good, as a type of governance (Meijerink & Dicke, 2008). Literature makes a distinction between three important coordination mechanisms for modes of governance: state, market and network. Each one of these three mechanisms has an important and specific role to develop and successfully implement flood risk management as a model for governance. The state represents the public stakeholder, the market represents the private stakeholder and the network represents community leaders and social acceptance for any proposal. Flood risk management turns into a delicate and complex model that involves all kinds of stakeholders to be successful. Finding a balance and common interest among the three aspects of flood risk management is crucial for long-lasting strategies. Additionally, Flood risk management has to be adapted to the local circumstances, especially in countries with low per-capita income and thus, low capacity for large investments. For countries with these characteristics it is difficult to stand the massive expenses related to traditional flood-control structures, such as dikes, bridges and barriers, as described in the reduce-probability-to-flood strategy that focuses on hazard control. Conversely, a shift from classic flood protection (technical and engineering) towards flood risk management based on social and communicative approach is recommended (Dewan, 2013).

As a result in many countries, flood risk management is currently experiencing a model shift that is no longer based on one single dimension as it used to be in past decades. The traditional technical approach of making large investments on infrastructure to ‘keep floodwater out’ does not seem to be the accurate approach in most cases. Instead, the models are shifting towards a more strategic, holistic and long term approach characterized by mitigating both flood risk and adaptation, or increasing resilience to flood events. Flood risk management is a complex model that implies governance, uncertainty and involves large temporal and spatial scales (Scott, 2013).

2.5 Flood resilience

The term resilience was introduced as a new way to describe the capacity of a system to absorb external changes. In 1973 it was defined as follows:

"Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb change of state variable, driving variables, and parameters, and still persist" (Holling, 1973). Since then, the term is particularly useful for social and environmental systems in which the capacity to absorb changes from external sources is a critical factor to keep functioning properly and stable. The concept of social resilience of a city also entails the main characteristic of coping capacities and adapting to unexpected changes that might occur in the future due to flood events. This is specially noted in the following concept of resilience: the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard (flood event) in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions (United Nations Office for Disaster Risk Reduction, 2009). Developing resilience in prone-to-flood areas of a community or city implies strengthening local capacities to make inhabitants adaptable to change from flood to non-flood time, and prepared to minimize the negative impacts of a flood event. Resilience extends to an array of measures involving public administration, decentralization, organizational and institutional development (strengthening local neighbours), community-based strategies, engineering design and regulation, settlement development and land use planning (Westen, 2011).

There are different levels of resilience that can be developed particularly or commonly for elements at risk. The adequate approach and scale of the levels vary significantly from place to place, from situation to situation and have different characteristics that need to be identified. However, in general these levels can be: 1) Individual, 2) Family, 3) Tribe or clan, 4) Locality or neighbourhood, 5) Community, 6) Social associations such as clubs and faith congregations, 7) Organization (such as a bureaucracy or a private sector firm), and 8) Systems such as environmental systems and economic systems (Paton & Johnston, 2006). Even more specific, regarding hydro-meteorological hazards, resilience is understood as the capability of the city to resist, by means of its own coping capacity, the harm of a flood event (Dewan, 2013). In this context, resilience thinking has emerged as a key framework in examining the role of spatial planning within flood risk management (Scott, 2013). Flood risk management makes a clear difference between two strategies to address a flood event; resistance and resilience (Restemeyer, Woltjer, & van den Brink, 2015). When developing resistance, the aim is focus on the reduction of the probability that the hazard affects the city in a negative way. On the other hand, the strategy of developing resilience, aims to prioritize efforts for minimizing the consequences of flood, being the adaptation in the middle and long term the most accurate way to achieve it. This framework reconsiders the understanding of the ability of a place to bounce back in the aftermath of a shock, such as a disaster from a flood event. Even a more progressive perspective of resilience, is to include the terms of adaptability and transformability (Scott, 2013), which referrer not only to the capacity to bounce back but also to constantly work focused on reducing the exposure of the elements at risk to future risks. Consequently an evolutionary perspective of resilience places significance on transformation, which invariably includes the paradigm shift from flood defence towards flood risk management (Scott, 2013). This means a new perspective in which communities and cities live with water as part of the environment, however the inhabitants are prepared to reduce the negative impacts to the minimum with the awareness that at some point they will have to experience periodic flood events.

2.6 Transition in flood risk management

Traditionally, the perception to deal with flood events around the world has been based on the idea of keeping the water out of the community or city, an approach merely protective. However, a changing awareness is rising, as a result of realizing that floods are natural phenomena that cannot easily be avoided, nor accurately predicted and impossible to get rid of. Under the traditional approach, three long held perceptions are conceived: 1) The actual sources of flooding are thought to come from rivers and the coasts, 2) the governing of floods at a national level is the way to address the problem, and 3) the efficacy of large scale flood defences is the most effective intervention approach (White, The more we know, the more we don't know: Reflections on a decade of planning, flood risk management and false prediction, 2013). The traditional approach used to be suitable in cases were large capacity of investment and technology were conducted by central government. The high profile of the infrastructure and the increasing rate of flood events worldwide, stimulated academic research to look for other alternatives that drove a new policy shift from flood defence to flood risk management. A new pragmatic public message emanated from policy circles in which society should live with water and expect to experience periodic flooding (White, The more we know, the more we don't know: Reflections on a decade of planning, flood risk management and false prediction, 2013).

The recent shift from centralized flood defence towards a holistic flood risk management implies decentralization in governance, investment and capacity building. Consequently a greater diversity of stakeholders has to be included in the process of flood management and the development of new roles and different forms of both horizontal and vertical collaboration (Kuhlickea & Steinfuhrer, 2013). The resulting model is a governance that prioritize the preparedness in which stakeholders from different sectors are brought together to collaborate on a single common strategy. The aim is to impact positively regarding the administrative practice of flood risk management from various sectors, such as public, private and civil society, each one with its own role and responsibility. At the same time this shift towards 'governance of preparedness' is associated with new form of authority and control as well as interchanging distribution of the responsibilities and roles (Kuhlickea & Steinfuhrer, 2013). In flood risk management, preparedness is the priority to reduce the negative effects of flood events, thus communication among all stakeholders is a key tool for making agreements regarding flood governance. In addition, most plans and mitigation measures have to be communicated to the public through a process of information distribution, but most important is that this is in a one-way manner and with only limited opportunities for the population to interact (Kuhlickea & Steinfuhrer, 2013) and find consensus to develop an effective capacity building process, accurate preparedness strategies and implement mitigation measures that are feasible and sustainable in the middle and long term, as a result of the recognition of all the stakeholders involved in the process. The transition from protective approach based on engineering towards flood risk management to build flood resilience, focuses on local context, characteristics and needs of a community to successfully develop social capacity building at different scales. The capacities from all stakeholders work together as a whole to make the community resilient to a flood event. Five different types of social capacity building for flood risk management have been identified: 1) knowledge, 2) motivation, 3) social networks, 4) financial resources and, 5) Governance capacities (Kuhlickea & Steinfuhrer, 2013). The transition in approach; with flood defence becoming flood risk management means a new understanding that society needs to learn to live with floods and make space for water instead of continuously struggle to keep water out of the city (White, The Absorbent City: Urban form and flood risk management, 2008).

2.7 Sustainability and flood risk management

The extent of resilience that a city has developed, comes as a result of the way in which a city manages the probability of flooding (accordingly to its disaster risk profile) and how the consequences of a flood event are addressed. The resilience extent can be low or high in correspondence to its capabilities of adapting by means of absorbing the negative impacts of flooding. If the city develops a high resilient extent, it is likely that the negative impacts of a flood event will be addressed in ways that allow the city to keep away from collapsing. This relation has a deep significance regarding economic growth and development. Sustainability is intrinsically linked to flood risk management in cities with a flood risk profile, as it is not just concerned with balancing economic, social and environmental interests; it seeks to enhance all three components to ensure that there are no overall adverse effects (Lavery & Donovan, 2005). Sustainability and flood risk management share a nature of being a mixture of long term policy and develop strategic capacities that can bring solutions together by implementing a series of adaptive and sequential steps that provide the best possible response to changing situations in future time. Especially those that might be unexpected, for instance, due to climate change conditions and can suddenly configure differently the flood risk profile of a city.

A traditional flood defence approach tends to limit adaptability in the long term, thus the nature of the approach comprises solutions based only from a technical-engineering perspective, restricting the possibility of adaptation to work with nature, which might be interpreted as unsustainable approach in the long term. As part of the transition from flood defence to flood risk management, it is necessary to research regarding the possibilities of use and accommodation of flood by developing management options within the flood prone areas rather than restricting the options to the ones based on flood defence along. The approach of working with nature is perceived as sustainable and is referred to as localized flood management and rivers edge protection (Lavery & Donovan, 2005). As explained before, the strategies of resistance and resilience focus on different components of flood risk management, hereafter, resistance is less sustainable due to the limited adaptability and high financial cost of investment that is needed at first stage, and consequently the maintenance and operation. Conversely, a strategy of resilience approach takes the possibility of flooding as a fact and thus, prepares the city not only with multi-purpose infrastructure but mainly develops a community based flood risk management system that trains inhabitants of the city throughout capacity building processes. Resilience strategies rely on risk management instead of on hazard control (Restemeyer, Woltjer, & van den Brink, 2015). Building resilience is also a parallel process of building sustainability in the long term. To achieve a high level of adaptability and sustainability within a flood risk management system, a combination of both resistance and resilience approaches has to be implemented in different stages along a long term, taking into account the specific and local circumstances of the place with a flood risk profile.

2.8 Urban flood risk management

Food risk management at urban level implies a holistic approach and the necessary transition from a reactive policy/approach, towards a proactive approach. That means a more complete understanding of flood risk, from technical reasons that cause the flood to social interactions, economic impact and all the dynamics within the city that are affected by periodical flood events. Additionally, the capacity of society for coping with periodical flood events is a key issue to set up a resilient city which learns how to manage flood events and is able to bounce back to a stable condition after a flood event. Developing of strategic skills and specific capacities for technical, political, economic and social components is a must for urban societies, such as big cities that present a prone to flood profile. Important is to mention that this new approach of urban flood risk management has arisen based on the idea of developing capacity of society to manage nature by means of adapting to it instead of modified it. In retrospect, the management of flooding can be understood as following a three-stage process, being the last one a proactive approach (White, The Absorbent City: Urban form and flood risk management, 2008):

1. Self-protection, mainly characterised by individual response.
2. Then, the mid 20th century witnessed a period of increasing engineered defence in which, although the location of development was loosely controlled, there was systematic construction of hard defences.
3. Current processes of emerging natural management -as the limitations of the techno-centric approach are recognised-, land is given back for floodplain restoration and more room is made for rivers.

The proactive approach of natural management referred in the third point, demands policies for working alongside with nature instead of constantly defending the city from it by means of reactive engineering. The change towards a proactive approach requires a long term vision to build strategic and effective resilience to flood risk. An essential component of the proactive approach is the development of legal and policy framework for spatial planning headed to move towards a reflexive, absorbent city (White, The Absorbent City: Urban form and flood risk management, 2008). The approach has a social scale that involves several governmental and private stakeholders, as long as civil sectors and non-governmental organizations.

Cities are complex and uncertain systems where human activities and natural phenomena constantly interact around many unexpected variables. The idea of absorbent city lays on adaptation and contingency for diverse scenarios, it aims to take advantage of local characteristics and the use of spatial planning for the advancing a reduction of hazard, vulnerability or exposure. The absorbent city concept comprises three principles: the reflexive city, the knowledgeable city and the adaptive city (White, The Absorbent City: Urban form and flood risk management, 2008). The reflexive component refers to the ability of the city to keep track memory of the past events regarding flood, be connected with its historical weaknesses and strengths so that the city can learn from past, both disasters and successful experiences. Learn from mistakes and boost the effective mitigation measures creates a process of self-reflexion and positive feedback that leads to improvements by innovation while being aware of the causes and effects of flooding. Being reflexive is part of being proactive and comprises the first step towards a transition management approach.

The knowledgeable city is the second component towards an absorbent city. It is a fundamental issue to build flood-resilience. This aspect refers to the carrying out of local diagnosis, analysis of local circumstances and research of local conditions for both technical and socio-political issues. Having a good understanding of the territory that is prone to flood events and its characteristics, allow planners and local authorities to formulate and implement clear and more precise policies and projects. The social, economic and geospatial information from research can be accurately use to feed the planning and land use decisions, especially over the middle and long term strategies. The main driver within this approach would be to link geographical features more tightly with the nature of development within a city so that the layout and functioning of urban areas can adapt to current risks and predicted future changes (White, The Absorbent City: Urban form and flood risk management, 2008). The use of geospatial techniques such as impact analysis, support the process to build a knowledgeable city and can be utilized effectively in the entire spectrum of the disaster risk cycle which can save lives and property from natural hazards such as flood, as well as support informed decision making during emergencies (Dewan, 2013).

The last component, the adaptive city, refers to the capacity of the city to work in both flooding and non-flooding situation. The implementation of spatial planning strategies and infrastructure design that is compatible with both situations is a key step to develop Infrastructure that is hybrid, adaptive and efficient to absorb the impact of a flood event. The design of multi-functional infrastructure that area capable to combine flood storage and recreational purposes in public property such as green spaces and open areas is one of the most common practices of combining environmental management and flood risk management. Simultaneously, the green belts and multi-function areas also help improving the urban landscape while subsequently having a positive impact on quality of life for citizens that may do otherwise uncontrolled sprawl. The ability to map the extent of floodplain inundation presents a first predictable opportunity to further the absorbent city: a need to tightly manage new development in functioning floodplains (White, The Absorbent City: Urban form and flood risk management, 2008).

2.9 Flood impact analysis

A flood impact analysis is a method to identify prone-to-flood areas within an exposed element such as a community or city. This type of analysis was firstly introduced for evaluating environmental impacts as part of the feasibility studies of large scale projects. However, due to its capability for evaluating changes with a holistic approach, that means: before and after an event, the methodology finds special utility when it comes to flood risk management. The findings of a flood impact analysis are the first input for policy makers, housing developers and local authorities. Moreover, municipal authorities are frequently responsible for leading a flood risk management strategy aiming to develop resilience in vulnerable communities or cities. Flood impact analysis results are meant to be used by authorities, as input to start a debate regarding how to deal with flood risk profile and evaluate the possibility of a shift from responsive approach towards proactive approach. Flood impact analysis is an excellent method to diagnose the existing conditions and environment, assembly of relevant information concerning floods, collection of spatial data and finally the evaluation of degree of vulnerability in case of flood (Anjaneyulu & Manickam, 2007). The information contained in a flood risk analysis is the first vital diagnostic tool for the formulation of accurate strategies and decision making processes aiming the construction of resilience against flood and sustainability in the long term. Important is to define that an impact is essentially a change over a determined element in the environment, people or public facilities, that takes place during or after the flood event (Anjaneyulu & Manickam, 2007). The impact analysis aims to understand the changes caused by a flood event by comparing points with and without a given event. The "impact" is the difference between what would happen with the action and what would happen without it (Lawrence, 2013). Impact analysis is used as an input for understanding the degree of risk of a community or city that is being evaluated. The process to carry out an accurate impact analysis comprises the following three phases (United Nations Environment Programme, 2002): 1) identification: to specify the elements at risk and impacts associated with the event, 2) prediction: to forecast the nature, magnitude of the main impacts, and 3) evaluation: to determine the significance of impacts and identification of mitigation measures. The objective of a flood impact analysis is to identify how many infrastructure, property and social facilities are negatively impacted during and after a flood event, making sure that direct and indirect effects, which may be potentially significant, are not inadvertently omitted (United Nations Environment Programme, 2002). The process of identifying and evaluating the impacts are based on the specific environmental characteristics of the area that is being evaluated. These characteristics mainly include land use, forest cover, orography (slope), social facilities at risk and population density among the most important.

There are several techniques for conducing impact identification studies; one of the most common and simplest techniques is the use of checklist that can be applied easily and within a fast period of time. This technique is carried out without the need of specialized technicians, high technology or large investments. In contrast, the most advanced technique is the use of geographical information systems that can be applied to flood impact analysis when all the geospatial data is available digitally. However this technique is often expensive and requires specialized humans resources, computer software and hardware. To analyse the impacts of flood events on the basis of identifying prone areas and environmental characteristics, geographical information systems is the most suitable methodology due to its capability to analyse social, physical and environmental data at the same time. The use of remote sensing technologies for overlaying geospatial data, give additional value to perform analysis. The following chart describes the impact analysis identification methods with their respective pros and cons (United Nations Environment Programme, 2002):

Table 2, advantages and disadvantages of impact identification methods

No.	Technique	Advantages	Disadvantages
1	Checklist	• easy to understand and use • good for site selection and priority setting • simple ranking and weighting	• do not distinguish between direct and indirect impacts • do not link action and impact • the process of incorporating values can be controversial
2	Matrix	• link action to impact • good method for displaying EIA results	• difficult to distinguish direct and indirect impacts • have potential for double-counting of impacts
3	Networks	• link action to impact • useful in simplified form for checking for second order impacts • handles direct and indirect impacts	• can become very complex if used beyond simplified version
4	Overlays	• easy to understand • focus and display on spatial impacts • good siting tool	• can be cumbersome • poorly suited to address impact duration or probability
5	GIS and Computer Expert systems	• excellent for impact identification and spatial analysis • good for experimenting	• heavy reliance on knowledge and data • often complex and expensive

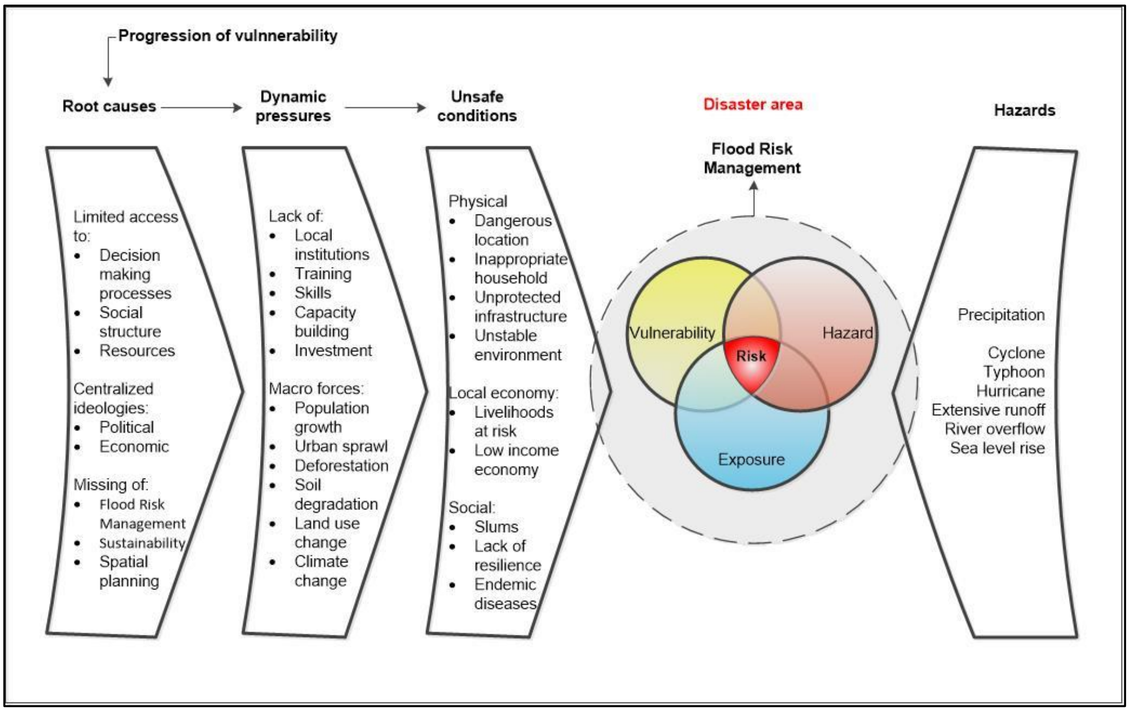
The use of geospatial techniques in flood risk management is separated into three categories: flood mapping, damage assessment, and evaluation of flood risk and vulnerability (Dewan, 2013). To carry out accurate assessments, a variety of data comprising topographic, biophysical and socioeconomic aspects and characteristics of the location is used as a primary source for flood risk analysis in locations with a disaster risk profile. Geospatial techniques are the most suitable method to evaluate large areas by using remote sensing technologies that allow experts to run models without doing extensive fieldwork. There are three broad categories in which geospatial approach plays a critical role in flood risk management (Dewan, 2013): 1) flood mapping and monitoring, 2) damage assessment, and 3) risk assessment, including hazard and vulnerability estimation. A complete flood impact analysis covers the three categories mentioned above.

2.10 Conceptualizing flood risk management

Flood risk management is an approach to address disaster risk regarding flood events. As mentioned before, disaster risk is the combination in time and location of vulnerability and hazards over the elements at risk (exposure). Disasters are a result of the interaction of both over exposed elements (see figure 1). There cannot be a disaster if there are hazards but vulnerability is (theoretically) nil, or if there is a vulnerable population but no hazard event comes to happen (Wisner, Blaikie, Cannon, & Davis, 2004). A flood event is categorized as disaster when a large number of inhabitants of a community or city is directly impacted and negatively affected in social, emotional and economical terms, as they suffer damage to their livelihood system and human integrity. Every disaster due to flood events comes to happen in vulnerable populations, this vulnerability is often rooted in factors that belong to a macro level such as political and economic ideologies that comprise the structure and society of the population itself. The political and economic model of vulnerable populations frequently does not take into account a holistic approach based on proactive strategies. Instead, a reactive management and mitigation measures are conducted every time after the population has already been impacted by a flood event. Consequently, the negative impacts are higher in every other event and response to emergency appears to be the main problem. As a result of a linear and centralized model of general governing, dealing with flooding is also vertical; thus, population has limited or no participation in the decision making processes, making the social structure hierarchical and limiting the policies, projects and proposals with regard to dealing with floods (see root causes on figure 1). The hierarchical governing model regarding dealing with flooding limits the society to be culturally empowered to develop their own coping capacities.

Within a hierarchical model, vulnerability can be seen as a progressive process, once the main causes are rooted at a macro level, a cascade effect start developing weakness at meso, micro and finally personal level, affecting a large number of populations. The root causes at macro level inevitable create dynamic pressure in the rest of society (Wisner, Blaikie, Cannon, & Davis, 2004). This is manifested in the population by a lack of capacities building network in regard to flooding. In a society that is highly vulnerable and no flood risk management strategy has been developed, the lack of community based skills to deal with flooding is evident. In other words flood management training, development of local coping capacities or warning systems are missing. As a consequence of missing this set of social skills and preparedness against flood, vulnerability is sharpened as the population is directly impacted without any awareness or ability to respond in advance to a potential flood event. An important dynamic to mention, is that coping capacities are not only individual, but work as collective good as the city is seen as a complex body. For instance, population growth, urban sprawling and environmental degradation also create dynamic pressure, however this is a phenomenon created collectively and thus very difficult to monitor and take control of it. The dynamic pressure factors lay intrinsically within social and environmental conditions of the community or city, but refer to the collective characteristics of the city that is vulnerable, refer to the meso level after the macro rooted causes of vulnerability.

Figure 2, Conceptual model of flood risk within Flood Risk Management



Source: Pressure and release model (PAR), adapted from Wisner et al. 2004

The lack of social capacities and degraded environmental conditions has a direct influence in families and individuals when it comes to deal with the disaster risk profile of a city. This scenario creates unsafe conditions for the inhabitants who are permanently exposed to vulnerable conditions. Depending on the neighbourhood, some families or individual might be in higher risk compared to others in the same city. For instance, those living in slums and growing into urban sprawling, put more direct pressure to the surrounding environment, suffer from endemic diseases and have low income economies. As a result, those individuals are the most vulnerable due to the fact that most of the time, the infrastructure, household and location are the worst prepared against flood, and the coping capacities are minimal or inexistent. In contrast, those individuals who live in the middle and upper class neighbourhoods, have access to better information systems, public infrastructure and household, putting less direct pressure to the surrounding environment and subsequently are less vulnerable than those at the slums areas. However, in spite of the individual vulnerability, the lack of social capacities and degraded environmental conditions make the city itself at risk of flooding.

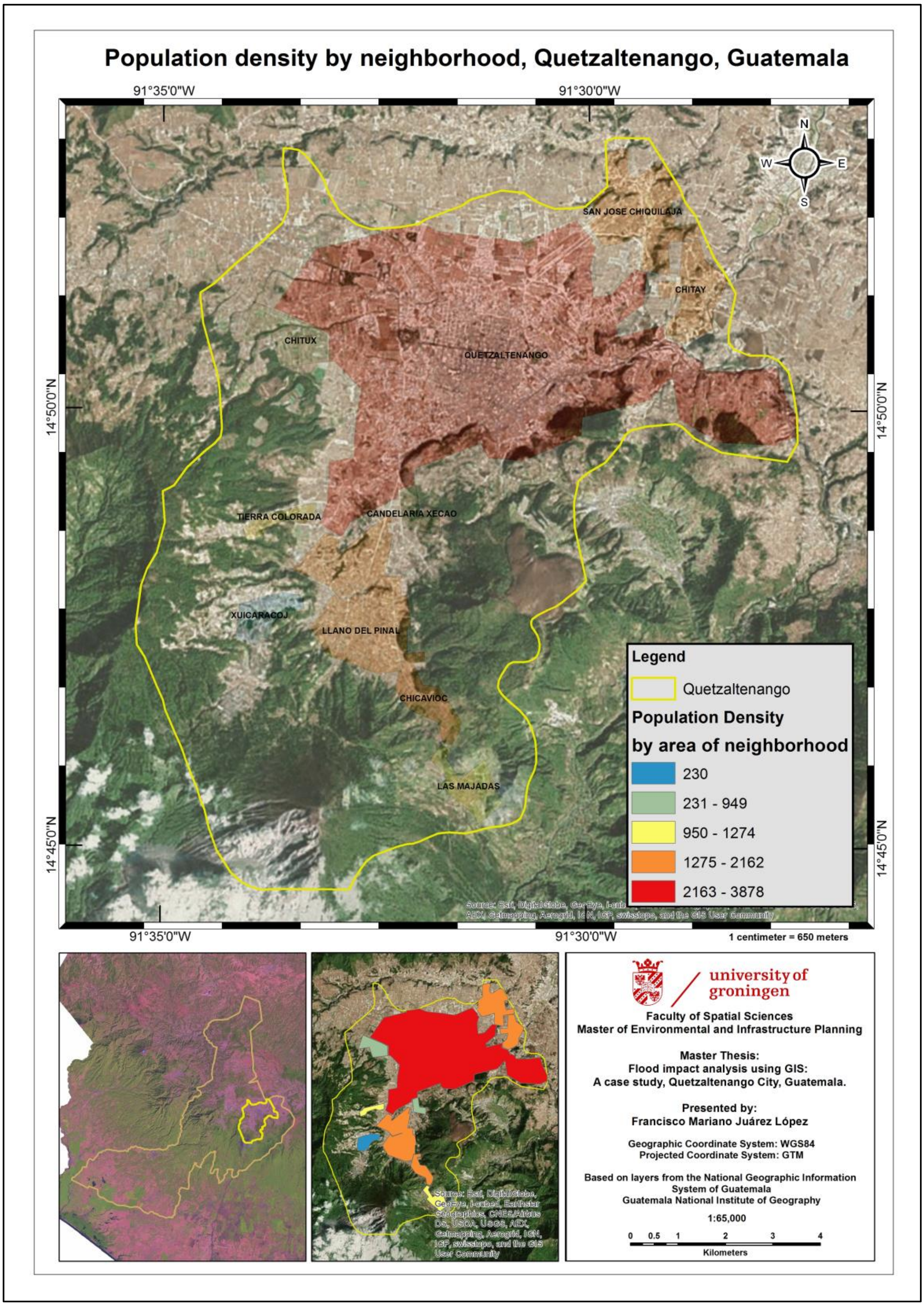
In sum, as depicted in figure 1, vulnerability is generated by three elements: root causes, dynamic pressures, and unsafe conditions (Dewan, 2013). Root causes are the economic and political processes that create policies and governance models and investment; dynamic pressures are mostly social activities or processes derived from the effects of the root causes on society, such as a lack of appropriate skills, population growth and environmental degradation in the surroundings. Finally, the lack of preparedness to face a flood event creates unsafe conditions to particular communities and individuals. A disaster caused by flooding occurs when opposing forces intersect, that is, processes that generate vulnerability intersect with exposure to a hazard (Wisner, Blaikie, Cannon, & Davis, 2004). Once these forces collide, a disaster area is created, which has all the characteristics to make it vulnerable and thus, prone to negatively receive the impact of a flood event. If such situation is diagnosed in a community or city, an alternative is to develop a flood risk management strategy based on a proactive approach, so that important stakeholders look for a consensus regarding how to address the issues to reduce vulnerability and build resilience against flood events. The key stakeholders to promote an inclusive process usually involve local government, local leaders (civil society), private sector and non-governmental institutions, among the most important. Development of a flood risk management is the key approach to holistically address vulnerability, exposure and hazard control in an integrated long term strategy.

3 CHAPTER THREE, STUDY AREA

3.1 Location

Guatemala is located on the interoceanic pathway of natural hydro-meteorological phenomena (Global Facility for Disaster Reduction and Recovery, 2010). This makes the country prone to be impacted by tropical storms and hurricanes that cause frequent events of extended rainfall during the rainy season (May to November); subsequently floods take place in the lowlands and urban areas located in floodplains (Global Facility for Disaster Reduction and Recovery, 2010). Guatemala is politically divided into 22 provinces, (see appendix, map 2) being Quetzaltenango province the second most important economic area, although it represents only 2% of the national territory (2,132.48 square meters). As a result, the Municipality of Quetzaltenango host the second largest city nationwide and thus, one of the most densely populated areas.

Figure 3, Average of population density, municipality of Quetzaltenango



Quetzaltenango city remained relatively invulnerable to flood events and related disasters such as landslide; this safety characteristic was due to its location in the floodplain of western highlands at the bottom of Santa Maria volcano and surrounding mountains. The basin is considered a watershed hydrographic recharge areas (Consorcio CEDEPEM ALDES, 2008) for the Samalá River draining its hydrographic flow down the basin to the Pacific Ocean. The historical disasters of these highlands used to be related to volcanic and seismic activity. Nonetheless, in recent decades, flooding is becoming frequent in Quetzaltenango city to a point of serious concern, as it is causing considerable personal harm and property damage to both private and public infrastructure within the city. This increase of vulnerability to flooding is associated to several factors that mainly include changes in land use in the surrounding mountains, reduction of forest cover as a result of sprawling of urban areas and higher population density. For instance, from 1964 to 2006 an area of 724.77 hectares from municipal protected areas dedicated to forest cover, have been invaded and used for developing new household projects and squatter settlement. (Alvarado Quiroa, H; Araya Rodríguez, F., 2013).

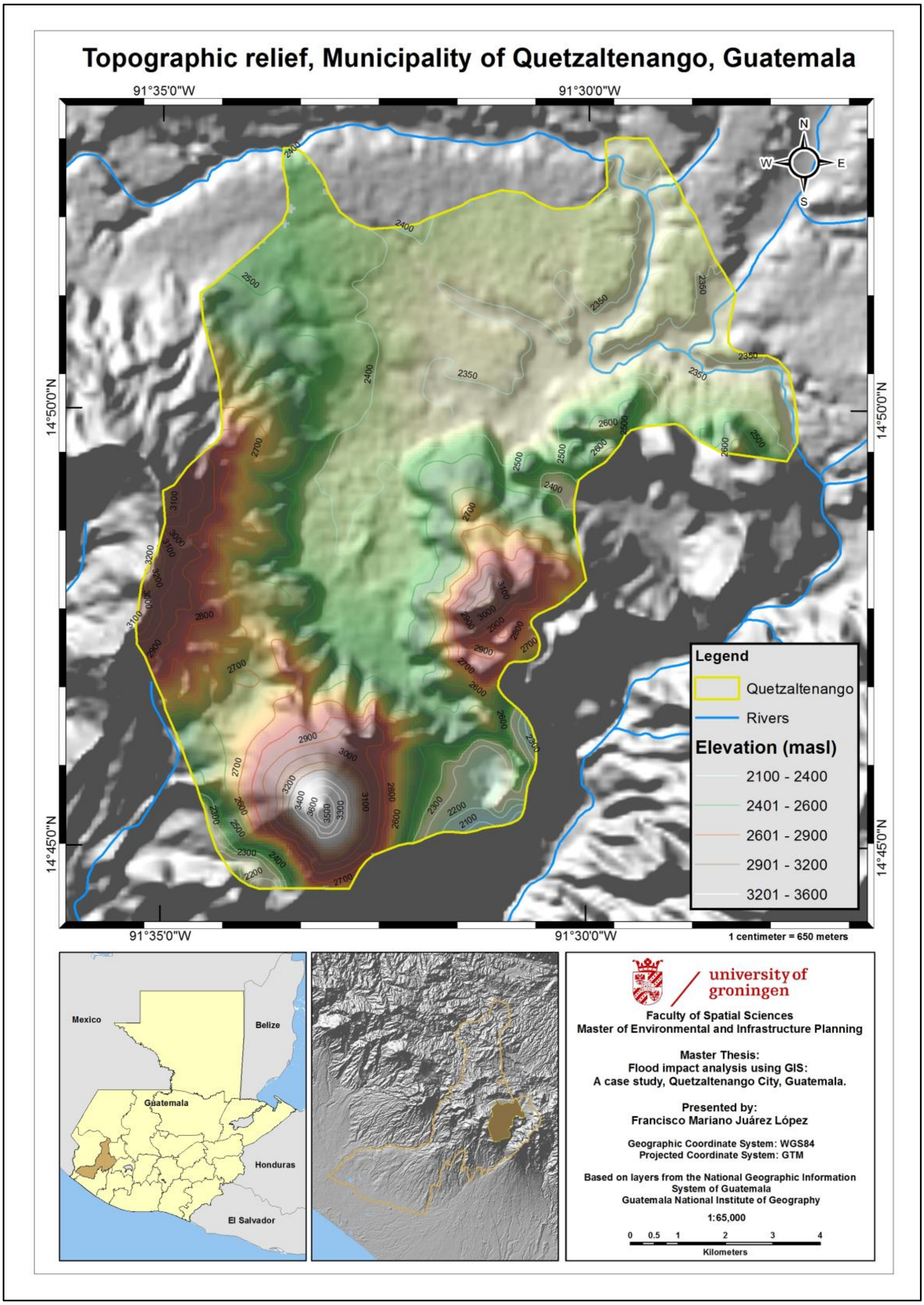
Quetzaltenango city is not located directly in the river flow basins either on areas with direct access to water bodies; this characteristic prevents the cities to be directly impacted from a river overflow or water level rise. However, the city is prone to flood events mainly due to the characteristics of the floodplain where the city lays down. The location is a mountain valley in which the critical defence line from runoff is the natural forest cover on the mountains that surround the city. Known the geomorphologic conditions, environmental management in the surrounding areas is crucial for naturally counteract the potential negative effect of the runoff towards the city. As an additional factor, public infrastructure for water drainage in the municipality of Quetzaltenango is poor and insufficient for the water inflow that comes into the city due to extended rainfall (Prensa Libre, 2013).

3.2 Characteristics

The natural orography and hydrology of the area implies extensive rainfall during the rainy season (from May to November), making the superficial runoff water a potential threat to the city, causing floods in prone areas with the lowest altitude level or where the urban sprawling is taking place and thus, the soil has been waterproofed with concrete, causing poor water drainage and increasing accumulation. Quetzaltenango city has experienced frequent flood events in the last decade, making the runoff water the major hazard for the city, defining hazard as a dangerous phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (United Nations Office for Disaster Risk Reduction, 2009). Vulnerability to floods in Quetzaltenango city is the result of a complex combination of characteristics that involve environmental, social, political and economic factors; these characteristics are mostly of human kind and are strongly related to uncontrolled land use, geographic location and lack of spatial planning policies at municipal level.

Urban areas with high vulnerability to flood events can be affected by pluvial, groundwater flows and artificial system failures (Global Facility for Disaster Reduction and Recovery, 2012).

Figure 4, Topographic relief, municipality of Quetzaltenango



In the case of mountainous areas, where communities are settled on the bottom of the floodplain, like Quetzaltenango city, land use and spatial planning policies play a critical role since it is important to accurately manage forest cover to take advantage of natural dynamics and prevent progressive increase of water runoff. High intensity rainfall causes flooding because natural drainage systems do not have the necessary capacity to cope with overflows. A parallel problem is that the artificial drainage system is unable to cope with the volume of water in the city; therefore water enters the sewage system in one place and resurfaces in others places within the city (Global Facility for Disaster Reduction and Recovery, 2012). The vulnerability of Quetzaltenango city affects its stability as the second largest city in Guatemala and slows down its economic growth and thus, development, as a result of the fact that the city receives negative impacts from flood events every other year.

Quetzaltenango is the second economic area in the country and one of the most densely populated cities in Guatemala (Alvarado Quiroa, H; Araya Rodríguez, F., 2013); public infrastructure, private property and industrial areas are exposed to be directly impacted by a flood event. Understanding the exposure to this particular hazard is a critical component to fully depict the disaster risk profile of Quetzaltenango city. In other words, because people and property (a community) are vulnerable to be impacted by a hazard (flood), the community is categorized as an element that is exposed; this means that is an element at risk of flood. The municipality is politically administrated in 10 sectors that all together compose the urban area of the city, the sector are the following: 1) San José Chiquilaja, 2, Quetzaltenango (Town Center), 3), Chitay, 4), Chitux, 5) Candelaria Xecao, 6) Tierra Colorada, 7) Llano del Pinal, 8) Xuicaracoj, 9) Chicavioc and 10) Las Majadas.

3.3 Disaster risk management in Guatemala

3.3.1 National level

Nowadays, climate change represents the major threat to Guatemala as a whole, impact from hydro-meteorological phenomena are frequent, such as extended rainfall due to tropical storms and hurricanes is highly expected in the future (Global Facility for Disaster Reduction and Recovery, 2010). Therefore, flood events are becoming the most imminent hazard for both coastal and highlands cities in Guatemala. Looking at the future, Guatemala faces the challenge to formulate and implement policies, plans and projects to adapt to the new environmental and climatic conditions given by these natural phenomena. The aim from national level is the reduction of vulnerability as much as possible by means of developing resilient cities and communities and increasing the coping capacities of local authorities and citizens. The negative impacts caused by natural hazards like hurricanes and tropical storms pose a considerable threat to human life, especially when associated with storm surges, and have devastating impacts on the productive economy by the impact of extensive floods (Benson & J. Clay, 2004). Guatemala is mainly an agriculture-based economy, which makes the country to have enormous economic losses when a flood event occurs. In case no resilience is developed in vulnerable areas, environmental degradation and economic losses can reach a point in which agricultural production, urban and social facilities will be seriously compromised.

As a response to the critical disaster risk profile, Guatemala is attempting to incorporate disaster risk management strategy within its development agenda. The strategy includes a program for capacity building regarding preparedness, prevention and mitigation at national, regional and local level. Since 2011, Guatemala's central government has made efforts to implement a nationwide new framework called National Program for Disaster Prevention and Reduction, which was formulated by national and international experts and subsequently approved in 2009 by the national congress. The master plan comprises a set of legal tools and institutional mechanisms to allow several governmental institutions to coordinate actions and execute financial public funds in case of emergency due to natural disaster, especially those concerning flood events. The program includes the creation and funding of a permanent board of directors at national level whose responsibility is to be in charge of monitoring the country's vulnerability index, continuously monitor and identify potential hazards, set up a warning system and coordinate all activities concerning disaster risk management from natural phenomena with other institution (Congreso de la República de Guatemala, 1996), this board of directors is called the National Coordinator for Disaster Reduction (CONRED) and its Secretariat (SE-CONRED) and is basically the authority regarding disaster risk management nationwide.

CONRED is not meant to be an institution itself, but it works as a coordinating body system that enables a national platform and legal framework for conducting inter-ministerial coordination and activities in case of disaster. It is commanded to lead preparedness processes during non-disaster time, and initiate the response and mitigation measures protocol in case of a disaster occurs. As a coordinating body, it is also in charge to organize the cooperation of all public institutions, private support and international cooperation related to an emergency due to disaster and especially those related to flood events. During non-disaster time, according to Guatemala law, the coordinator body is responsible for carrying out activities regarding community bases disaster risk management and capacity building, especially in the most vulnerable areas. It is responsible for supporting municipal authorities in issues such as formulation of local plans and strategies for response and mitigation (Congreso de la República de Guatemala, 2012). At the moment, this coordinating body has successfully formulated the National Plan for Response and Mitigation in case of Disaster and fruitfully pushed in the congress, the approval of the National policy for Disaster Risk Reduction in Guatemala, which was approved on 2011 as well. These are key technical and legal instruments for accomplishing the agreements that Guatemala signed within the Hyogo framework; but most important, to start an integrated approach regarding disaster risk management in the country as a national priority that aims to prevent direct impacts from flooding (Congreso de la República de Guatemala, 2011). Nonetheless, so far, most of the initiatives and efforts from the government regarding flood risk management remain only in the way of a legal framework and top down policies that have little or no positive impact on the real process of creating resilient communities. This is the outcome of a short term planning and a low investment policy regarding flood risk management nationwide. The national policy and the entire efforts done so far are mainly based on a reactive approach towards disaster in general, but mainly towards flood events. The national plan itself limits the possibilities to develop a long term strategy based on proactive approach that will allow the communities to be adaptive towards changing conditions in the future.

3.3.2 Municipal level

Guatemala is divided into 22 regions or so called departments, and sub divided into 334 municipalities, being Quetzaltenango city the second in economic importance. Since National Coordinator for Disaster Reduction (CONRED) was stablished in Guatemala City in 2009, the organization has progressively extended its operation to the 22 departments due to the legal mandate that states it has to reach the 334 municipalities (Congreso de la República de Guatemala, 2011). Quetzaltenango City has a permanent CONRED municipal delegation which is responsible for conducting training regarding community based disaster risk management for school children and neighbourhood groups from civil sectors. However, most of its work in the city has mainly consisted in coordinating activities in contribution with external projects funded by international donors. These initiatives usually focus their efforts on training workshops for focal groups in order to develop capacity building related to immediate response in case of a disaster event (World Health Organization, 2011). In spite of having all the legal framework and institutional design, CONRED at Quetzaltenango city frequently runs out of funding from central government and the activities for strengthening the disaster risk management system is constantly interrupted; therefore the results have insignificant impact compared with the magnitude of the flooding impacts (Prensa Libre, 2013).

The Municipality of Quetzaltenango city has a planning department that is mandatory according to national law (Congreso de la República de Guatemala, 2010). It comprises an engineering & projects unit, a geographical information systems unit, an environmental services unit and a planning & development unit (Municipalidad de Quetzaltenango, 2006). However, within its organic structure, there is a lack of a specific unit for disaster risk management. Financially speaking, the Municipality is unable to fund either effective preventative measures or massive investments to prevent flooding to occur, which would be a proper reactive approach. Currently, the efforts of the municipality do not include preparedness or adaptive measures for the long term. Similar as the approach taken at national level, local efforts focus only in actions during a post-disaster time; it entails the coordination with CONRED only for responsive activities that do not match the scale of what is needed. This local model puts in evidence the lack of planning in Quetzaltenango city and pointed to the need for appropriate disaster risk management system and social organization to address the impact of flood-related hazards.

3.3.3 Current approach to flood risk in Quetzaltenango

As flooding is becoming more recurrent in Quetzaltenango city, the municipality faces the challenge to adapt the city with its current conditions into a safer and sustainable urban area. Nevertheless, the municipality has been concentrating its efforts solely in responsive actions during disaster, and small mitigation measures after disaster. Most of the municipal strategy so far, entails the cleaning of the drainage and sewage collection system of the city every year. Additionally, the Municipality edits and delivers informative material for preparedness in case of a flood event takes place. These actions have been carried out primarily in the neighbours that have been previously affected by floods (Prensa Libre, 2010).

The Municipality relies on developing a top-down organization system that is capable to response in case of a flood disaster, this model seems to be insufficient to reach all the coverage and detailed training that is needed in terms of capacity building for flood disaster management in prone areas. The current policy at municipal level is missing holistic components to achieve an intergraded approach to flood disaster management in the long term, as now is purely responsive. All the efforts so far, do not represent a proposal to solve the urgent situation regarding the need of preventing flood in Quetzaltenango city. In addition, these actions do not belong to an effective strategy to cope the problem by means of environmental management and spatial planning for urban development in the long term. Another weakness of the current approach is that the plan is not taking into account proactive actions to lead the city towards changing into an adaptive city that can deal with global external factors, such as climate change.

4 CHAPTER FOUR, METHODOLOGY

4.1 Geographic Information Systems (GIS)

The versatility of GIS for various applications regarding modelling and evaluating geographical information make it the optimal method to carry out flood impact analysis for Quetzaltenango city. GIS allows analysing environmental conditions regarding flood risk in the municipality of Quetzaltenango as well as identifying prone areas by grade of vulnerability. Throughout the application of GIS techniques, it is possible to overlay various datasets of layers that contain characteristics of the valley where the municipality of Quetzaltenango is located, presenting the ability to map a scenario regarding the behaviour of the floodplain inundation. This information is a first predictable opportunity to further evaluate the possibilities towards an absorbent city (White, The Absorbent City: Urban form and flood risk management, 2008). Furthermore, the applicability of GIS is widely adaptive and can be used for diagnosing, evaluating and monitoring characteristics such as vulnerability and exposure to flooding. Additionally, GIS databases can be updated periodically to compile a historical record of land use variables that directly affect vulnerability and exposure in the municipality of Quetzaltenango. The factors that mainly contribute to changes in vulnerability and exposure are urban sprawling, changes in land cover (especially forest reduction) and changes in population density. Having a GIS-based monitoring program of such factors is greatly positive for developing an effective flood risk management system for the municipality, due to the fact that changes in digital geographic data and information technologies combined, support decision making processes at all scales for multiple purposes (National Research Council, 2003), and thus the use of GIS-based maps and visual information is a need for starting a debate concerning how to build resilience to flood events in the municipality of Quetzaltenango. Using GIS for flood risk management is a methodology that takes into account specific characteristics of the surrounding environment, hydrologic characteristics and social aspects of the municipality that allow mapping prone areas to flood events and assessing social facilities at risk of flood. The GIS-based vulnerability maps are the basis for identifying measures towards building a first scenario that technicians, authorities and population at the municipality, can have as a fist insight of the current situation (Albrecht, 2007).

GIS involves elements of different kinds to be functional and successful in achieving its goal. The system is a complex structure itself and comprises the following six summarized components: people, data, hardware, software, procedures and network (Dawsen, 2011). The first component, people, refer to qualified technicians who are skilled in designing a procedure to perform a spatial analysis in GIS and who are well trained to identified the key information and datasets that are needed, either from fieldwork or remote sensing technologies. The second element, data, refers to the geospatial information; this is the crucial element of the system to be able run toolboxes, procedure or models in GIS. The most critical component is to generate or collect data that is precisely georeferenced and that represents the actual terrain or social characteristics of the study area, municipality of Quetzaltenango in this case. If unreliable data is run in a GIS model, the results will be unreliable and far from reality to the point that it becomes useless. The third and fourth elements, hardware and software, are intrinsically linked, a computing system and a GIS program is need to set up a geographical information system that is able to run GIS tools for analyse the geodata collected. For the analysis in the present research, the software AcrGIS version 10.2.2 by ESRI is used. The fifth component of the geographical information system; the procedures, comprises all the set of GIS toolboxes, programming codes, techniques and methods for analysing the datasets. The design of a procedure and selection of tools requires skilled technicians as well as the interpretation of both the input and the output datasets (see figure 3 for this study). The last element of the system is the network; it refers to the intranet and/or internet connexions, such as sharing data with other GIS, remote and online servers, remote sensing technologies and other online services. Sharing datasets and georeferenced information throughout the internet is a key capability for national agencies and private business to deliver their spatial data and make it available worldwide. In the case of this work, this component of GIS is crucial to get all the geospatial information from official Guatemalan institutions. The information is obtained from national institutions especially dedicated to do fieldwork, analysis and generate the primary information needed for the spatial analysis regarding flood risk management in the municipality of Quetzaltenango. Given the possibility of getting all the data from the remote GIS national system of Guatemala, and having the required skills to perform an accurate spatial analysis, the use of a GIS approach for the case study of the municipality of Quetzaltenango is the most appropriate approach from the methods available (refer to table 2).

For evaluating the case of the municipality of Quetzaltenango, the six elements of GIS mentioned above are needed; however, the analysis took special support on the networking elements, since critical datasets are obtained via remote sensing technologies for which networking and internet connexion is indispensable. No primary information from fieldwork has been generated in the present work, all the geospatial data used is obtained by means of connecting to Web Map Services and digital platform of the Guatemala Institute of Geography. As a secondary source for getting the imagery related to road infrastructure, online platforms from public available engines such as Google maps and Bing maps were loaded into the geographical information system software used for the present work.

4.2 Data collection

This is the crucial stage to perform a flood impact analysis showing accurate results. For the present research, the geospatial dataset are collected by electronic communications with official governmental institutions in Guatemala. Some institutions have been contacted personally via e-mail, phone calls and skype video conferences to request the editable data, while others only by connecting to their geoportal services online. This provides certainty on the quality of data and prevents any possibility of disambiguation in geospatial criteria. Several official institutions dedicated to generate geospatial data are consulted to gather the most up to date information. Additionally, for complementary data such as urban imagery and orthophotographic imagery, several remote sensing technologies are compared to get highest quality data available. Nonetheless, the primary source platform to obtain the required geospatial data is the Guatemala geoportal services. Hereafter, there is the list of Guatemalan institutions which have been consulted as source for datasets:

1- Instituto Geográfico Nacional (National Institute of Geography) http://www.ign.gob.gt/geoportal/index.html
2- Instituto Nacional de Estadística (National Institute of Statistics) http://www.ine.gob.gt/
3- Instituto Nacional de Bosques (National Institute of Forestry) http://www.inab.gob.gt/Paginas%20web/Cobertura.aspx
4- Consejo Nacional de Áreas Protegidas (National Board of Protected Areas)
   http://www.conap.gob.gt/index.php/servicios-en-linea/sig.html
5- Secretaría de Planificación y Programación de la Presidencia (National Board for Planning and Projects)
   http://ide.segeplan.gob.gt/geoportal/index.html
6- Guatemala Ministry of education
   http://www.mineduc.gob.gt/ie/
7- Ministerio de Alimentacion, Agricultura y Ganadería (Guatemala Ministry of Agriculture and Food Control)
   http://web.maga.gob.gt/sigmaga/suelos-1-250/
8- Instituto Nacional De Sismología, Vulcanología, Meteorología e Hidrología (National Institute of Seismology, Volcanology, Meteorology and Hygrology)
   http://www.insivumeh.gob.gt/hidrologia/ATLAS_HIDROMETEOROLOGICO/Atlas_hidro.htm

4.2.1 Datasets for the analysis

Layers of the municipality of Quetzaltenango were derived from the official national layers from the Guatemala National Institute of Geography. The datasets are adjusted to the needs of the case study for Quetzaltenango. Furthermore, all dataset are projected from Universal Transverse Mercator into the Guatemala Transverse Mercator -GTM- projection, using the Geographic Coordinate System WGS1984. The primarily datasets, criteria for flood impact analysis and the relevance of the data to achieve the research objectives and answer the questions of this study, are shown in the following table.

Table 3, Datasets used for the spatial analysis

Datasets	Criteria for flood impact analysis Quetzaltenango	Relation and relevance for impact analysis
Guatemala regional borders	Georeferenced official datasets with GTM projection	Mapping referential framework
Guatemala Municipal Borders	Georeferenced official datasets with GTM projection	Delimitation of study area, delimitation of sectors within the municipality.
School facilitates	Georeferenced official datasets with GTM projection. (Only public schools)	Identification of schools at risk of flood and that can be negatively impacted.
Health care facilities	Georeferenced official datasets with GTM projection. (Only public health care centres)	Identification of health care centres at risk of flood and that can be negatively impacted.
Contour lines	Horizontal distances @3 meters @50 meters @100 meters	Generation of digital elevation model, terrain relief, identify hydrographic characteristics within the municipality.
Digital Elevation Model (DEM)	Cell size 50, 50 Topography @30 meters	Identify prone areas to flooding by means of deriving the slope, flow accumulation and flow direction, which are inputs for weighted overlay analysis.
Land cover	Cell size 30,30 No older than 5 years with the following variables: % Forest Cover % No Forest Cover % Deforestation % Afforestation	Identify prone areas to flooding by means of being an input for weighted overlay analysis.
Precipitation	Rainfall in mm/year, Isohyets intervals @200mm Average record of 30 years	Identify vulnerable areas to flooding by means of overlay analysis and identification of life zones in the municipality of Quetzaltenango
Population density	People per km2, from census municipality of Quetzaltenango (2005)	Identify areas within the city with the highest vulnerability to flooding due to the potential amount of people that can be impacted by a flood event.
Satellite imagery	Orthophotographic imagery @1 meter resolution	By means of overlaying with vulnerable areas, identify

Datasets	Criteria for flood impact analysis Quetzaltenango	Relation and relevance for impact analysis
	@0.3 meter resolution @0.5 meter resolution	neighbourhoods and other public infrastructure that might be located in vulnerable areas.

4.3 Data analysis

.No single impact analysis technique is appropriate to use in all kind of cases; for purposes of the present work, GIS analysis is the most suitable due to the fact that all the base layers and datasets required for the analysis are officially generated and publicly available. Due to the complexity of using GIS as the technique to carry out this research, the results comes as a combination of GIS analysis, professional judgement and expert opinion to design and interpret the impact analysis for the municipality of Quetzaltenango. Using GIS techniques for this case study represents a new approach and opportunity to depict the flood risk profile that is challenging the municipality of Quetzaltenango. Important is to mention that the sub-basin where the Municipality of Quetzaltenango is settled can be independently analysed without studying the whole Samala River system and show accurate results in terms of hydrographic behaviour. Very important is this factor in the Quetzaltenango case study, because the municipality and its hydrographic dynamics can be studied independently from the neighbouring municipalities and the rest of the Samala River basin.

4.3.1 Data models

Geographic Information Systems offer very powerful computational tools, to carry out spatial analysis, GIS differentiate rigorously between two types of spatial perspectives. First, the field view that is typically represented using raster data, and second, the object view comprised by vector data (Albrecht, 2007). In other words, in GIS there are raster and vector data models. Raster data represents a graphic object as a pattern of dots, whereas vector data represents the object as a set of lines drawn between specific points (Fazal, 2008). To carry out the flood impact analysis for the municipality of Quetzaltenango, both types are used. For instance, municipal borders, population density and water streams are displayed by vector type datasets. Conversely, all environmental characteristics such as topographic altimetry of Quetzaltenango, slope degrees of the surrounding mountains and land cover within the municipal jurisdiction, are display by raster type datasets.

4.3.2 Spatial analysis

Spatial analysis is based on the principle of examining locations, its characteristics and the relationships among all the elements of the surrounding environment. The terminology describing the general concept of spatial analysis using GIS is the following: studying the locations and shapes of geographic features and the relationships between them. It traditionally includes overlay and contiguity analysis, surface analysis, linear analysis, and raster analysis (Environmental Systems Research Institute Inc., 2000). Spatial analysis using GIS is suitable for the present research; given the fact that large amount of complex data from the Samala River basin will be processed simultaneously with social and environmental datasets.

The municipality of Quetzaltenango is located within the Samala River basin, where complex hydrological interactions take place; this dynamics can be better understood by applying spatial analysis techniques with GIS as a main analytical system. GIS allows acquiring a holistic understanding of a problem and its dynamics (Galati, 2006). The purpose of spatial analysis is to gain knowledge on how the current environmental conditions of the surroundings of the 10 sectors of Quetzaltenango, have an effect in increasing the vulnerability of prone areas to flooding. The most important inputs to consider include land cover in the surrounding mountains of the valley, degree slope that might increase the water runoff flow, digital elevation model of Quetzaltenango municipal jurisdiction, population density in the municipality, precipitation records of the area and location of social facilities within the municipality. All the geographic, spatial and statistical information is organized on a geodatabase and displayed to analyse the current situation of the municipality regarding vulnerability and exposure to water runoff (natural hazard) that can cause a flood event. The outcome of spatial analysis is a new set of information that answers the two sub questions of this research, by identifying the most vulnerable areas to flood and the social facilities that can be directly impacted in case of a flood event. This new information is represented on the simplest possible way, such as maps, charts and diagrams. The main question of this research is answered by analysing all the mapping products; calculate statistical percentages of vulnerability per sector and identifying the priority measures to be implemented in each sector of the municipality.

For the present research, the spatial analysis is considering two scales; the first is the province of Quetzaltenango, which is used as a reference to identify topographic, orographic and hydrographic references, for instance position the municipal territory within the provincial territory and defining the hydrological boundaries of the watershed. At this stage, no other analysis than overlaying and identifying key issues for mapping will be performed. The second scale is at municipal level; the spatial analysis will be performed using the municipal boundaries as reference to perform both simple overlay analysis, and weighted overlay analysis using map algebra techniques to identify vulnerable areas to flooding and respond to the first sub-question of this research. The vulnerable areas are derived from analysing reclassified datasets of slope, land cover and flow direction respectively (see appendix, maps 14-16); afterwards the vulnerable areas are overlayed with datasets containing population density and location of social facilities in order to generate final vulnerability maps (see appendix, maps 17-18). Given the fact that the nature of the spatial analysis in the present work is related to hydrodynamics of the Samala River basin, defining the scale and limits to be used for the spatial analysis was based on identifying natural hydrographic watershed boundaries and compare them with municipal boundaries. After the preliminary comparison, it is obvious that municipal borders match the natural hydrographic borders of the sub-basin located at the upper area of Samala River basin. This matching implies an enormous advantage in respect of being able to apply GIS techniques using the municipal boundaries as frame for spatial analysis and still get accurate and significant results.

4.3.3 Methods of spatial analysis

The spatial analysis focuses on identifying three types of scenarios that occur in case of a flood event: 1) areas within the municipality which have physical vulnerability to be flooded, 2) areas with high population density and poor quality urban facilities, where many people are affected in case of a flood event, and 3) schools and health care facilities that are located at risk of flood. By identifying such areas through techniques of overlay and weighted overlay, it is possible to identify the most vulnerable areas in the municipality and point out which sectors of the municipality are more vulnerable compared to the rest. The first scenario requires the most complex use of GIS techniques while the las two can be achieved by overlaying datasets and visual interpretation. To achieve an accurate analysis of the first scenario, a combination of 3 datasets have been combined in a weighed overlay analysis: slope (in degrees), flow direction of water runoff (in number of pixels) and land cover (density). Each dataset has different dimensional units; degree for slope, pixels for flow direction, and density for land cover. Previously to run the analysis, these 3 datasets have been reclassified (using the spatial analyst tool) into one single scale of four values of vulnerability, which are 1) no vulnerability, 2) Low vulnerability, 3) moderate vulnerability and 4) high vulnerability. After completing the reclassification, a weighted overlay analysis is performed, resulting in identifying the areas with physical vulnerability to flooding.

As listed in table four, for the slope factor, the flattest areas (with slope inclination from 0-10 degrees) are considered to contribute to high vulnerability because the water accumulation rate is higher than in those areas with steep slope in the peaks of the basin (with slope inclination from 51-85 degrees) which are not liveable areas, consequently no vulnerability is identified. Similarly, in case of land cover factor, the areas that have been severely deforested and have no forest cover, are considered to contribute to high vulnerability. The lack of woods contributes to decrease infiltration capacities of soil and thus, increase the volume of water runoff streaming down towards the bottom of the basin where Quetzaltenango city lays. In contrast, areas with natural forest cover help soil to retain water, benefitting water infiltration and regulating the hydrographic cycle of the sub-basin; therefore, areas with forest cover are determined as no vulnerable. In case of flow direction, the areas with fewer pixels (1-28), imply that runoff is not easily streaming and thus tend to contribute to cause flooding in case of significant volume of water. Conversely, the areas with more pixels (136-255) correspond to areas where the water can easy stream down, limiting the possibility to get flooded. In the following table there is the detail of the reclassification values that are used for the analysis.

Table 4, Reclassification values for weighted overlay

Factors affecting flooding	Original values	Scale	Reclassification value
Slope (degrees)	0-9	4	High Vulnerability
	9-23	3	Moderate Vulnerability
	23-51	2	Low Vulnerability
	51-85	1	No Vulnerability
Land cover (density)	Without Forest Cover	4	High Vulnerability
	Degrading Forest Cover	3	Moderate Vulnerability
	Recovering Forest Cover	2	Low Vulnerability
	Forest Cover	1	No Vulnerability
Flow Direction (pixels)	1-28	4	High Vulnerability
	28-80	3	Moderate Vulnerability
	80-136	2	Low Vulnerability
	136-255	1	No Vulnerability

When performing the weighed overlay analysis, values of influence were assigned to the 3 inputs datasets listed in table four. For the scenario that is modelled in this research, the values of influence are the following: flow direction 20%, slope 30% and Land cover 50%. The outcome of this scenario is used for all the mapping products and the results in the present research. Land cover is considered the factor with more influence (50%), since porosity, water retention capacity and infiltration capacity of soils is directly proportional to the land cover and vegetation present on soil. The second factor is slope (30%) since the degree of soil inclination is directly proportional to speed and volume of water runoff streaming down the basin. The evaluation intends to identify elements that might be hit by water runoff during extensive rainfall. The factor with less influence is flow direction (20%) since it indicates the possible direction of runoff and it is part of a hazard which is frequently considered out of human control. Mathematically speaking, risk can be defined in the following form (Mirfenderesk & Corkill, 2009):

Risk = (Hazard) * (Exposure) * (Vulnerability)

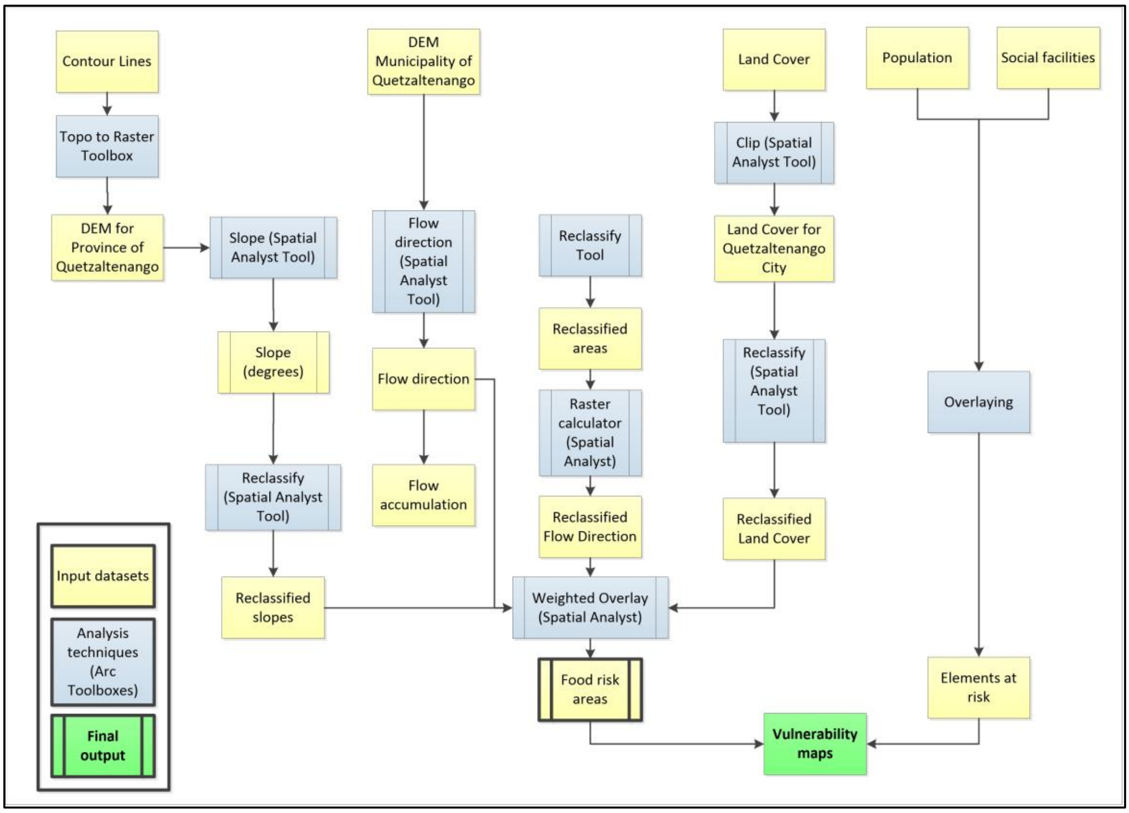
In order to assign weights to the factors affecting flooding, each factor of the risk formula is associated with its corresponding input factor for the weighted analysis. Secondly, to obtain the relative influence of each factor related to each other, a double-entry matrix is used to compare the influence of each factor with the other two. Four values are set for the comparison: no influence (0), inconsequential (1), related influence (2) and significant influence (3). The results are shown in table 5, land cover is the factor that is not affected by the other two, and this is interpreted as the fact that land cover is not directly affected by natural phenomena but by anthropogenic causes. In contrast, flow direction is the most affected factor from the other two, responding the principle that a stepper slope with no forest cover, tends to increase the flow direction and accumulation. Correspondently, the most affecting factor to flooding is also land cover, secondly vulnerability and the least is flow direction. The values for the comparison will serve as classes for the reclassified datasets and the values from the column of affecting factors are expressed in percentages and used for the weighted overlay analysis using GIS.

Table 5, Double-entry matrix for calculating weights for analysis

Risk factors	Input analysis	Flow direction	Land cover	slope	Affecting factors
Hazard	Flow direction	0	0	2	2
Exposure	Land cover	3	0	2	5
Vulnerability	slope	3	0	0	3
Affected factors		6	0	4	10

The method of data analysis is based on the use of overlaying techniques using as primary input the following dataset: contour lines, digital elevation models, lad cover, population density and location of social facilities. To evaluate the impact of a flood event on densely populated areas and social facilities for educational and health purposes, visual examination and interpretation of simple overlay techniques are assessed. The outcome dataset of the weighted analysis is overlay with imagery from remote sensing servers to analysis if there is any significant impact on road infrastructure or any other critical public service. The spatial analysis is complemented with statistical interpretation and graphics of the dynamics of flood risk in the municipality of Quetzaltenango. In figure 3, the flow chart of the method of data analysis is represented.

Figure 5, Flow chart of spatial analysis procedure



In order to achieve the objectives of the research, the method of spatial analysis depicted in the flow chart above, allow mapping out prone areas to flood throughout weighted overlay analysis. The flood risk areas identified with this type of analysis are the areas prone to be flooded. Secondly, assessing social facilities at risk and identifying measures to develop a flood risk management approach in the municipality of Quetzaltenango is address by applying overlay analysis and visual examination and interpretation of the surrounding environment of each sector. Important is to mention the use and interpretation of statistics that do not appear in the flow chart above, however, it is crucial to identify how many schools and health care centres are located in areas with high vulnerability per sector in order to calculated specific measures for flood risk management for each of the ten sectors that comprise the municipality of Quetzaltenango. In sum, the methodology allows to identify and map out areas that are prone to flooding, identify social facilities within such areas and proposing measures to establish a firs scenario for developing a flood risk management approach for the municipality of Quetzaltenango. In table 6, the processes depicted in figure 3 are explained in detailed.

Table 6, Procedures of spatial analysis

Phenomena to analyse	Spatial information	Dataset needed	GIS process (toolbox)	Outcome
Terrain model, differences in	Elevation, z values of the	Boundaries of Quetzaltenango	By Remote sensing	Dataset of contour lines,

Phenomena to analyse	Spatial information	Dataset needed	GIS process (toolbox)	Outcome
altimetry from x to y points	terrain at distances of 3 meters	at provincial and municipal levels	technologies, derived the contour lines @3 meters.	@ 3 meters.
Orographic characteristic of terrain. Inclination of natural terrain	Differences in altimetry, inclination of terrain by analysing the z values of each cell	Digital elevation model @ 50 meters. Digital elevation model @ 3 meters	Slope, spatial analyst tool.	Dataset classifying the natural slope with value ranges between 0° to 90° degrees
Altimetry and depressions at the lowest points of the basin.	False depression areas which might be interpreted as false inundation areas	Digital elevation model @ 50 meters Digital elevation model @ 3 meters	Fill, spatial analyst tool	A digital elevation model with no false depression areas
Hydrographic behaviour in the sub-basin, Water runoff direction	Identify the possible paths where water runoff streams down the basin	Digital elevation model @ 3 meters with no false depression areas	Flow Direction, spatial analyst tool	Flow direction dataset with the paths where water streams down the basin
Natural inundation areas due to accumulation of water	Identify the lowest areas in the sub-basin where water tends to accumulate	Flow direction dataset showing the paths where water stream down	Flow Accumulation, spatial analyst tool	Flow accumulation dataset with areas where water accumulate due to lower altimetry or natural depressions
Prone areas to be flooded.	Identifies area in four categories: no vulnerability, low, moderate and high vulnerability to flooding	Datasets of slope, flow direction and land cover	Weighted overlay analysis with a common measurement scale and weights factors according to its importance	Vulnerability dataset with four categories of vulnerability
Flood impact on household, property damage and estimate of affected people due to flooding	Identifies areas with the highest vulnerability index	Dataset of people per km2 and vulnerability dataset with categories of vulnerability	Overlaying	A map highlighting the areas within the city with the highest vulnerability index

Phenomena to analyse	Spatial information	Dataset needed	GIS process (toolbox)	Outcome
Flood impact on school and health care facilities due to flooding	Identify facilities located at risk of flood	Datasets of location of public schools and health care centres	Overlaying	A map pointing out social facilities at risk of flood

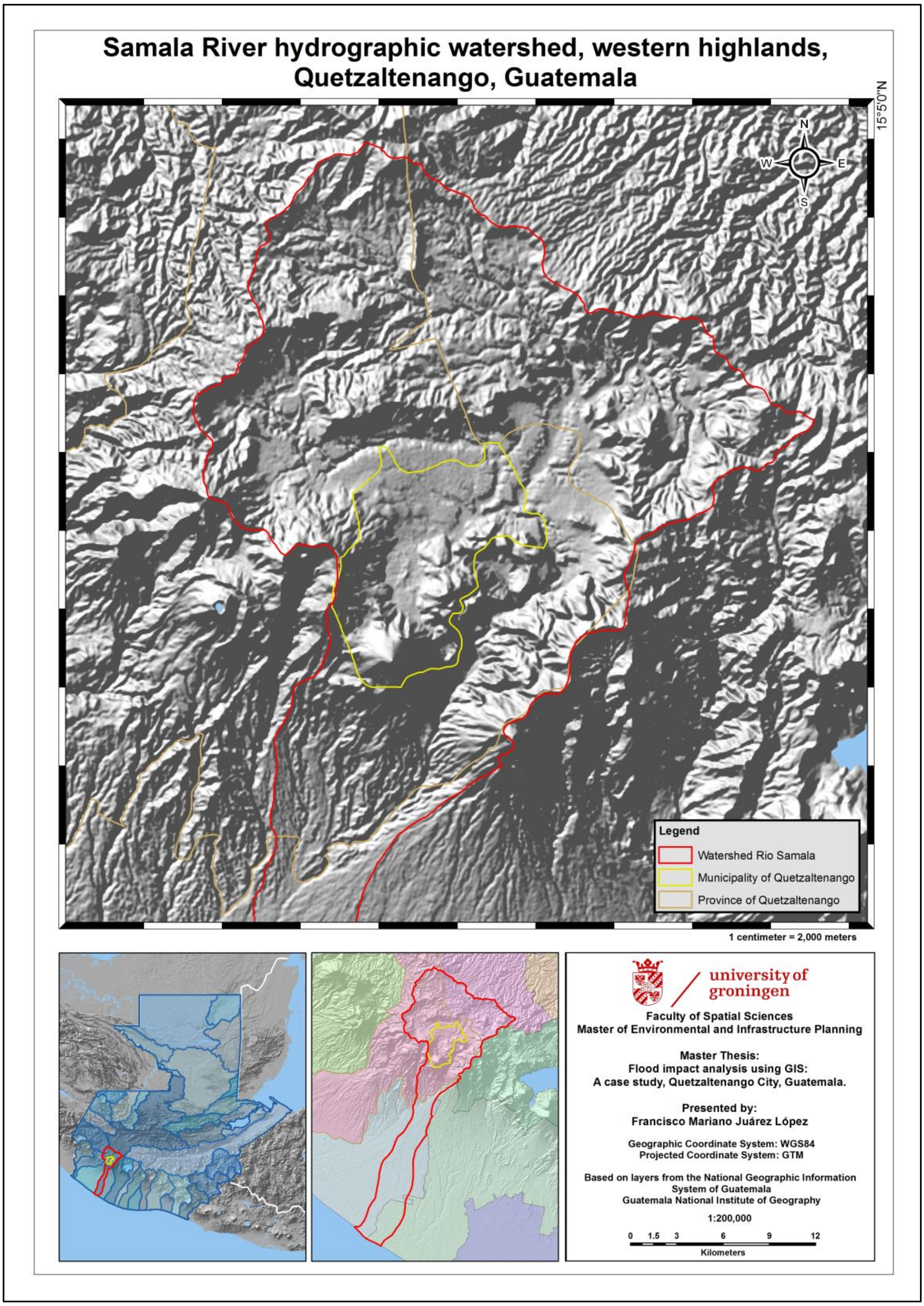
5 CHAPTER FIVE, RESULTS AND ANALISYS

5.1 General mapping products

The municipality of Quetzaltenango is laying in the mountainous valley located in the upper basin of the hydrographic basin of the Samala River (See figure 6). The area is part of the so called western highlands that belong to the Sierra Madre pacific mountain range, which drains towards the Pacific Ocean. The total perimeter of the Samala River Watershed is 271.56 kilometres that cover a total area of 1,479.11 square kilometres. The natural boundaries of the hydrographic Samala river watershed show that the whole basin is located within the territory of the provinces of Quetzaltenango, Totonicapan, Retalhuleu and Suchitepequez (See appendix, map 6). The upper basin is part of Quetzaltenango and Totonicapan provinces respectively, while the rest of the basin is located in the Retalhuleu and Suchitepequez provinces, both comprising the lowlands towards the Pacific Ocean shore. The mountains and volcanoes that surround the valley where the municipality of Quetzaltenango lays, coincidently matches the natural boundaries of one of the upper sub-basins within the Samala River hydrographic system. The municipality is perfectly enclosed by peaks on the east, west and south sides that comprise a sub-hydrographic system, which is part of the whole Samala River watershed dynamics.

The municipality of Quetzaltenango has a perimeter of 55.87 kilometres covering an area of 126.83 square kilometres. In the map can be appreciated that the area of the Municipality of Quetzaltenango represents 5.94% of the total area of the Quetzaltenango province and 8.57% of the total area of the Samala River basin. In other words, the present case study focuses on analysing 8.57% of the total area of the Samala River basin, which at the same time, corresponds to the upper sub-basin of the Samala hydrographic system.

Figure 6, Natural hydrographic border, upper watershed Samala River basin



The Municipality of Quetzaltenango is divided into 10 sectors which are administrated by the municipal council as independent neighbourhoods; however, they all depend on the same political and legal administration. In the following table the general data for each of the sectors:

Table 7, Administrative sectors of Municipality of Quetzaltenango

No.	Name	Perimeter (kms)	Area (Kms2)	Population 2016	Population density	% of Total (by sector)
1	San José Chiquilaja	10.18	3.69	6,409	1,737	7%
2	Quetzaltenango (Town Centre)	36.89	35.20	136,491	3,878	69%
3	Chitay	6.76	1.76	2,968	1,686	3%
4	Chitux	5.45	1.38	1,309	949	3%
5	Candelaria Xecao	3.35	0.48	409	852	1%
6	Tierra Colorada	3.98	0.48	555	1,156	1%
7	Llano del Pinal	13.07	4.87	10,531	2,162	10%
8	Xuicaracoj	4.27	0.91	209	230	2%
9	Chicavioc	5.74	1.12	1,981	1,769	2%
10	Las Majadas	5.58	1.05	1,338	1,274	2%
Total/Average		**95.27**	**50.94**	**162,200**	**1,569**	**100%**

Important is to notice that the Municipality has a total area of 126.83 square kilometres, from which only 40.16% of the municipal territory is considered suitable as liveable areas. This is equivalent to 50.94 square kilometres of the municipal territory; the rest of land is categorized as non-liveable areas due to the natural vocation as forestry-oriented lands with a natural slope of 30° degrees and above. In spite of the fact that the neighbourhoods belong to the same municipality, each of the 10 sectors vary considerably in several aspects from one to another. For instance, the town centre is expanded in a larger area than the rest of sectors. The town centre is occupying up to 69% of the area suitable for living, while together Candelaria Xecao and Tierra Colorada occupy only 2%. As a result of the disparity in distribution, the population density rates also vary significantly from sector to sector, although the average is situated in 1,569 inhabitants per square kilometre.

The demographic concentration in Quetzaltenango down town is more than twice the average than in the rest of the sectors of the Municipality. Quetzaltenango has a peak of 3,878 inhabitants per square kilometre; this means 247% more than the average of the rest sectors. A map depicts the population density in more detail within the 10 sectors of the Municipality; it shows the composition of the demographic concertation in specific areas of the city, those neighbourhoods in the city centre in which the population even surpasses the 3,878 inhabitants per square kilometre. The map contains key information for identifying the most vulnerable areas taking into account the amount of people that might be directly affected in case of a flood event.

Figure 7, Population density by sector, municipality of Quetzaltenango

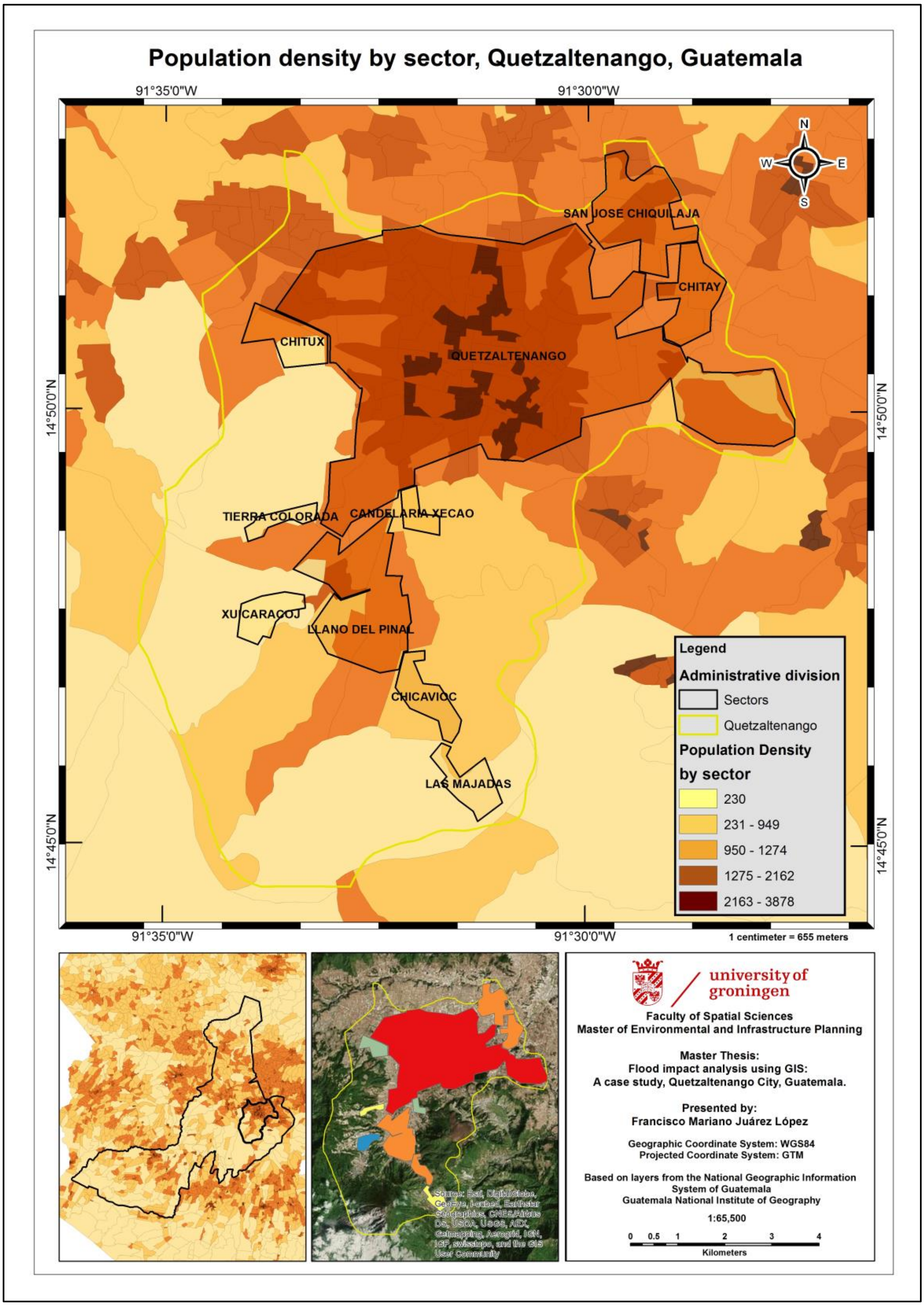
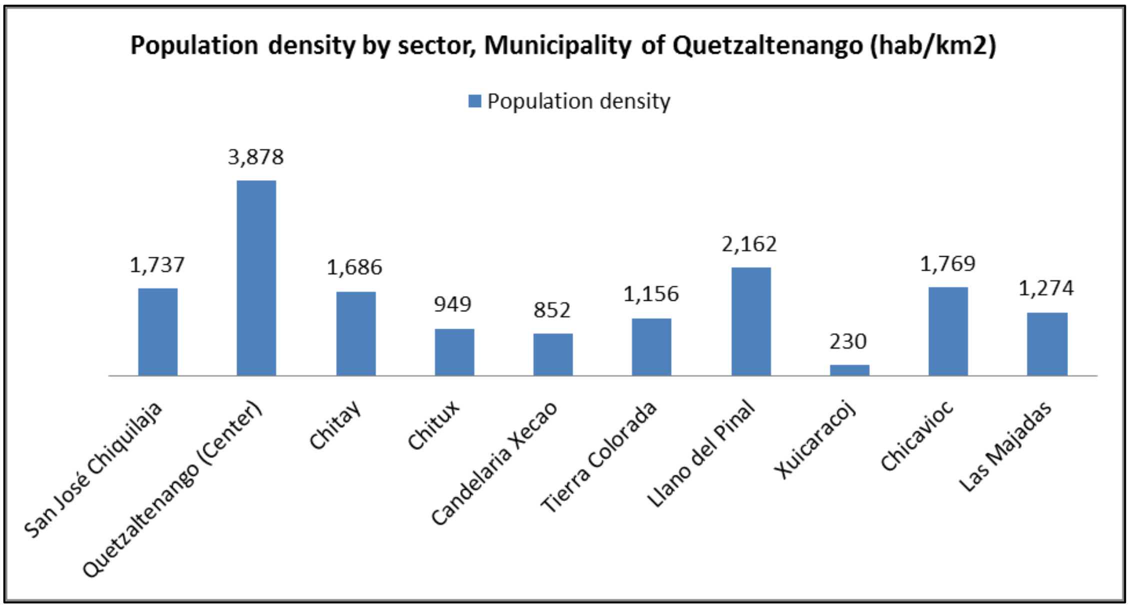


Figure 8, Population density by sector, Municipality of Quetzaltenango



In addition to population density, the identification of vulnerable areas takes into account the natural slope of the surrounding mountains (see appendix, map 12) and the land cover percentage (see appendix, map 13, Figure 9). For these elements of the analysis, independent maps for each criterion are presented. The slope is represented in different colours that indicate degrees from 0° to 90°. The land cover variable is presented in the following four categories 1) forest cover, 2) no forest cover, 3) deforestation and, 4) afforestation, each category represent the result of a monitoring field work from 2005 to 2010 regarding changes in land use. The resulting map shows graphically the loss of forest in areas that are naturally suitable for forestry and currently are used for agricultural purposes or urban sprawling is starting to take place. A Brief description for the interpretation of the land cover map is presented in the chart below.

Table 8, Land cover mosaic 2005-2010, Municipality of Quetzaltenango

Type	Land cover %	Area (kms2)	Description
Forest Cover	24%	31	Forestry area, contains natural forest and currently under natural land use
No Forest Cover	68%	86	Agricultural or urban area, no forest cover and subject to land use change
Deforestatio n	5%	6	Forestry area that is currently under degradation due to deforestation
Afforestation	3%	4	Areas where reforestation projects are currently taking place
Total	**100%**	**126.83**	**n/a**

Figure 9, Land cover, municipality of Quetzaltenango

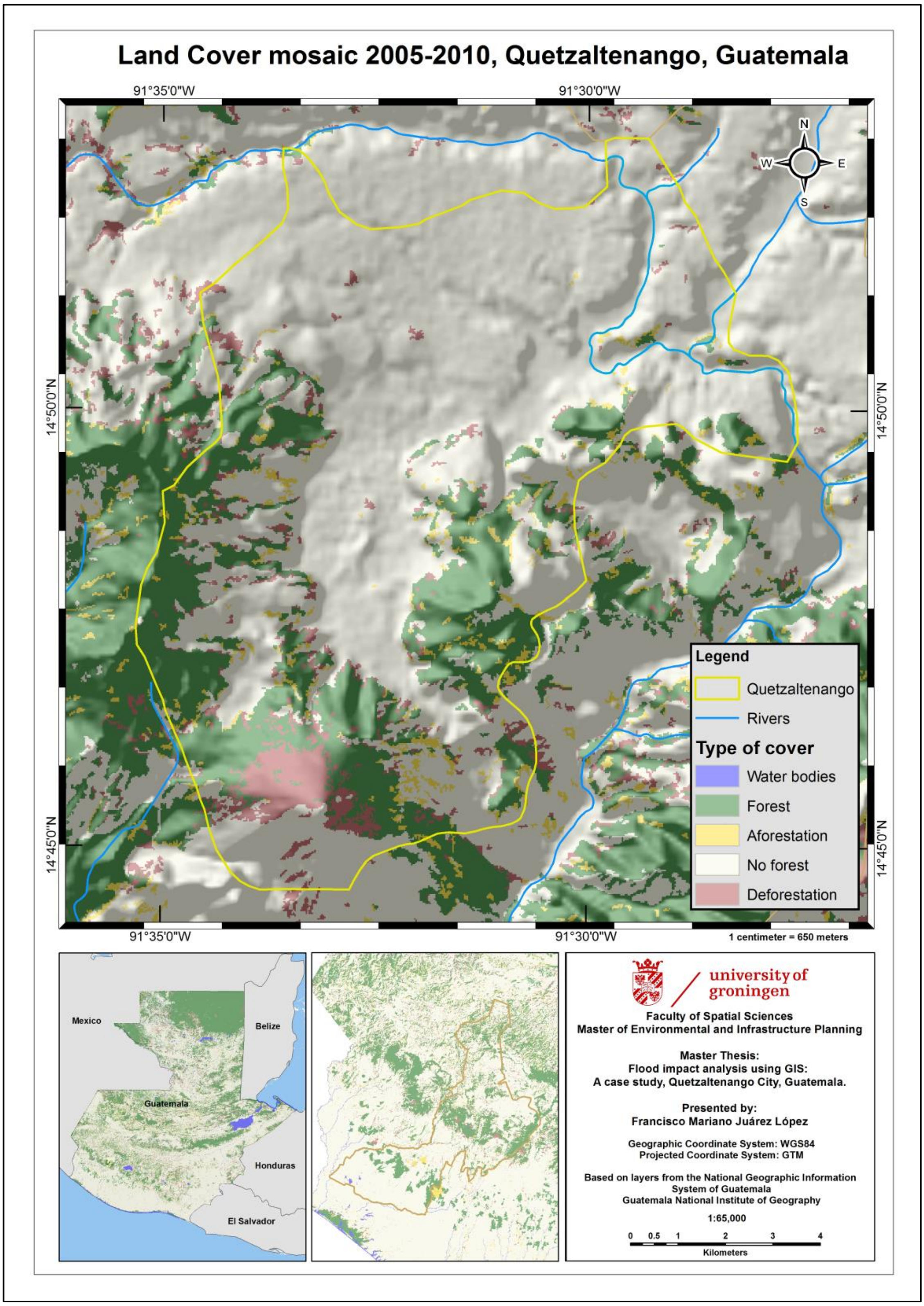
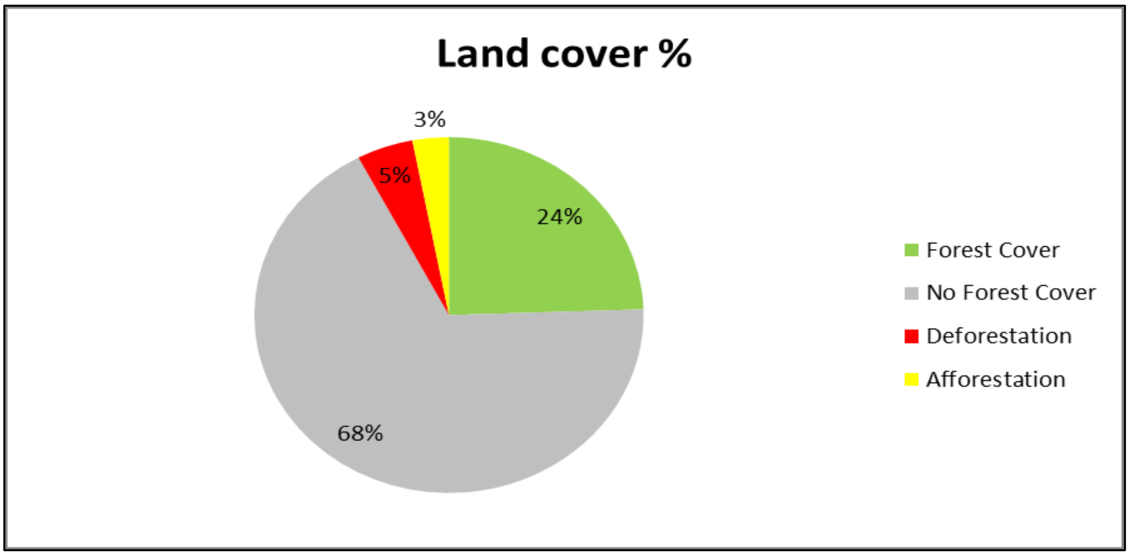


Figure 10, Land cover dynamic 2005-2010, Municipality of Quetzaltenango

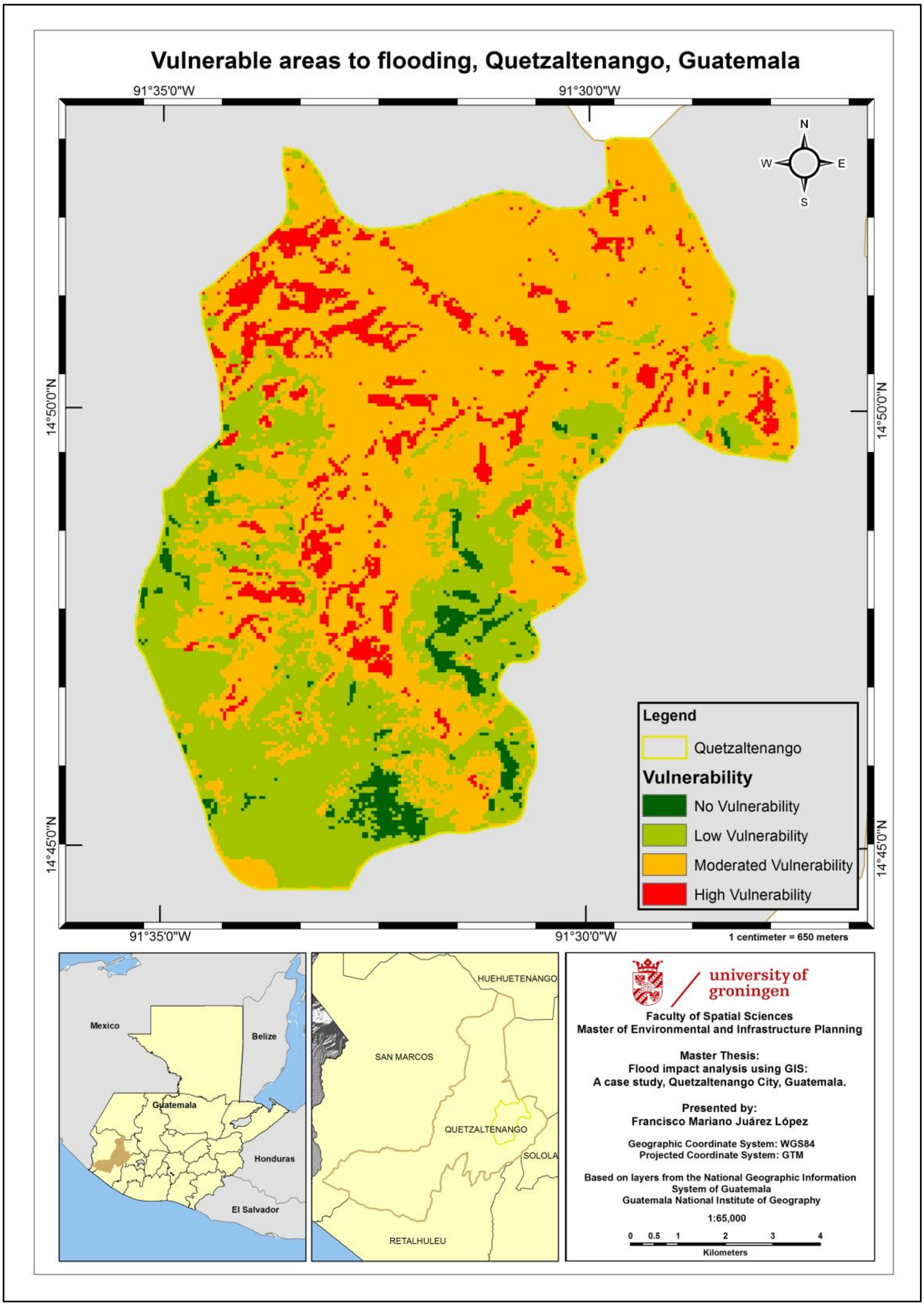


From the map product and the graphic above referring to land cover, important is to notice the fact that deforestation rate is 2% higher than the reforestation rate. The 2% gap means that the efforts for recovering the middle and low levels of the sub-basin have not been sufficient to contain the overall reduction of the forest cover in the sub-basin where Quetzaltenango city lays. In other words, there is a real reduction of forest cover by 2% yearly by means of deforestation and changes in land use.

5.2 Flood impact analysis products

Using the technique of map algebra and overlaying layers there has been generated a set of maps that show the potential endangered areas that might be negatively impacted in case of a flood event. A water flow accumulation map derives from analysing the slope and water flow direction (See appendix, map 16). The lower areas of the sub-basin are identified at an altitude of 2,300 and 2,350 meters above sea level. In case of a flood event, the probability of concentrating greater volume of water in these areas is higher than in the rest of the city. By analysing the flow accumulation map, the natural water path can be observed and deduct which neighbourhoods are more vulnerable to flooding in comparison with the rest of the city at a higher altitude of 2,400 and 2,500 meters above sea level. The vulnerability layer is the outcome of the weighted overlay analysis and is the main product derived from the impact analysis (see appendix, map 17, 18; figure 11). It depicts the vulnerability to flooding within the whole Municipality of Quetzaltenango. In this map four categories have been set in order to categorize the whole municipality into different areas according to the grade of vulnerability to flooding. The categories are: 1) No vulnerability, 2) Low vulnerability, 3) Moderated vulnerability and, 4) High vulnerability.

Figure 11, Classification of vulnerable areas to flood, municipality of Quetzaltenango

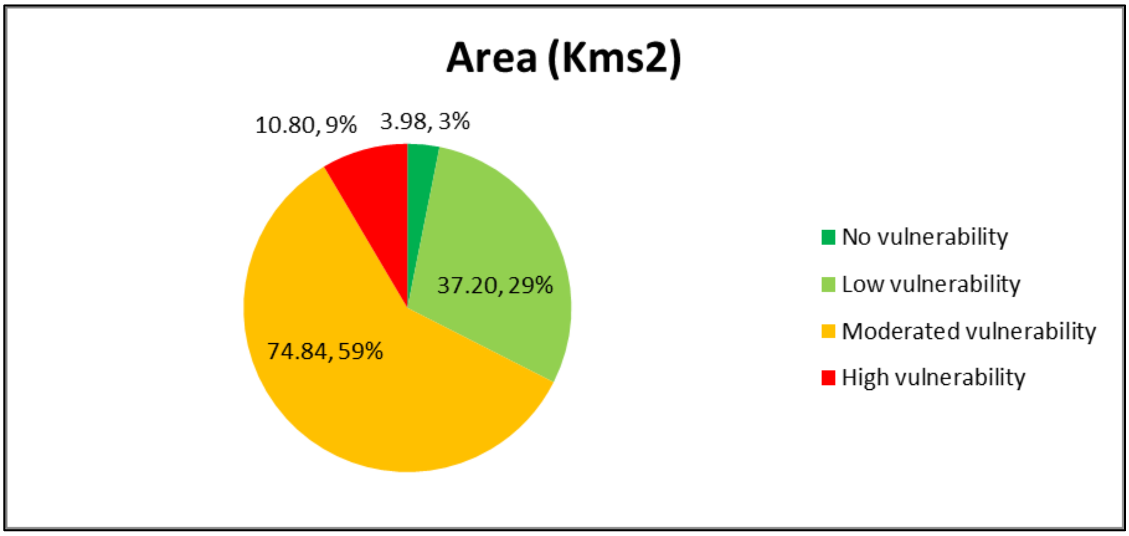


The categorizing procedure established a method to identify and the most vulnerable areas within the city and by applying overlaying techniques, identify neighbourhoods or social facilities that might be negative impacted in case of a flood event. In the following chart the results are presented.

Table 9, Vulnerability to flooding, Municipality of Quetzaltenango

Value	Vulnerability grade	%	Area (Kms2)	Description
1	No vulnerability	3%	3.98	No liveable areas, located at the highest peaks of the sub- basin.
2	Low vulnerability	29%	37.20	No liveable areas, located at the middle areas of the sub- basin, commonly water recharge zones.
3	Moderated vulnerability	59%	74.84	Liveable and/or agricultural areas that in the middle and long term could be impacted by a flood event because of water accumulation.
4	High vulnerability	9%	10.80	Liveable and/or agricultural areas that have the most potential to be flooded, currently and in the near future.
Total		**100%**	**126.83**	**n/a**

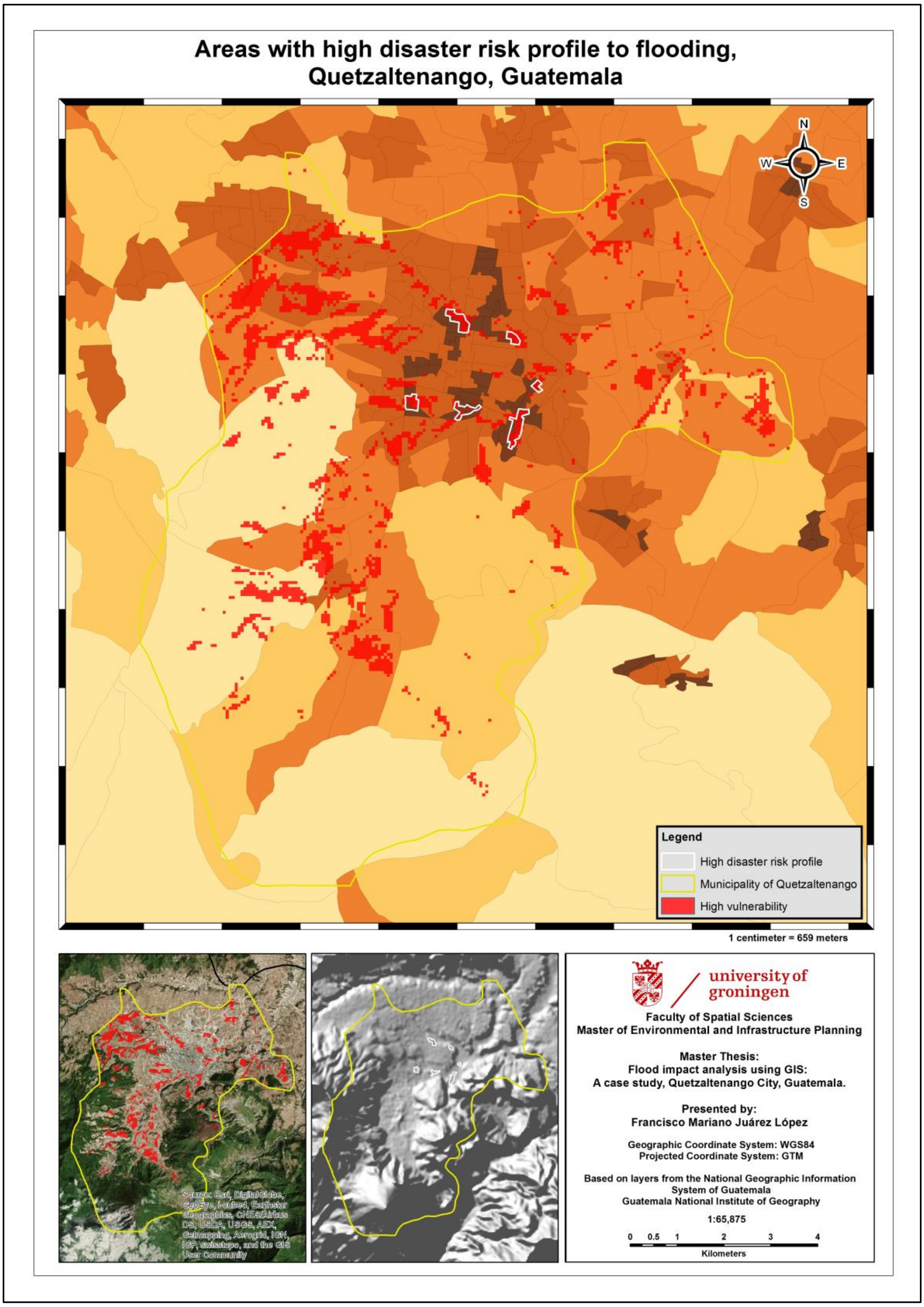
Figure 12, Distribution of areas by vulnerability to flooding, Municipality of Quetzaltenango



In sum, there is 10.80 square kilometres, equivalent to 9% of the territory of the Municipality of Quetzaltenango that is categorized under high vulnerable. These areas are all distributed in the 10 sectors of the municipality; some are urban areas and others are agricultural areas. The map show that the western and southern side of the municipality are the most spotted with high vulnerable areas, while the center and eastern sides of the municipality are less likely to have high vulnerable areas. An important observation is that the northern side of the municipality contains no vulnerable spots, the same condition is for the neighbourhoods that are located higher than 2,350 meters above sea level within the city centre.

The areas and percentages shown in table 6 correspond to calculations based only in physical characteristics, (slope, land cover, flow accumulation). However to establish the areas with the highest flood risk profile within Quetzaltenango city, population density is a critical aspect to consider.

Figure 13, Areas with the highest risk profile, municipality of Quetzaltenango



The number of people and property that can be affected in case of a flood event determines the grade of impact and the magnitude of a disaster caused by flooding. To establish the areas with the highest risk profile, an overlay analysis of high vulnerability areas over population density was carried out. The outcome is a map that identifies 6 polygons located in the city centre where three characteristics come together: 1) lowest areas in the basin, thus susceptible to flow accumulation, 2) high vulnerability to flooding and, 3) the most densely populated areas in the municipality. The resulting polygons show the areas that can be considered as the most vulnerable to flooding in the municipality of Quetzaltenango.

Table 10, highest risk profile to flooding, municipality of Quetzaltenango

No	Location	Area (mts2)	Area (kms2)	Area (Ha)	Perimeter (kms)
1	North	80,574.54	0.08	8.06	1.22
2	Northeast	87,766.77	0.09	8.78	1.90
3	East	31,713.19	0.03	3.17	0.82
4	Southeast	169,443.09	0.17	16.94	2.62
5	South	50,719.04	0.05	5.07	0.98
6	Southwest	122,948.13	0.12	12.29	1.83
Total		**543,164.76**	**0.54**	**54.31**	**9.37**

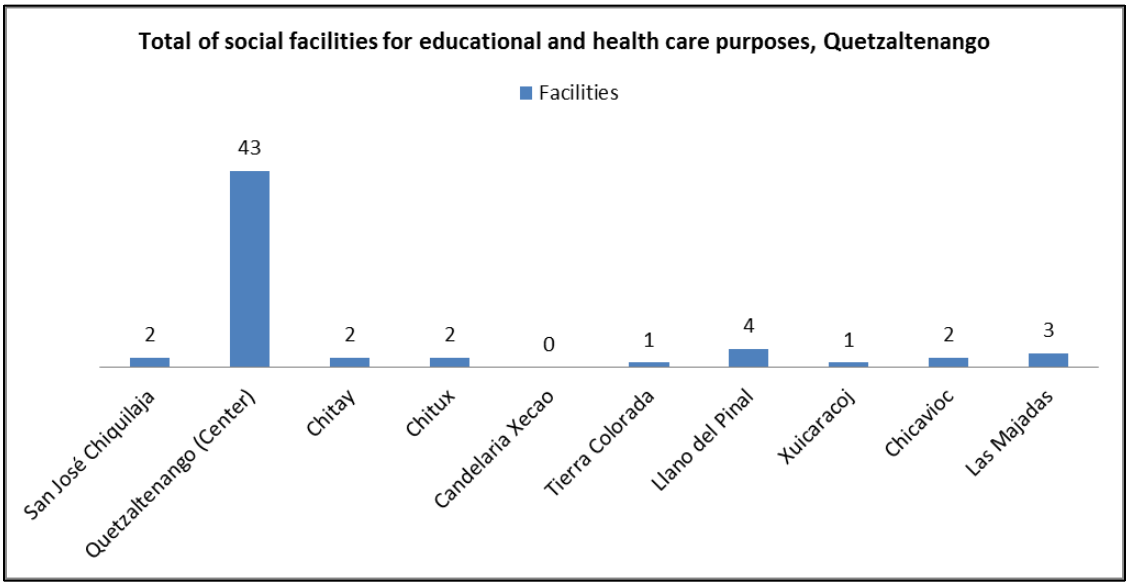
Reading the polygons on the map in a clockwise direction, the total area that is identified with the highest risk profile to flooding is 0.54 square kilometres. For practical application on Quetzaltenango city, the area is presented as 54.31 hectares due to the fact that; with the exception of the old city centre, blocks in Quetzaltenango city are based on hectare units. The 6 polygons are located in urban areas of Quetzaltenango town centre sector covering different blocks belonging to zones 1, 2 and 3 according to local nomenclature.

Complementary to the identification of areas with the highest risk profile in Quetzaltenango city, an overlay analysis was carried out in order to establish the potential impact that a flood event will cause to social facilities that is used to deliver basic social services. The social facilities that have been plotted refer to the location of primary and secondary school buildings, as well as health care centers all over the municipality. For the 10 sectors of the municipality, the analysis included the creation of individual maps showing the areas with high vulnerability to flood, as well as showing the overlap between vulnerable areas and the social facilities mentioned above (see appendix, maps 22-35). Vulnerability of a sector increases proportionally to the number of social facilities that might be directly impacted by a flood event

Table 11, Existing social facilities per sector, Municipality of Quetzaltenango

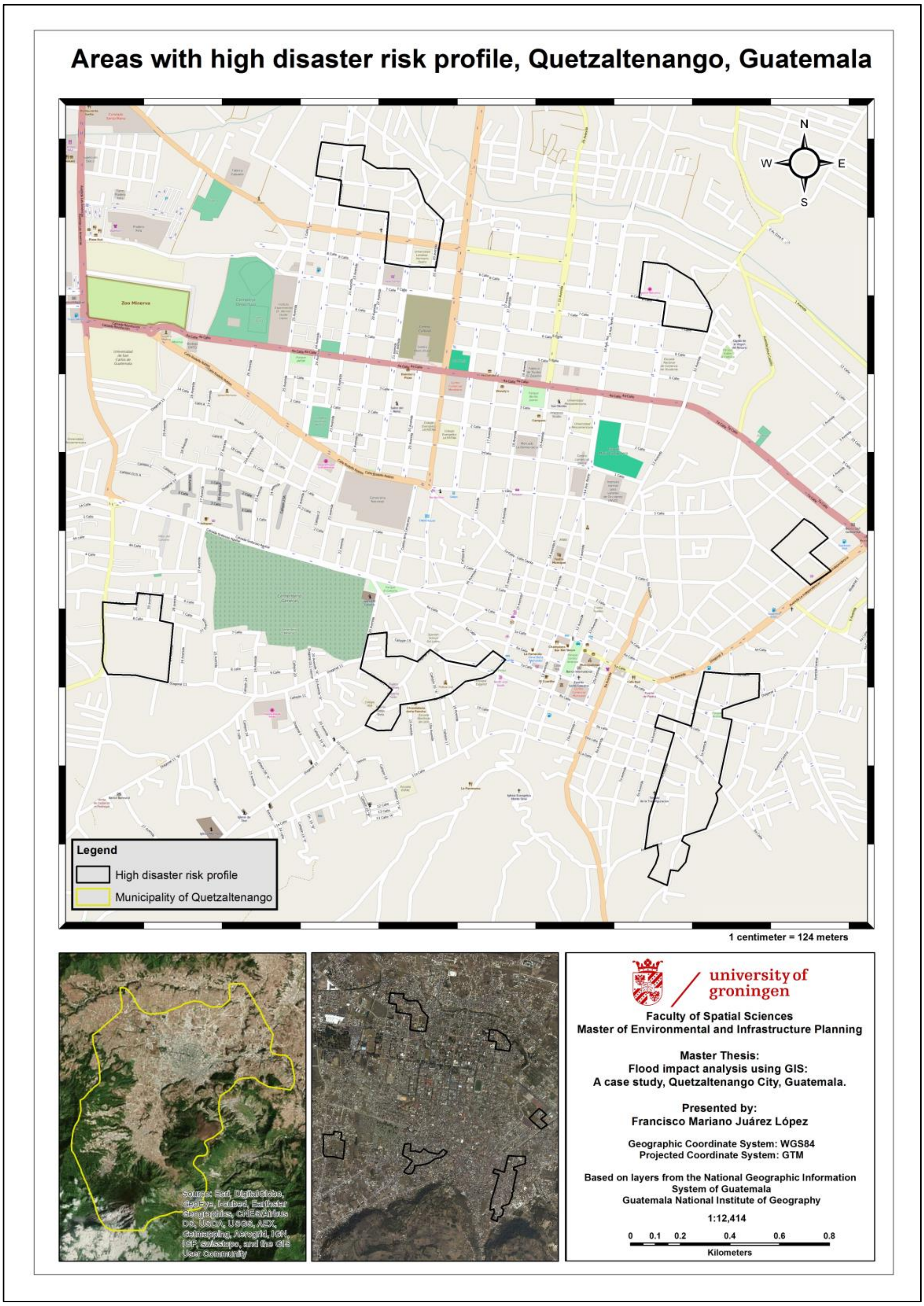
No.	Name	Area (Kms2)	Population 2016	Population density (hab/kms2)	Primary Schools	Secondary Schools	Health care Centers	Total social facilities	% of total (facilities)
1	San José Chiquilaja	3.69	6,409	1,737	1	0	1	2	3%
2	Quetzaltenango (Center)	35.20	136,491	3,878	28	4	11	43	72%
3	Chitay	1.76	2,968	1,686	1	0	1	2	3%
4	Chitux	1.38	1,309	949	1	0	1	2	3%
5	Candelaria Xecao	0.48	409	852	0	0	0	0	0%
6	Tierra Colorada	0.48	555	1,156	1	0	0	1	2%
7	Llano del Pinal	4.87	10,531	2,162	2	0	2	4	7%
8	Xuicaracoj	0.91	209	230	1	0	0	1	2%
9	Chicavioc	1.12	1,981	1,769	1	0	1	2	3%
10	Las Majadas	1.05	1,338	1,274	2	0	1	3	5%
Total/Average		**50.94**	**162,200**	**1,569**	**38**	**4**	**18**	**60**	**100%**

Figure 14, Distribution of social facilities per sector, Municipality of Quetzaltenango



In the summary chart, it can be appreciated that social facilities for basic social services such as education and health care are mostly in the sector of Quetzaltenango Town Centre. There is a big disparity in distribution of services due to concentration of economic and social activity in Quetzaltenango Town Centre, while the other 9 sectors remain in a rural condition or a transition from rural to urban areas.

Figure 15, Polygons with highest risk profile, municipality of Quetzaltenango



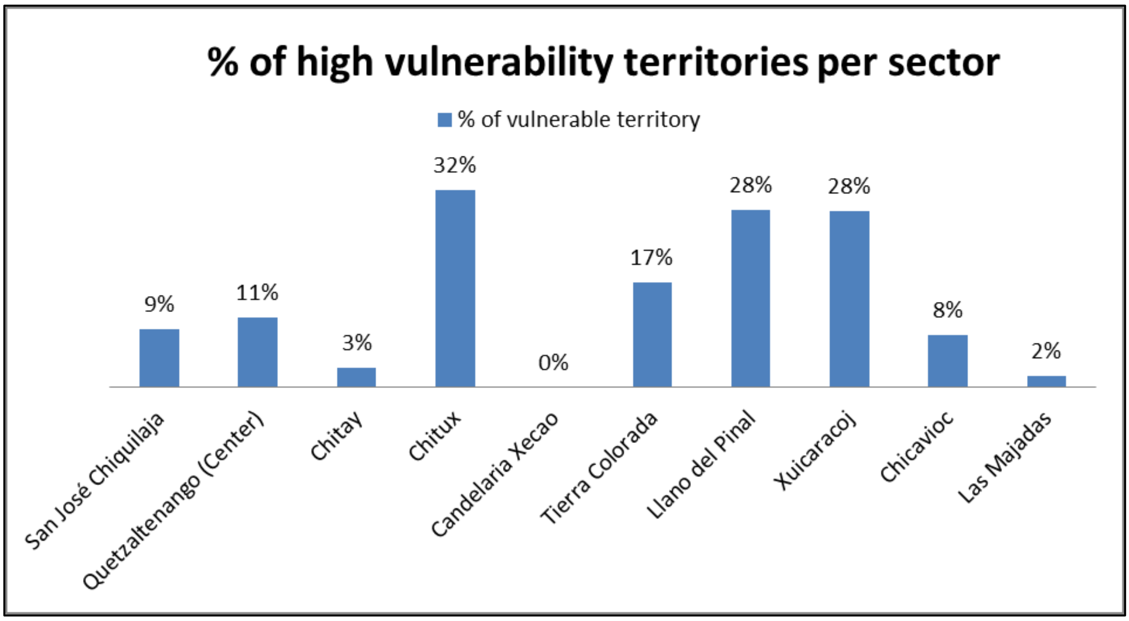
5.3 Flood risk zones

The analysis shows that 59% of the total area of the municipality of Quetzaltenango is vulnerable to floods in a moderated degree, while 9% appears to be highly vulnerable to a flood event. The interpretation of the data should not be extremely alarming by assuming that 59% of territory is going to be flooded in the near future. The GIS model that was applied for the present case study showed the result based on fixed physical characteristics. This means that the model assumes that everything is constantly happening at once. However in reality that is not the case, therefore, moderated vulnerability is interpreted as a scenario that might happen during an extreme event such as Hurricane Mitch in October 1998. Fortunately, natural phenomena with such characteristics have a long return period up to 100 years. However, 9% of the territory within the municipality is considered with high vulnerability to flooding. These areas are subject of the present analysis and, important is to mention that several spots are accurately identified as endangered locations which are actually reporting flood events year after year. For instance, such is the case of La Independencia Avenue in zone 2 (polygon 3) and the Barrio El Calvario (polygon 5) in zone 1, both in Quetzaltenango Town Centre sector.

The city centre is the most densely populated area of the whole municipality; nonetheless, with the exception of the polygons where there is an overlap with high vulnerability, the majority of areas that hold a population of 2,100 inhabitants per square kilometre and above, are not classified as highly vulnerable according to the analysis. Giving the information in table 7, the sum of the area of the 6 polygons with a high disaster risk profile is 0.54 square kilometres in which there is a population density of 3,878 inhabitants per square kilometre. By these numbers, the estimated population that can be directly impacted in a negative way in case of a flood event raises up to 2,110 persons, representing 1.3% of the total population of the municipality by 2016. The total area that is endangered in the 6 polygons with high disaster risk profile represents 1.5% of Quetzaltenango Town Centre sector. This perspective suggests that the city as a whole urban area is not considered to be under a category of high risk profile municipality due to the fact that the flooding vulnerability is determined in focal areas.

For the other 9 sectors that belong to the municipality, the population density is lower than 2,000 inhabitants per square kilometre. Additionally, through the orthophotographic images, it is significant to notice that most of the sectors have plenty of open areas such as agricultural fields, unpaved road and less compact urbanization design in comparison with Quetzaltenango Town Centre composition. These characteristics help the soil maintaining a higher natural permeability coefficient, helping both rainfall and runoff infiltration into the ground. A higher infiltration coefficient reduces the probability of high volumes of water accumulation that might turn into a flood event. Indeed, the 10 sectors that comprise the municipality have their own spots marked as high vulnerable areas according to the results of the flood impact analysis; however, some areas are more like to be impacted by a flood event due to their urbanistic characteristics than others.

Figure 16, percentages of territory under high vulnerability



The population density varies in each sector of the municipality; therefore the number of persons that might be affected in case of a flood event increases dramatically in Quetzaltenengo Town Centre and Llano de Pinal in comparison with Chitux and Xuicaracoj. The demographic distribution in the Municipality is centralized in the Town Centre as well as most of economic activities. A cause of this dynamic is that Town Centre sector has an extension of 35.20 square kilometres while Candelario Xecao and Tierra Colorada are less than half square kilometre. The result of the unequal distribution of the territory is materialized in centralization and demographic concentration, which are factors that significantly increase the disaster risk profile regarding flooding. For instance, according to the results of the impact analysis, the three sectors that hold the highest percentages of their territory under high vulnerability are Chitux (32%), Xuicaracoj (28%) and Llano del Pinal (28%). In Chitux and Xuicaracoj there is a small population, thus a low population density rate which suggests that currently these areas are not facing flooding problems, however in case the population increases by sprawling into the high vulnerable areas, flood events will become recurrent. In such case, promoting urbanization, reduction of green areas and changes land use in the near future without mitigation measures will derive in a significant increase of vulnerability to flood and affected people. Conversely is the case of Llano del Pinal, which shares the same percentage of its territory under high vulnerability as Xuicaracoj, but holding more than 9 times the population density in comparison with Xuicaracoj and more than double in comparison with Chitux. Although Llano del Pinal has 4 perceptual point less of its territory under high vulnerability in comparison with Chitux, its disaster risk profile regarding flooding is more critical due to the higher population density that reaches 2,162 inhabitants per square kilometre. With such profile, the approach must include mitigation measures for current flooding events as long as planning strategies for contingency and future development.

The amount of people per sector that are can be affected in case of flood has been calculated with the data in figure 8 and the population density rates for each sector. In terms of people that might be directly or indirectly affected by a flood event, Quetzaltenango Town Centre and Llano del Pinal are the most critical. Both together reach a disquieting amount of 18,244 people that can be negatively impacted by different means. Those living in Quetzaltenango Town centre will receive the direct impact (2,110 persons) in their properties and households located in the lowest areas and highly populated. The remaining 13,137 inhabitants from Quetzaltenango Town Centre receive an indirect impact by means of social facilities and road infrastructure that is flooded, temporary collapsed water supply system and urban transportation that is temporarily unavailable. Different is the case for Llano del Pinal, which is not as densely populated as Quetzaltenango Town Centre due to the agricultural activities that take place in the sector. In the maps can be identified large agricultural parcels along with households distributed all over the sector. The agricultural activity is intense in Llano del Pinal, suggesting that in case of a flood event, the main direct impact for the inhabitants is related to loss of agricultural crops instead of property and household that might be severely damage. So the impact is related to the economic activities of the inhabitants instead of struggling from the public social facilities and public services.

Analysing Xiucaracoj sector on the imagery from the impact analysis, up to 95% of its territory in dedicated to agricultural production with scarcely households and property. The sector is located on the southwest side of the municipality where the mountains start raisin. The sector has a transverse length of 1.5 kilometres and a difference of 130 meters in altitude from the southern side towards the northern side. The average slope of the sectors is 8.6% with no forest cover at all. This condition is what makes the sector to have a high percentage of its territory under high vulnerability (28%). The direct impact of a flood event in this sector is relatively low, with only 59 people affected. The changes in land use from natural forestry to forced agriculture have gradually increased the vulnerability in the las decades up to the 28% nowadays. As a result, the impact of a flood event would be sensible as an indirect impact by means of loss of agricultural crops, soil degradation and increasing the runoff water towards the western side of Llano del Pinal which is more densely populated.

The sectors Chitay and Las Majadas are the most stable out of the 10 sectors that comprise the municipality, a reasonable population density, located in natural flat area with slopes around 5% in average and up to 97% of its territory is not categorized as high vulnerability. Chitay in the northern side of the municipality counts with a paved access (7a Avenida), has plenty of open green areas and is not directly exposed to the lowlands of the mountains, therefore the probability to increase the runoff is less likely to occur. In the opposite direction, Las Majadas is located in the southern side of the municipality with moderate agricultural activity and an approximate of 35% of the territory dedicated to natural forest. These sectors constitute potential areas to develop new urbanization project which must be based on a proactive approach towards flood risk management instead of putting more pressure on the sectors that are already under high risk.

The sector Candelaria Xecao with a total area of 0.48 square kilometres is barley populated and its territory presents no vulnerable areas according the impact analyses. Through the orthophotographic images, it can be appreciated that the sector borders with Llano del Pinal to the west and natural forest cover to the east. This area represents a potential option to promote urbanization with minimal mitigation measures and prioritizing adaptability designs and forestry management for the natural areas on the east side. Similar criteria can be applied to Las Majadas sector in the west side of Llano del Pinal, which is more than twice the size of Candelaria Xecao and hold a population density by 42% less that Llano del Pinal. In other words, instead of Llano del Pinal growing towards the north trying to reach the Town Centre sector, an accurate strategy to prevent vulnerability to flooding to keep growing, is to promote planning and urbanization to the east and west of Llano del Pinal. At the same time, the Municipality can develop an integrated watershed and forestry management masterplan that prevent the increase of vulnerability to flooding in the long term.

In sum, excluding Quetzaltenango Town Centre and Llano del Pinal, the population that might be affected by a flood event raises to 1,468 inhabitants. Most of them are located in semi-rural areas with agricultural production as the main economic activity, therefore the impact is declared to be indirect. Nonetheless the nature of the impact is no related to basic needs such as household, drinking water and property, the effect in the middle and long term has serious implications for families, individuals and for the local economy. In case of large areas of agricultural crops are flooded, a considerable portion of the horticultural production of the municipality will be lost, causing a shortage of vegetable products in the whole municipality, as well as food insecurity for individuals and families who lose the production cycle. The number of inhabitants that can be impacted during a flood event has been calculated by sector on the basis of the population density and the areas under high vulnerability the showed the flood impact analysis. The outcome is summarized in the table 9.

Table 12, Number of affected people by sector in case of a flood event

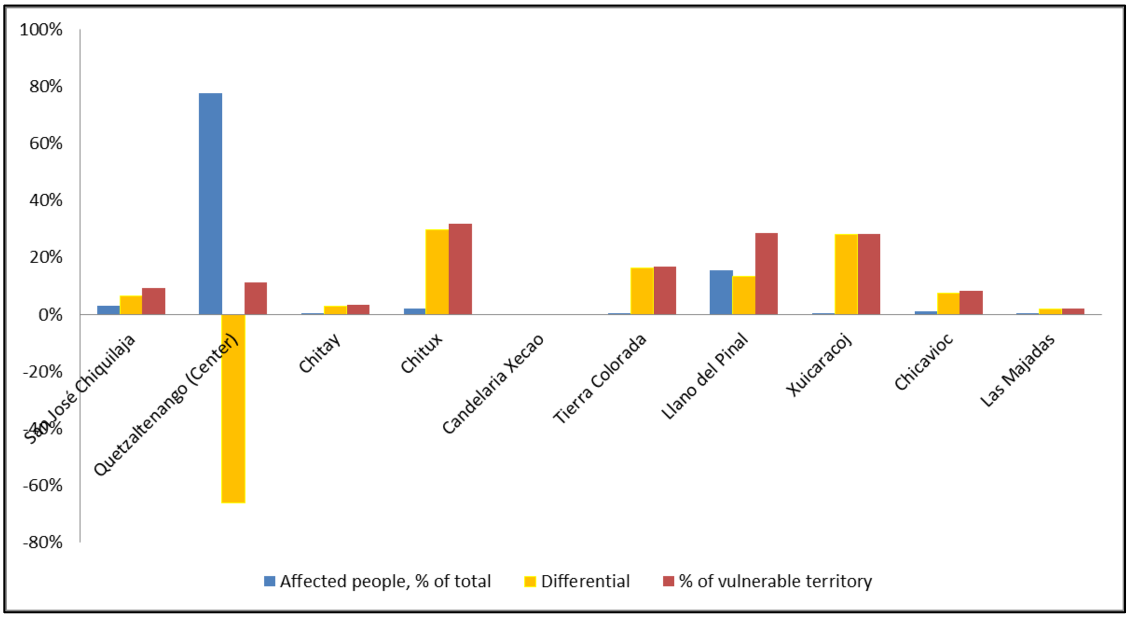
Name	Area (Kms2)	Population 2016	Population density	High vulnerability areas (kms2)	% of vulnerable territory	Impacted people
San José Chiquilaja	3.69	6,409	1,737	0.34	9%	597
Quetzaltenango (Center)	35.20	136,491	3,878	3.93	11%	15,247
Chitay	1.76	2,968	1,686	0.06	3%	95
Chitux	1.38	1,309	949	0.44	32%	415
Candelaria Xecao	0.48	409	852	0.00	0%	0
Tierra Colorada	0.48	555	1,156	0.08	17%	93
Llano del Pinal	4.87	10,531	2,162	1.39	28%	2,997
Xuicaracoj	0.91	209	230	0.26	28%	59
Chicavioc	1.12	1,981	1,769	0.09	8%	165
Las Majadas	1.05	1,338	1,274	0.02	2%	25
Total/Average	**50.94**	**162,200**	**1,569**	**6.60**	**14%**	**19,692**

To assess the disaster risk profile of each of the 10 sectors individually, essential is to depict the relation between the percentage of areas under high vulnerability per sector and the percentage of people that is impacted per sector. The resulting gap between these two factors establishes the clearance that each sector has to withstand more environmental and demographic pressure. For instance, Las Majadas sector has both factors very close one to another, with a differential gap of 6.2%. This small gap means that there is a low percentage of vulnerable spots within Las Majadas sector and a few people that is impacted in case of a flood event. In other words, there are safe areas and few people (low population density). In the other hand, in sectors where the gap between these two factors is bigger, the vulnerability to flood tends to increase in case more pressure and demographic density is added in the future. Such is the case of Quetzaltenango Town Centre, which shows a small percentage of areas under high vulnerability (11%) but, the highest population affected from total (77.4%). The interpretation is that Quetzaltenango Town Centre is already overpopulated, so no more pressure should be added. In sum, the ideal number is 0%, while the bigger the gap between these two factors, the less pressure the system can hold in the future due to either overpopulation or the existence of too many areas under high vulnerability. The comparison between sectors is a crucial step to address specific dynamics of each sector and identify tailor-made flood risk management and planning strategy per sector.

Table 13, Vulnerable territories and affected people per sector

Name	High vulnerability areas (kms2)	% of vulnerable territory	Amount of people	Affected people, % of total	Differential
San José Chiquilaja	0.34	9%	597	3%	6%
Quetzaltenango (Center)	3.93	11%	15,247	77%	-66%
Chitay	0.06	3%	95	0%	3%
Chitux	0.44	32%	415	2%	30%
Candelaria Xecao	0.00	0%	0	0%	0%
Tierra Colorada	0.08	17%	93	0%	16%
Llano del Pinal	1.39	28%	2,997	15%	13%
Xuicaracoj	0.26	28%	59	0%	28%
Chicavioc	0.09	8%	165	1%	7%
Las Majadas	0.02	2%	25	0%	2%
Total/Average	**6.60**	**14%**	**19,692**	**100%**	**n/a**

Figure 17, Difference between % of affected people and % of vulnerable territories



5.4 Social facilities

Part of the flood impact analysis for Quetzaltenango case study, includes overlaying techniques aiming to identify social facilities that is located within the areas under high vulnerability classification. The targeted social facilities to be included in the analysis comprise school buildings and health care centres all over the municipality. The school buildings layers refer only to public educational centers that are plotted in the national database. Excluded are private schools that might operate independently from the official GIS monitoring system of the ministry of education. The result is that those buildings are not officially included in the national database. For the analysis, the school buildings are divided into two categories: 1) primary school and, 2) secondary school. The same criteria were applied to health care centres that appear on the individual maps per sector. The analysis shows a positive overall profile in the regards to social facilities that in located at risk of flooding. A total of 60 buildings, including primary schools, secondary schools and health care facilities were identifies in the whole municipality, from which only 23% (14 buildings) are located at high vulnerable areas, therefore at risk of flooding. A total of 15% of elementary schools are in danger (9 buildings), 2% of secondary schools (1 building), and 7% of health care facilities (4 buildings). A first finding is that elementary schools are the most vulnerable segment of the social facilities evaluated while secondary schools the less impacted segment. The result corresponds to the fact that the total amount of public schools that offer secondary education in the whole municipality is only four, being one building at risk of flooding. Public education at secondary level is strongly centralized in Quetzaltenango Town Centre, making flood risk management a complex and challenging problem to overcome, due to population density and lack of social facilities for education purposes in the rest of sectors. Nonetheless, the health care facilities are better distributed among the 10 sectors of the municipality and most of them are located in areas without a profile corresponding to high vulnerability.

Quetzaltenango Town Centre is the sector that presents the highest amount of educational and health care facilities with a total of 43 buildings, equivalent to 72% of all public services of this kind. Llano del Pinal takes the second place as the most densely populated sector, having 4 buildings in total. Due to centralization regarding land use policy and spatial planning in the municipality of Quetzaltenango, the rest of sectors still remain in a rural or semi-rural condition, while Quetzaltenango town centre has gradually increased its population in a higher rate than the increasing rate of educational and health care services. The result is not only an increment in population density, but also more important is to notice that this dynamic is making access to social services and increasingly scarce opportunity for many people. In table 10 the distribution per sector of social facilities at risk of flooding are presented.

Table 14, Social facilities at risk of flooding, Municipality of Quetzaltenango

		Existing social facilities				Social facilities within vulnerable areas					
No.	**Name**	**Primary Schools**	**Secondary Schools**	**Health care Centres**	**Total of social facilities per sector**	**Primary Schools**	**Secondary Schools**	**Health care Centres**	**Total of social facilities at risk of flooding**	**% of social facilities at risk of flood (per sector)**	**% of social facilities at risk of flood (from total)**
1	San José Chiquilaja	1	0	1	2	0	0	0	0	0%	0%

		Existing social facilities				Social facilities within vulnerable areas					
No.	Name	Primary Schools	Secondary Schools	Health care Centres	Total of social facilities per sector	Primary Schools	Secondary Schools	Health care Centres	Total of social facilities at risk of flooding	% of social facilities at risk of flood (per sector)	% of social facilities at risk of flood (from total)
2	Quetzaltenango (Center)	28	4	11	43	5	1	3	9	21%	15%
3	Chitay	1	0	1	2	0	0	0	0	0%	0%
4	Chitux	1	0	1	2	0	0	0	0	0%	0%
5	Candelaria Xecao	0	0	0	0	0	0	0	0	0%	0%
6	Tierra Colorada	1	0	0	1	1	0	0	1	100%	2%
7	Llano del Pinal	2	0	2	4	2	0	1	3	75%	5%
8	Xuicaracoj	1	0	0	1	1	0	0	1	100%	2%
9	Chicavioc	1	0	1	2	0	0	0	0	0%	0%
10	Las Majadas	2	0	1	3	0	0	0	0	0%	0%
Total/Average		**38**	**4**	**18**	**60**	**9**	**1**	**4**	**14**	**23%**	**n/a**

From the 10 sectors of the municipality, 5 report no issues concerning any kind of social facilities at risk of flooding. In San José Chiquilaja, Chitay, Chitux, Chucavioc and Las majadas is not necessary to invest nor to take immediate strategies related to mitigation plans and preparedness for schools and health care facilities in case of a flood event. Nevertheless, the opposite strategy is recommended for Quetzaltenango Town Centre, Tierra Colorada, Llano del Pinal and Xuicaracoj, which have facilities located in high vulnerable areas to flooding. Especial attention has to be taken in Tierra Colorada and Xuicaracoj due to the fact that these sectors only have one facility which is in high risk of flooding. As shown in the imagery presented in the maps, the social facilities that is located in high vulnerable areas from the 3 sectors (with exception of Quetzaltenango Town Centre), have open access to safe areas nearby. This is a result of the low population density combined with open areas around households. An advantage can be taken from this characteristic by means of setting up a priority to develop preparedness plans and evacuation routs for schools in case of a flood event. Llano del Pinal and Quetzaltenango Town Centre are the two which report health care facilities within high vulnerability areas. In such a case, beside preparedness plans, a complementary strategy is to be taken towards adapting the buildings for flooding.

Figure 18, Social facilities located at risk of flood, municipality of Quetzaltenango

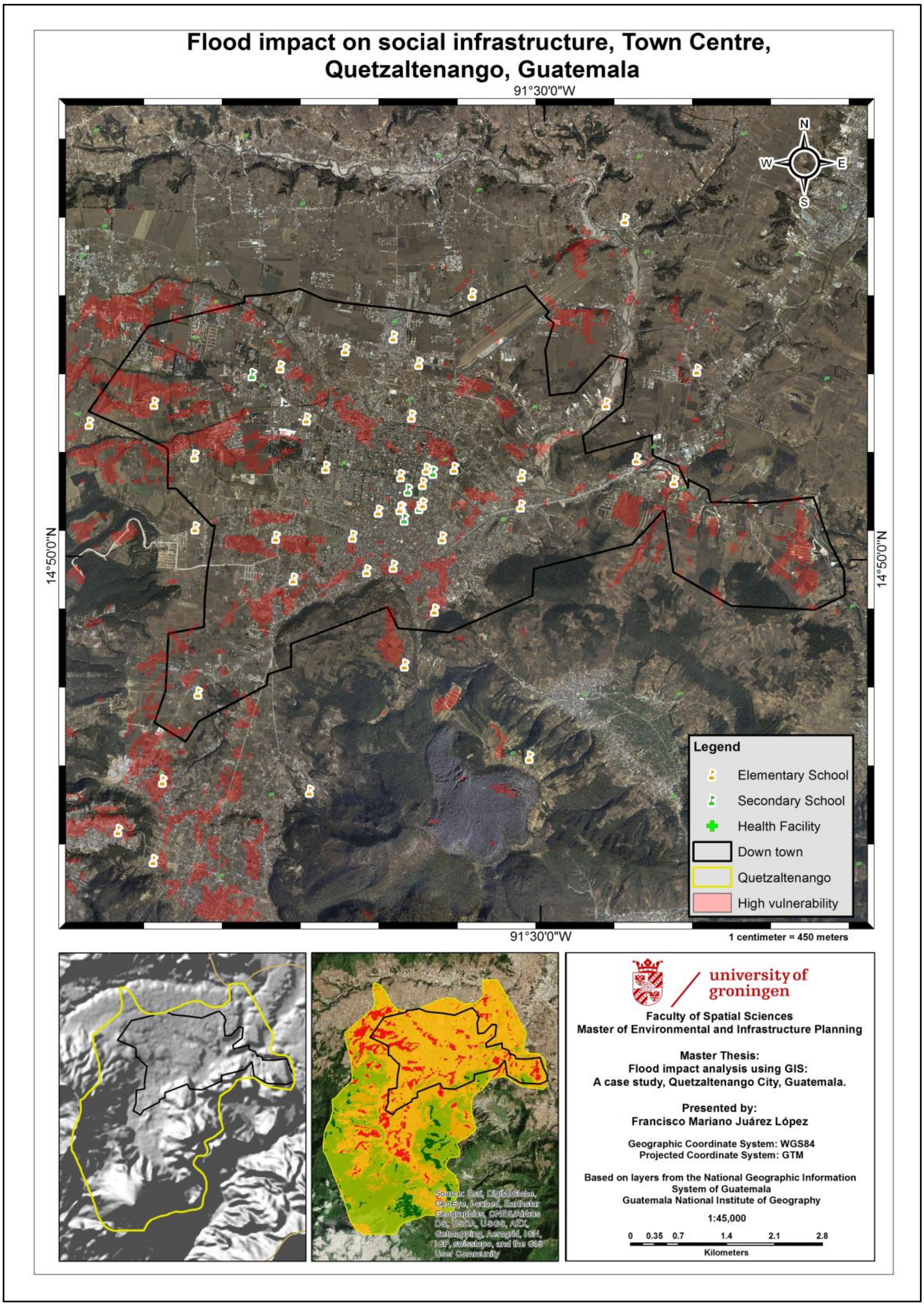
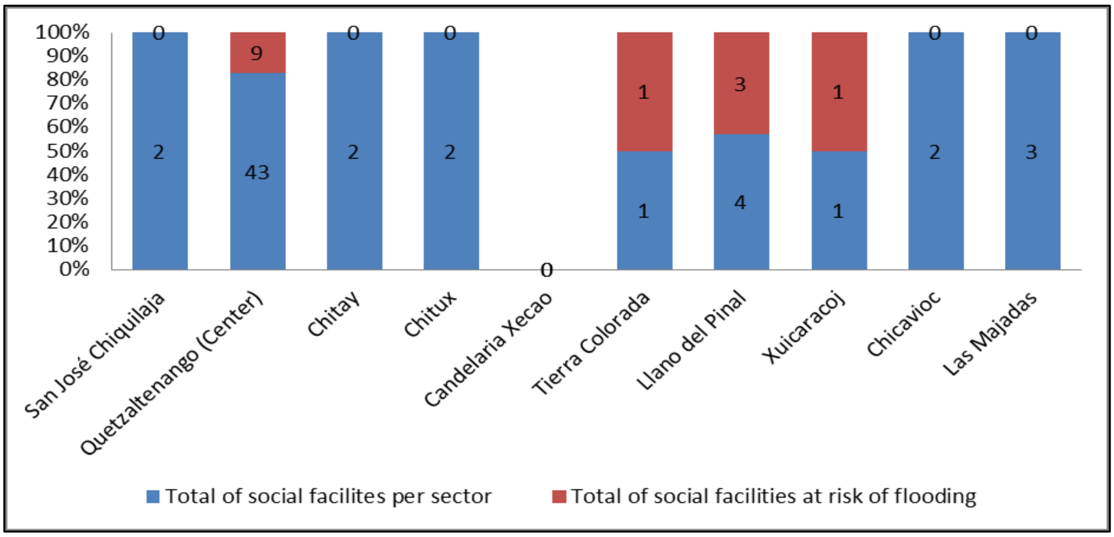
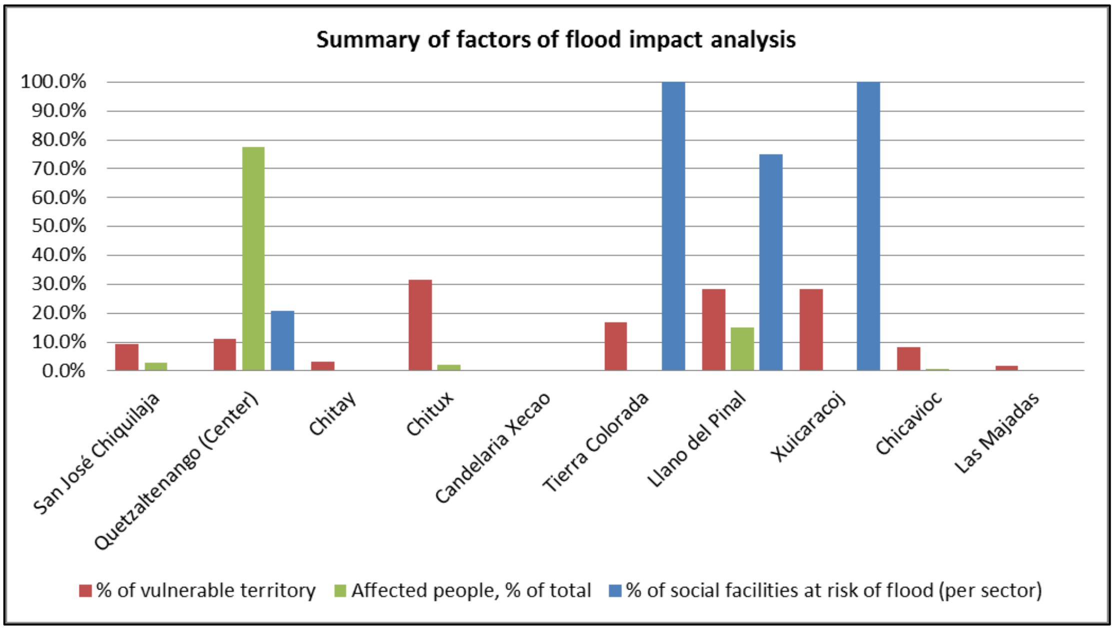


Figure 19, Social facilities located within areas with high vulnerability



The flood impact analysis for the municipality of Quetzaltenango has been based on calculating and evaluating three main factors: 1) the percentage of territory with high vulnerability for each of the 10 sectors that comprise the municipality, 2) the percentage of people (from total population in the municipality) that might be impacted in case of a flood event, and 3) the percentage of social facilities per sector that is located in high vulnerable areas. By analysing the characteristics and interactions of these three factors in the municipality, it is possible to assess the impact of a flood event in each of the 10 sectors of the municipality, while taking into account their own properties. As a final outcome it is possible to determine which areas in the municipality of Quetzaltenango are prone to flood events, as well as accurately identify the social facilities and property that can be negatively impacted in case of a flood event occurs in the near future.

Figure 20, Combination of factors for flood impact analysis



Combining these factors together, give an insight of the priorities in which every sector has to focus regarding flood risk management, both in the short and long term. For the short term activities and projects, each sector should focus its efforts and investments concerning flood risk management in the factor that presents the higher percentage of impact. This is because the higher is understood as the more critical at the moment. Naturally, for the long term activities and projects, factors that have the lowest percentage of impact, should be considered. For instance, in graphic 10 it is clear that in San Jose Chiquilaja sector, the negative impacts of a flood event are derived as an effect of high percentage of vulnerable territory while affected people in only at 3%. Then, in the short term San Jose Chuiquilaja should focus on a strategy to reduce vulnerability by using communicative and social proactive approach, for instance afforestation projects for the bottom of the basin. However in the long term, it should focus on a strategy to reduce the exposure by using an approach towards exposure control. For instance, introduce adaptive and regulated urbanization that will prevent overpopulation and urban sprawling.

Different is the case of Quetzaltenango Town Centre that presents a scenario in which a large number of affected people is the highest percentage, the second factor is vulnerable territory and the third is endangered social facilities. Because people is the most affected element, then the priority to start activities and projects should be an strategy to reduce exposure to flood by developing a proactive approach based on communicative and social techniques. The percentage in the middle is the corresponding to social facilities, which suggests that for middle term activities, should be taken a strategy to reduce the probability of flood and focuses on hazard control. For instance, build new schools building in a safe place or reconditioning the current building to make it adaptive to flooding. Finally, the lowest percentage corresponds to the percentage of territory that is under high vulnerability, then the strategy for the long term should emphasize vulnerability control to reduce the impact of flood, an example could be afforestation projects around the basin and master plan for integrated water resources management at municipal.

6 CHAPTER SIX, DISCUSSION

6.1 Planning and policies

Flood risk in the municipality of Quetzaltenango is depicted as the result of combining three factors in one place, first, the presence of extended rainfall and runoff (hazards), second, the existence of unprotected elements (exposure) such as people, property and infrastructure. The third factor includes the sum of disadvantageous characteristics regarding flood (vulnerability), for instance, dangerous location, inappropriate policies, unplanned urbanization, high population density and environmental degradation, among the most important.

(For reference see figure 1). Such flood risk profile can be tackled by developing a tailor-made flood risk management strategy than includes short, middle and long term actions. It can be accompanied with a master plan that points out the outlines to formulate specific projects and activities according to what is needed for addressing the root causes of flood risk profile. Flood risk management is a complex approach to manage critical factors that cause vulnerability and exposure to flood hazards. The municipality of Quetzaltenango has historically been administrated under a fully centralized model of municipal governance, most of municipal policies focus only on Town Centre sector in term of investments, infrastructure development and regulations. The remaining 9 sectors that comprise the municipality have considerable less financial resources and importance when it comes to decision making at municipal level. As a result of the political and economic centralization along the last 50 years, naturally, the city has evolve into a centralized urban area, an evidence of this behaviour is the high concentration of household in areas of Town Centre sector, as well as the distribution of public services, such as education and health care facilities.

Nowadays the municipality of Quetzaltenango depend on very weak legal and administrative tool to address the difficulties that imply having a high flood risk profile. The policies on which the governance model finds its basis represent an outdated reality from many years ago. The current approach regarding key issues such as environmental management, spatial planning, household taxation and municipal investment is limited to few criteria from local authorities who barely include flood risk management principles in the municipal strategic planning and investments annual plan. So far the municipality of Quetzaltenango has been dealing with its flood risk profile by focusing on hazard control, which results to be the toughest component to approach. The strategies adopted from local authorities have concentrated on reducing the probability of flood by applying technical and spatial mitigation measures after a flood event has taken place. The approach used by the municipality has been entirely reactive afterwards every single flood event, basing the strategy in short term response activities during the emergency period after a flood event. There have not been enough efforts from local government to develop a flood risk management strategy that includes the four stages of flood-disaster management cycle: 1) response, 2) recovery, 3) mitigation and 4) preparation (Asian Disaster Reduction Center (ADRC), 2005). Current local policies in the municipality of Quetzaltenango exclude the possibility of developing fundamental components of flood risk management, such as early warning systems, spatial planning based on flood impact analysis, capacity building and adaptive design, which all together will contribute to develop resilience in the long term. As mentioned in previous chapters, vulnerability and exposure is increasing in the municipality of Quetzaltenango due to economic and environmental degradation reasons; however, identified is a third factor in the process of progression of vulnerability, that is political and administrative practices which set up a model of governance that addresses flood risk profile through a reactive approach.

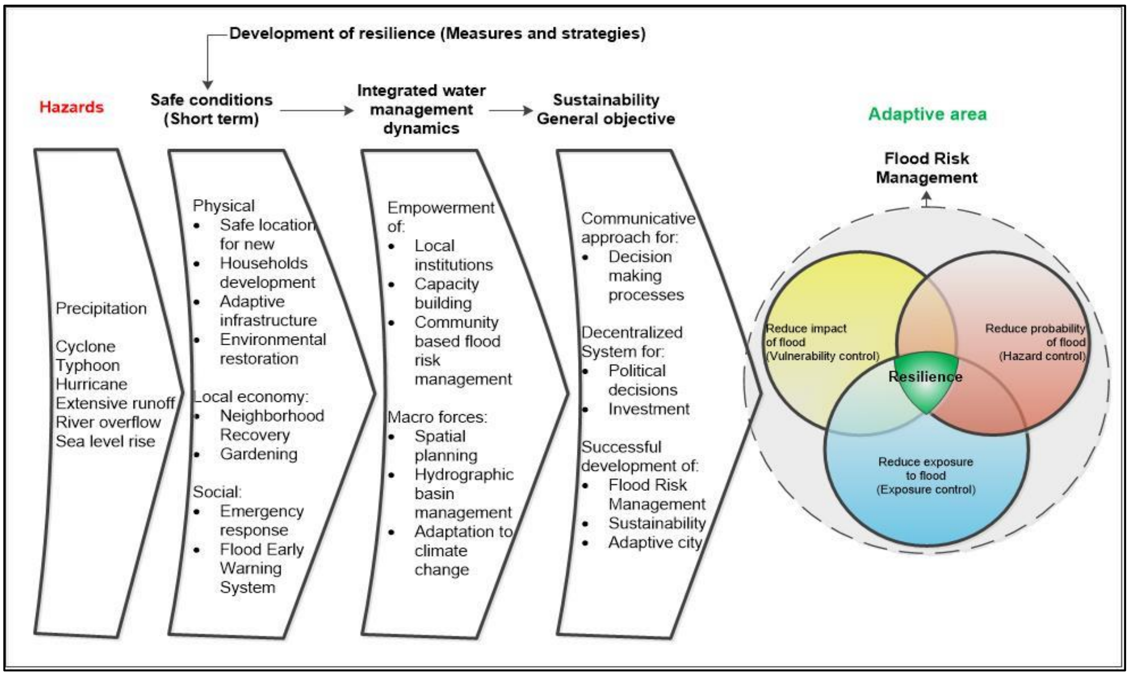
Under a reactive approach, the municipality of Quetzaltenango is targeting only on hazard control while missing vulnerability control and exposure control respectively. The reactive approach offers temporary solutions and is limiting the possibility to formulate integrated long term activities to tackle dynamics of pressure in the sub-basin and the root causes of flood risk profile. In order to promote a transition from reactive approach towards an integrated flood risk management model, the reactive approach has to be substituted by a proactive approach. New policies and regulations that make use of both technical and social tools for targeting not only hazard control, but also vulnerability and exposure control with a long term horizon, can help build resilience to floods by means of becoming an adaptive city.

Table 15, Flood risk management & flood management cycle

No.	Strategy	Approach	Measures	Focused on	Management cycle	Term
1	Reduce probability of flood	Technical, spatial (Reactive, centralized)	Dams, pluvial canals, dykes, levees, storm surge barriers and other civil engineering.	Hazard control	Response Recovery	Short
2	Reduce impact of flood	Communicative, social (Proactive, decentralized)	Flood early warning systems, capacity building, planning of evacuation routes, adjustments to houses and infrastructure (adaptability), environmental management (mainly hydrographic basin)	Vulnerability control	Preparedness Mitigation	Short Middle
3	Reduce exposure to flood	Communicative, social (Proactive, decentralized)	Relocating properties, inhibiting new developments in flood prone areas, spatial planning, access to decision making processes.	Exposure control	Preparedness Mitigation	Middle Long

The complexity that involves the political, social, economic and environmental circumstances in the 10 sectors of the municipality of Quetzaltenango, converge all together at the time when formulating and implementing a flood risk management model. The current model of governance is in need of a transition from technical-centralized approach towards a communicative-social approach in order for the flood risk management model to be successfully implemented and bring out result for turning the current flood risk profile into an adaptive and resilient profile in the future. Besides, the responsive and recovery efforts after flood events, local authorities are encourage beginning a transition process by developing a new approach based on communicative rationally and thus, collaborative planning. The aim is to decentralize the municipal government at technical, administrative and spatial level, especially the processes of problem analysing and decision making. Opening discussion boards with several stakeholders from civil society, private sector, central government and local authorities, will allow the municipality of Quetzaltenango to identify key issues to be included in the flood risk management plan, which will make it feasible to be implemented as a result of the approval of the stakeholder involved. Secondarily, the proposals that come out from an inclusive process of analysing and decision making, tend to be more realistic, as they resemble accurately the actual conditions in the field, as well as presenting agreed measures for addressing the flood risk profile of each of the 10 sectors that comprise the municipality of Quetzaltenango. By developing such decentralized communicative-social approach, there is more guarantee in succeeding at the time of implementing local regulations, taxations and controls regarding sensitive issues such as spatial planning, construction regulations, land use criteria for developing new projects, hydrographic basin management and social capacity building.

Figure 21, Conceptual model of resilience within Flood Risk Management



Building adaptability and resilience against flooding is a long term process that necessary involves stakeholders from all sectors as well as components of all kinds, from very technical to political and social issues. It is the result of integrating a wide set of measures aiming to keep under control the impact of hazards as well as the degree of vulnerability and exposure. It requires establishing clear legal instruments such as policies and regulations, effective technical interventions such as infrastructure for water drainage or hydrographic basin management, and committed political administration towards an inclusive governance model that pursues sustainability for the upper sub-basin of Samala River. In case there are significant discrepancies between legal, technical and political components, achieving an effective flood risk management model for the municipality of Quetzaltenango might turn into a process without legitimacy if formulated from an exclusive approach. That is why flood impact analysis can be used as a first approach to get an overview of the current situation, and from there on, the outcomes and mapping products a fist input to start the discussion with all stakeholders involved.

6.2 Flood risk management measures

A set of measures for counteract the negative impact of flood risk profile have to be realized in the municipality of Quetzaltenango; the implementation of such measures varies from sector to sector according the specific characteristic regarding vulnerability and exposure of elements at risk of flooding. According to the findings derived from the flood impact analysis (see appendix, map 17; figure 11) each sector need the same set of measures all along the process to build resilience, however, priorities between sectors differ significantly one from another. The reason is that every sector has substantial differences in land use, economic activities, population density and environmental surroundings. For instance, in Tierra Colorada, Llano del Pinal and Xuicaracoj sectors, there is an impact on social facilities that comparably is not present in Chitay, Chitux, Chicavioc and Las Majadas sector. Some of the sectors still have intensive agricultural production areas while others are struggling with population density and traffic pool.

A set of 17 measures have been listed and grouped by component within flood risk management. In order to depict the whole dynamic, flood risk management components have been matched with flood impact analysis, the resulting combination is practical for identifying which measure is accurate to tackle a specific problem and what component of flood risk management should be used to implement it successfully. In total, a sum of 170 measures are identified to be necessary in all sectors, nonetheless, depending on the sector some measures are priorities and some others are inconsequential at this moment, thus can be addressed in the long term. The temporality of implementation is based on the needs of each sector, additionally it is meant to be used strategically to distribute municipal investment in a form that most of critical issues concerning flood risk management of each sector are properly addressed.

After pondering the values for each sector and measure, the result shows that in the short term, the essential step towards a proactive approach for a successful flood risk management, is to promote an inclusive decision making process that will lead to a consensus for implementing the rest of measures. The second priority for the short term, with 7 point each, is the implementation of agroforestry system, land use and soil management in the sectors of the lower part of the sub-basin. A total of 56 measures are identified to be necessary in the short term. In the middle term, regulation take place as priority, mainly spatial planning and construction regulation to deal with population density and urban sprawling in the most crowed sectors, such as Quetzaltenango Town Centre, Llano del Pinal and Xuicaracoj.

The list of 17 measures listed in table 16 aims to be a fist proposal that the municipality can use to open the discussion regarding how to address the flooding problem at the municipality of Quetzaltenango. It is not intended to be a final solution nor a final plan on how to turn the flood risk profile into a flood-resilience profile at once. The first priority is to set an inclusive environment for analysing the actual situation, set up a desire situation and lead a decision making process to achieve feasible goal as a result of effective collaborative planning with all stakeholders involved.

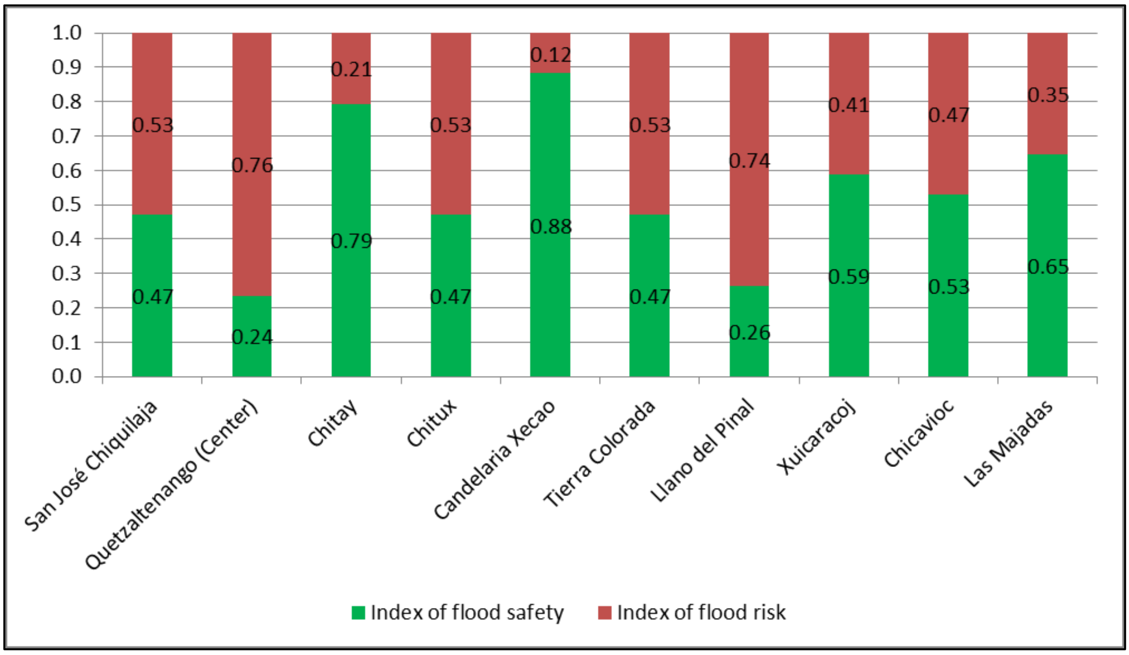
Table 16, Temporality of measures for municipality of Quetzaltenango

	Flood impact analysis	Facilities at risk					Vulnerable territory					Vulnerable/Exposed people							
	Flood risk management	Technical measures					Environmental measures					Social/Political measures							
No.	Measure / Sector	Drainage systems	pluvial canals	Solid waste management	Neighbourhood recovering	Adaptive infrastructure	Afforestation	Watershed management	Agroforestry systems	Land use/Soil management	Urban gardening	Flood early warning system	Spatial planning	Construction regulations	capacity building	Inclusive decision making process	Institutional capacity	Community based disaster risk management	Index of flood risk profile
1	San José Chiquilaja																		0.53
2	Quetzaltenango (Center)																		0.76
3	Chitay																		0.21
4	Chitux																		0.53
5	Candelaria Xecao																		0.12
6	Tierra Colorada																		0.53
7	Llano del Pinal																		0.74
8	Xuicaracoj																		0.41
9	Chicavioc																		0.47
10	Las Majadas																		0.35

Total measures for short term	1	2	1	4	5	3	3	7	7	1	2	1	1	3	10	1	4	56
Total measures for middle term	2	2	2	0	0	5	4	0	1	3	2	9	9	2	0	1	4	46
Total measures for long term	7	6	7	6	5	2	3	3	2	6	6	0	0	5	0	8	2	68

Some sectors need more time and investment to build resilience than others; each sector has different strengths and weaknesses that have to be addressed individually. In the following graphic can be appreciated the values of indexes for safety and risk per sector. Interesting is to notice that the safest places are Candelaria Xecao and Chitay; while the most risky ones are Quetzaltenango Town Centre and Llano del Pinal.

Figure 22, Weighing of flood safety vs flood risk per sector, municipality of Quetzaltenango



6.3 Limitations of flood impact analysis

Geographic information systems are a powerful tool for environmental analysis and spatial analysis, which together can be used to carry out a flood impact analysis based on geographic, topographic and demographic data. The findings in this research are the outcome of computing the data with a GIS model, thus exclude any type of fieldwork or corroboration in-situ. The mapping products and statistical findings that produced the flood impact analysis were mainly formulated from analysing related theory and data from remote sensing technologies. Although the analysis allowed mapping out and ponder flood risk zones in the municipality of Quetzaltenango, the case study is missing in-situ observations and social validation to corroborate the accuracy of the results presented in the present work. A more comprehensive flood risk analysis involves the participation of representatives from local authorities, community leaders and organized groups of civil society, such as NGO's. The aim of socializing the process is to validate the mapping products so that represent the reality in the most accurate way possible. Unfortunately this stage of the research was not possible to be included due to financial and logistic limitations. However, the outcomes of this research compose excellent and high quality products to be used as an input to open the discussion and decision making process regarding flooding in the municipality of Quetzaltenango. The mapping products alone are valueless, unless they are used for debating about the current approach regarding flooding and agree new strategies to deal with flooding in the future years. At that point, the mapping products and all the related outcomes of this research contribute to the decision making processes towards developing resilience in the municipality of Quetzaltenango.

The flood impact analysis is a first technical tool that is part of the complex process for developing a flood risk management model; it is limited to technical results and proposals based on the analysis of physical characteristics. In order to carry out the measures described in table 14, agreements have to be reached in social and political terms. The present research is limited to depict a first insight of the current situation and outline an overview of a possible approach towards a new model of governance in regards of flood risk management. Important is to mention that the mapping products are also limited in the sense of getting outdated every 3 years in average (by 2,018 in case of the present case study). Ideally, the mapping products and the database should be periodically updated with refreshed data, allowing the evaluation of changes that take place in any of the physical component. Flood impact analysis using geographic information systems can be a permanent tool along the process of developing and implementing a flood risk management model, contributing by providing constant inputs to diagnose and monitor dynamics, activities and projects of the study area.

7 CHAPTER SEVEN, CONCLUSION

The flood impact analysis in the present work has identified the factors that influence flooding in the municipality of Quetzaltenango; the mapping products have given valuable information for acknowledging the fact that the municipality has already reached a permanent high flood risk profile that should not be overlooked. In general terms, this work shows that the flood risk profile of the Municipality of Quetzaltenango finds its root causes deeply in the current model of municipal centralized government, reactive approach toward flood management and constant increase of population. All these factors together put more pressure on the surrounding environment and progressive increase of flood risk profile. Understanding flooding as an isolated disaster event and temporal problem in the municipality of Quetzaltenango is no longer the accurate approach to address a problem that involves political, social, economic and environmental issues related to multiple stakeholders which act in an intersubjective scenario. The outcomes of the flood impact analysis and the statistical interpretation of data results, show that the municipality of Quetzaltenango is a complex adaptive system (ten sectors) with all elements interrelate, depending and contributing one from each other as depicted in the conceptual model of the present work (see figure 1). Undoubtedly, the municipality of Quetzaltenango is a fast changing area; an emergent economic centre in western Guatemala, a place in which the combination of demographic dynamics and environmental characteristics have a unique scenario that is favourable for getting recurrently flooded if no flood risk management approach is developed. It is not a surprise that every year new neighbourhoods start facing inundation problems as consequence of the lack of a holistic flood risk management approach. The municipality of Quetzaltenango is certainly facing a challenging scenario to revert the flood risk profile that has already achieved; and turn it into an adaptive flood resilient profile. The centralized and responsive approach is generally perceived to be lacking an accurate extent to address the root causes of the flooding problem. The outcomes of the present work have the potential to contribute extensively to start the shift from the current reactive model towards a proactive approach; the set of measures identified in this case study provide the municipality with material and a first proposal to open the debate with local stakeholders on how to deal with negative impacts due to flooding events. The zoning of municipal territory into categories showing vulnerability to floods, and the identification of areas with the highest vulnerability ratio can be used as a first insight towards developing a spatial planning policy in the municipality of Quetzaltenango. The lack of a spatial planning policy aiming to be implemented as an administrative tool that includes flood risk management criteria for future years is one of the root causes generating dynamic pressure.

The municipality of Quetzaltenango needs to consider, as a governance priority, the transition from its current technical-centralized approach, towards a gradual shifting to a new proactive-decentralized approach based on collaborative planning. Such shift will allow the municipality to make use of local information, historical experiences and empirical knowledge regarding flood management in the municipality. Positive for debating on how to address the problem, are all the contributions and proposals from stakeholders who are involved in the roots causes of flooding. The debate will turn into an inclusive process of formulating policies, plans and projects regarding flood management and subsequently having a positive effect by means of changing the decision making model at municipal level. During the debate, it is important to analyse the reasons why up to now no positive results have been obtained out of the responsive approach implemented by the municipality. More important is to evaluate to what extent the activities realized so far by the municipality, match the characteristics found in this research for every sector regarding flood risk management. The activities conducted by the municipality have been merely responsive to emergencies and thus decontextualized according to the root causes of flooding for every sector described in this research. The municipality is lacking a policy with a holistic flood risk management approach that envisions activities and projects for the short, middle and long term in order to develop local capacity building and adaptive flood resilience profile. A better understanding of the flood risk profile of the municipality of Quetzaltenango can be achieved through the mapping products showing the prone areas to flooding within the ten sectors of the municipality and the identification of social facilities at risk of flood. The mapping products might be used as a basis to analyse particular situations of each sector and formulate tailored made short term measures and long term goals to reduce vulnerability and exposure of the flood risk profile. The findings presented in this cases study are mainly targeted to municipal authorities and municipal technicians working at the planning department and environmental department of the municipality of Quetzaltenango. Additionally, it is valuable information for the general community, especially for those living in prone areas to flooding. In case of developers in the real state and housing development sectors, the mapping products and statistical analysis can be of great benefit by using the material as an input for decision making in the private sector investments. In sum, the mapping and analysis generated in the present case study, find their most useful application to influence the decision making processes at the municipality of Quetzaltenango; mainly at local government level, but also in independent initiatives. The ultimate purpose is to provide a fist proposal to start a discussion on how to address the current situation regarding floods.

Looking at some opportunities derived from the current flood risk profile of the municipality of Quetzaltenango, local authorities are in a favourable moment to make evident to the public, the need to set up a discussion process and call all involved stakeholders to participate in a discussion board aiming to validate or reformulate the results of the present work. After the stakeholders perform a social recognition and validation of the mapping products by identifying vulnerable areas and social facilities, the municipality will count with a scenario of the flood risk profile that corresponds accurately to reality. Furthermore important is that mapping products and analysis correspond to a consensus among all the involved sector of society. This should be a great advantage regarding the debate on how to address the problem and the measures that have to be implemented in the short, middle and long term. As said before, the measures raised in the present work should be used as a fist input to be discussed, modified and adapted to the conditions of the debate and agreements on how to deal with flooding. At the time of developing such an inclusive process, a transition towards collaborative planning and proactive governance regarding flood risk management starts to take place. The outcomes presented in this research are a clear example of the potential role of GIS application and products within municipal decision making, policy design and spatial planning for helping minimise conflict and arrive at decisions that are acceptable to the majority of stakeholders through consensus building approaches based on awareness of the spatial implications of a decision problem (Nyerges, Couclelis, & McMaster, 2011).

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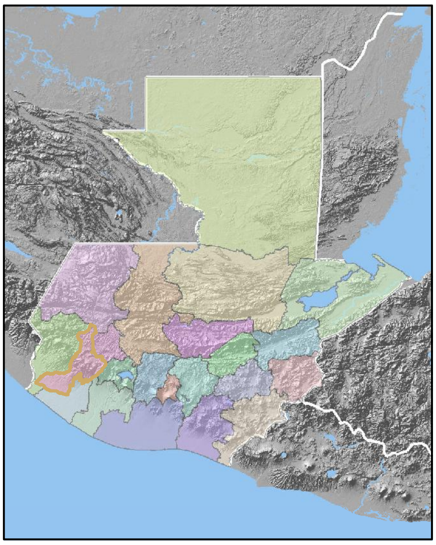
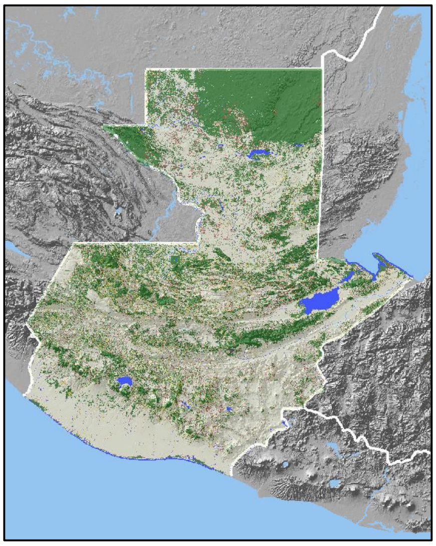
9 APPENDICES, COMPILATION OF MAPS

Topographic relief, Republic of Guatemala

1 centimeter = 18,782 meters





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Presented by:
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Geographic Coordinate System: WGS84
Projected Coordinate System: GTM

Based on layers from the National Geographic Information System of Guatemala
Guatemala National Institute of Geography

1:1,878,186

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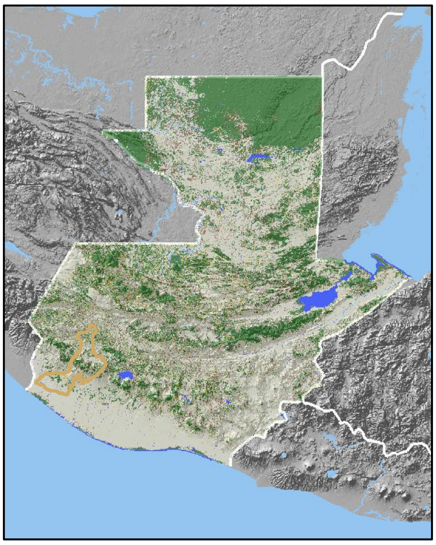
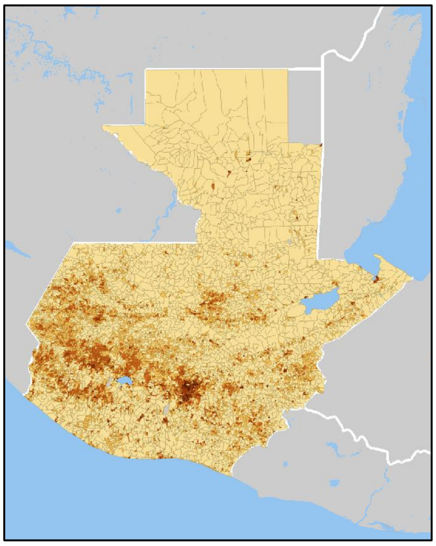
Kilometers

Political and administrative division, Republic of Guatemala





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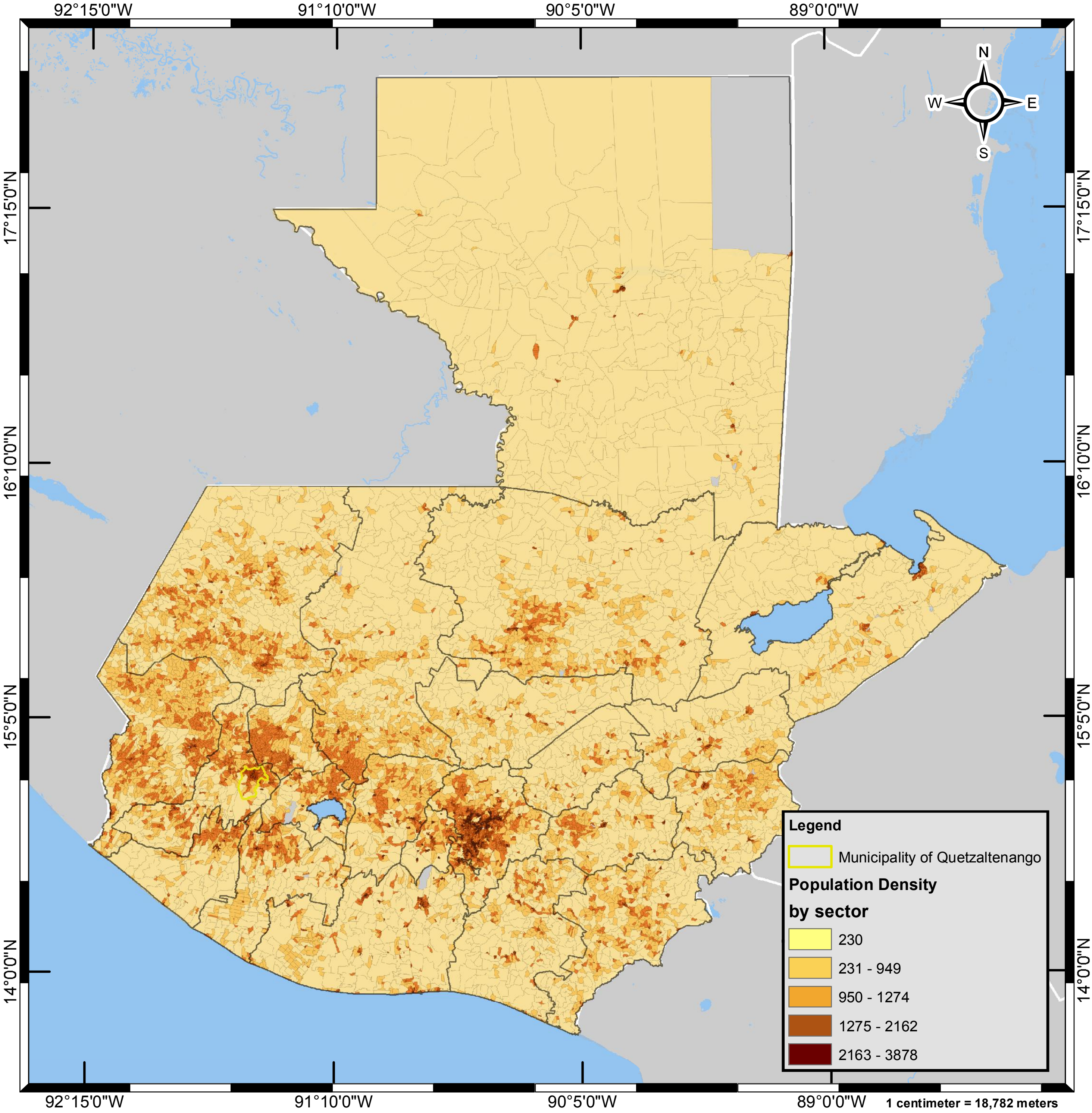
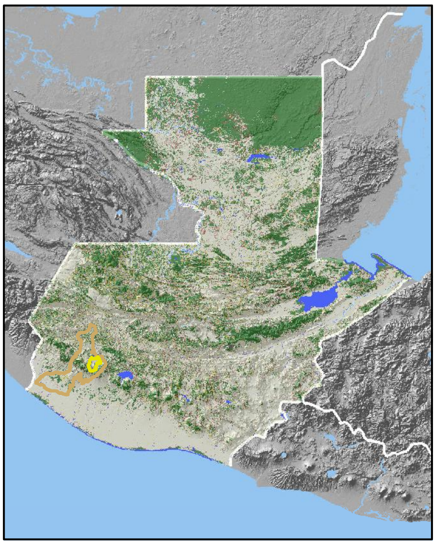
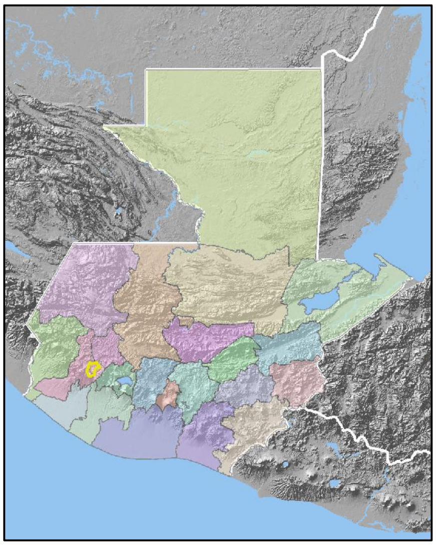
0 15 30 60 90 120
Kilometers

Population density by region, Republic of Guatemala







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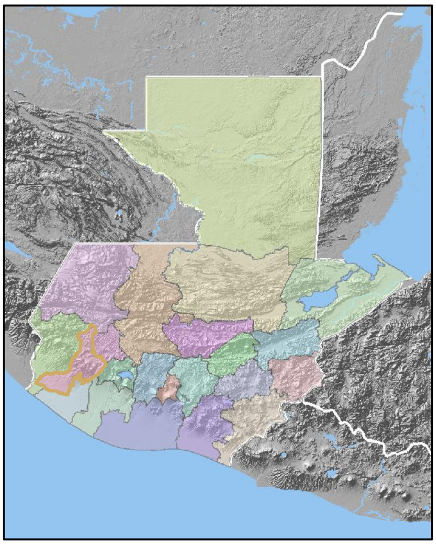
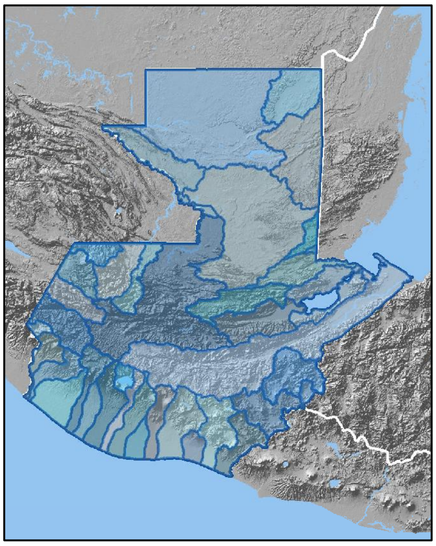
0 15 30 60 90 120
Kilometers

Land cover mosaic 2005-2010, Republic of Guatemala

1 centimeter = 18,782 meters





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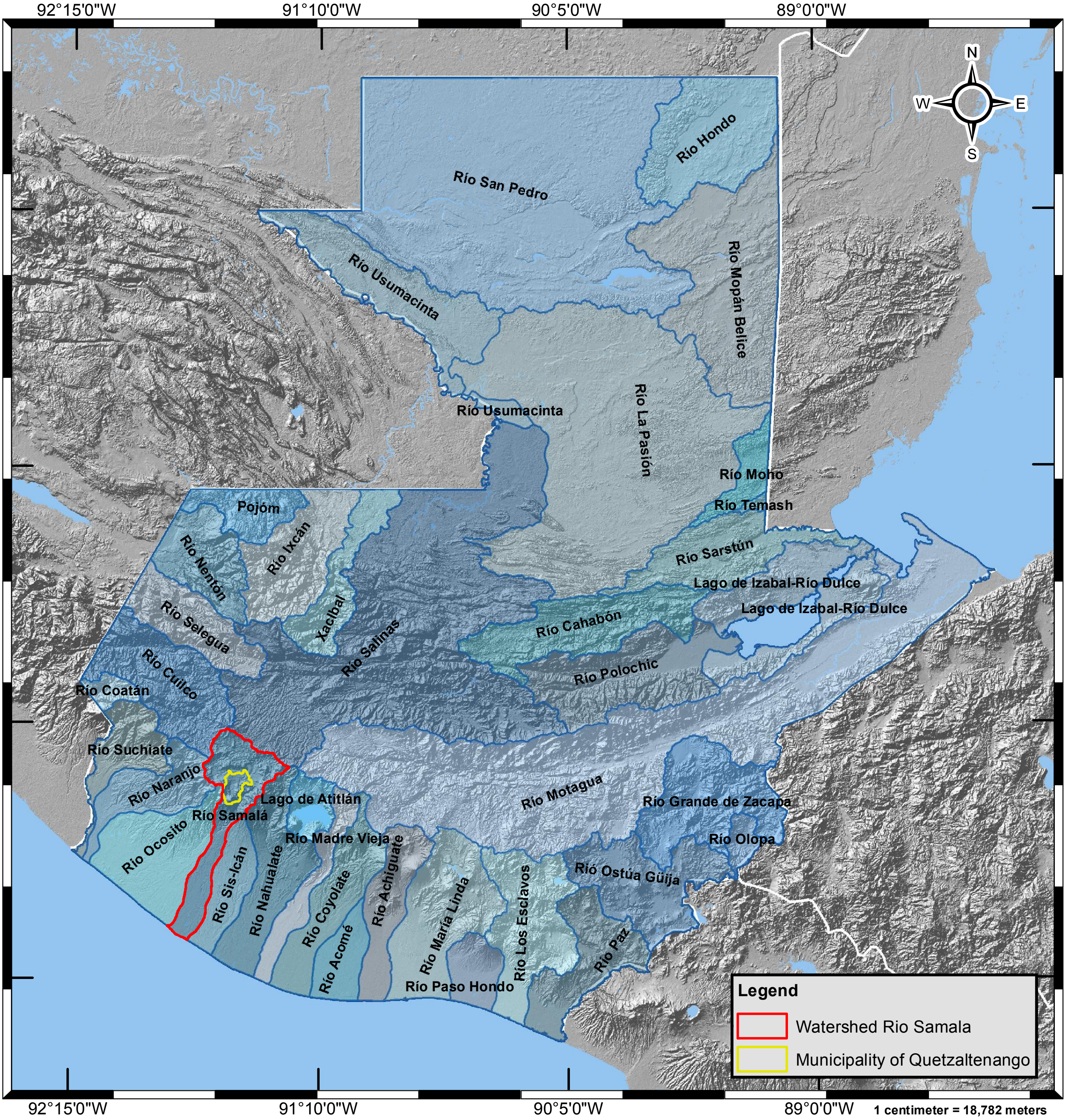
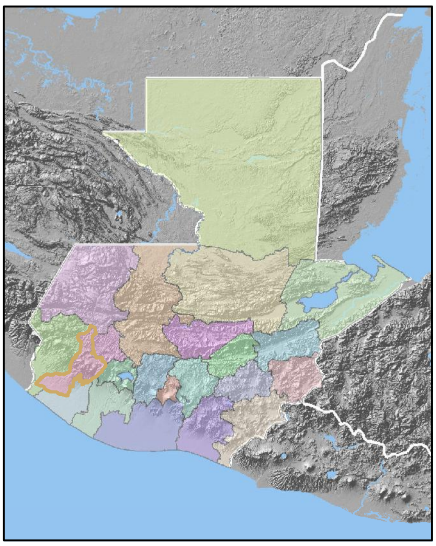
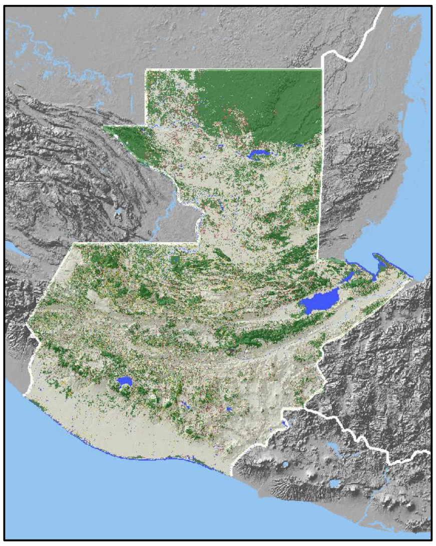
0 15 30 60 90 120
Kilometers

Hydrographic watersheds, Republic of Guatemala







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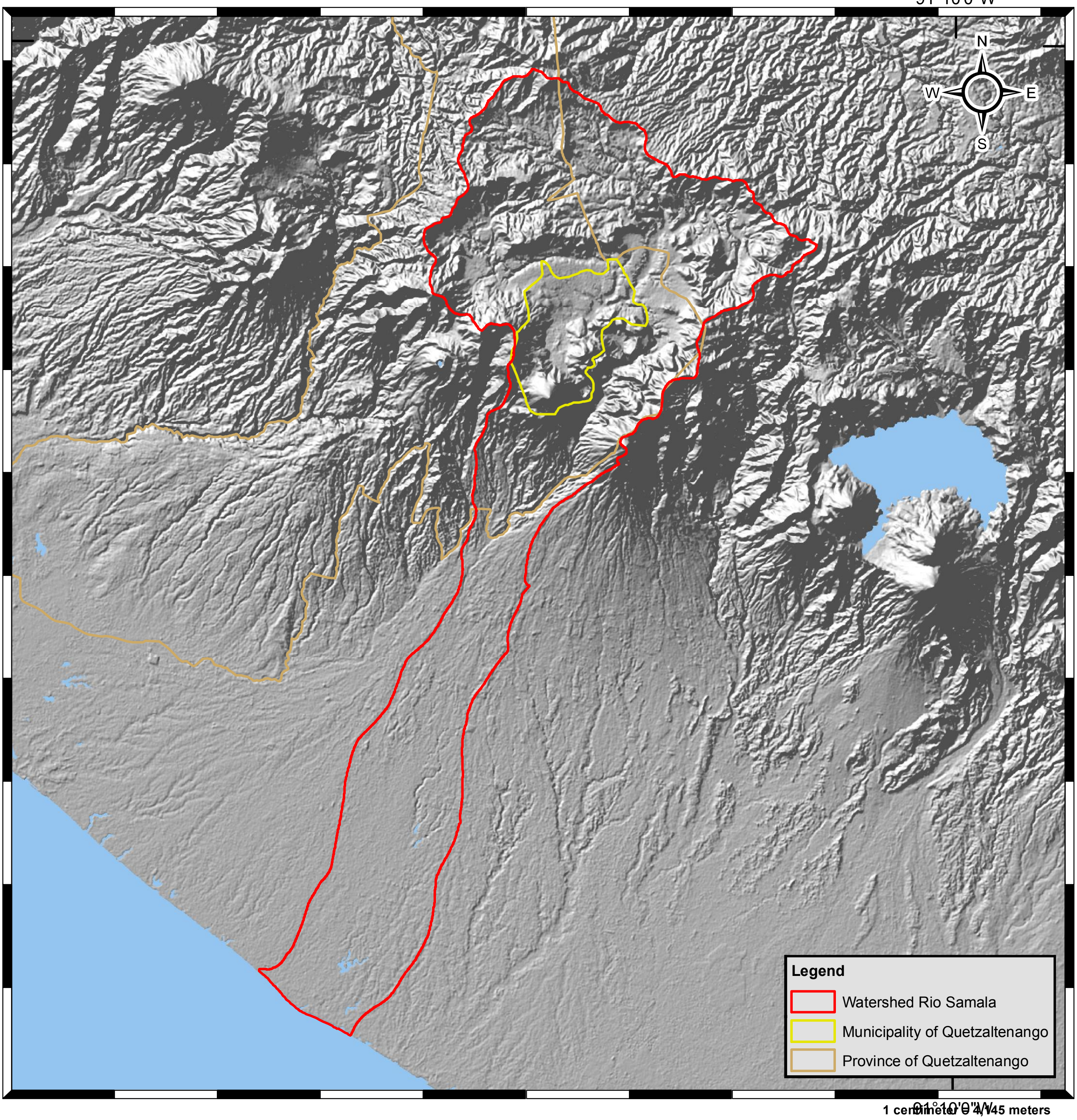
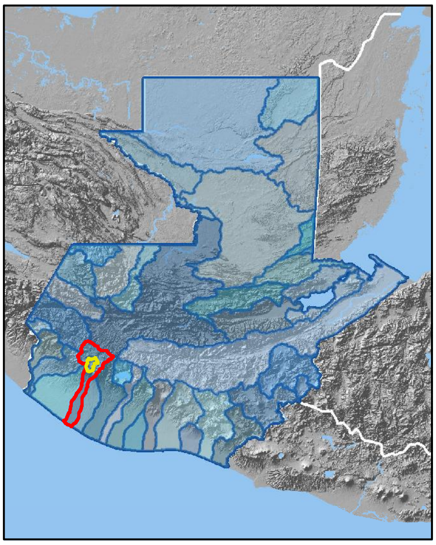
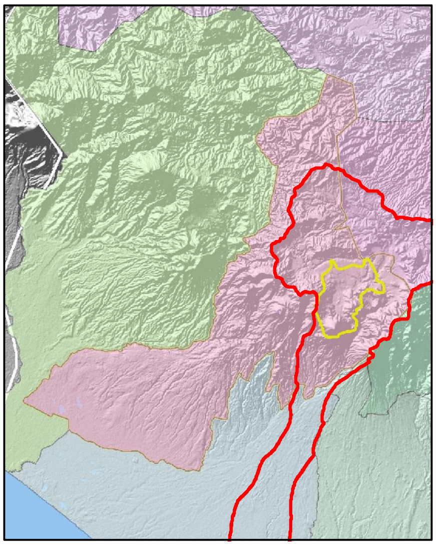
1:1,878,186

0 15 30 60 90 120
Kilometers

Samala River hydrographic watershed, western highlands, Quetzaltenango, Guatemala







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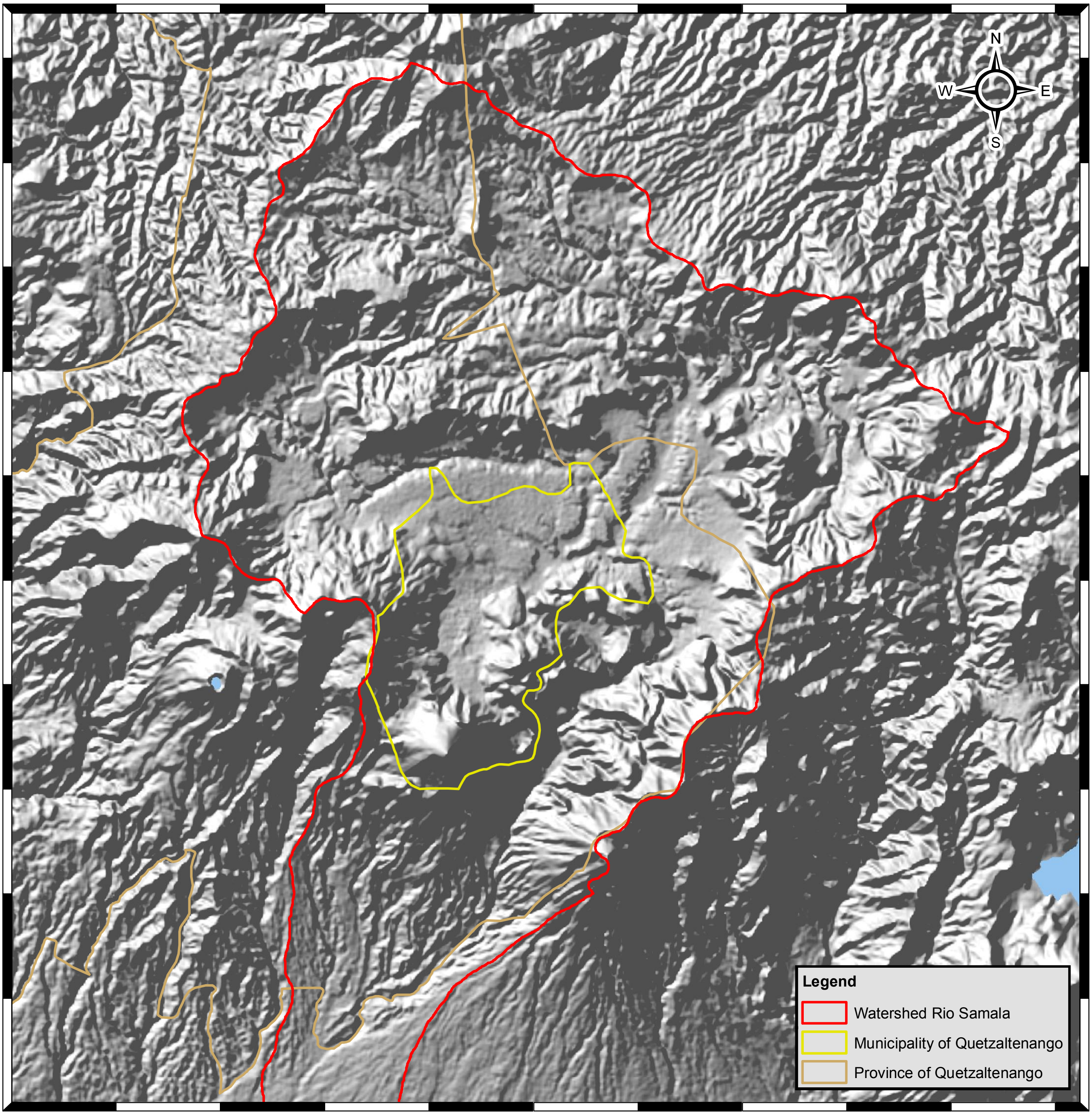
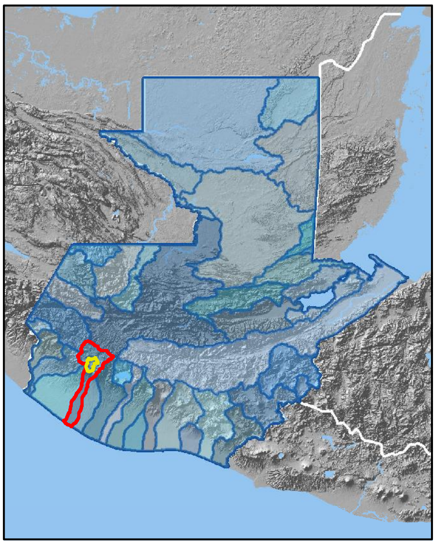
1:414,500

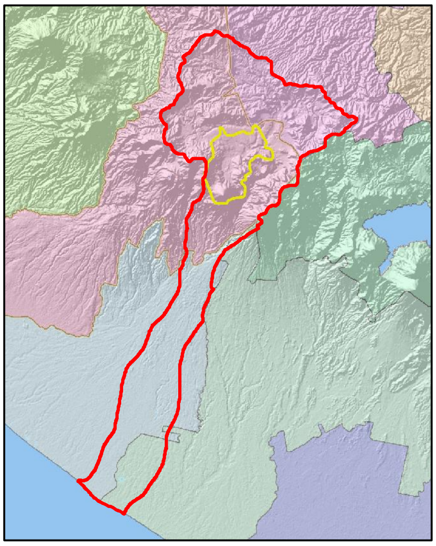
0 3.25 6.5 13 19.5 26
Kilometers

Samala River hydrographic watershed (upper basin area), Quetzaltenango, Guatemala



1 centimeter = 2,000 meters





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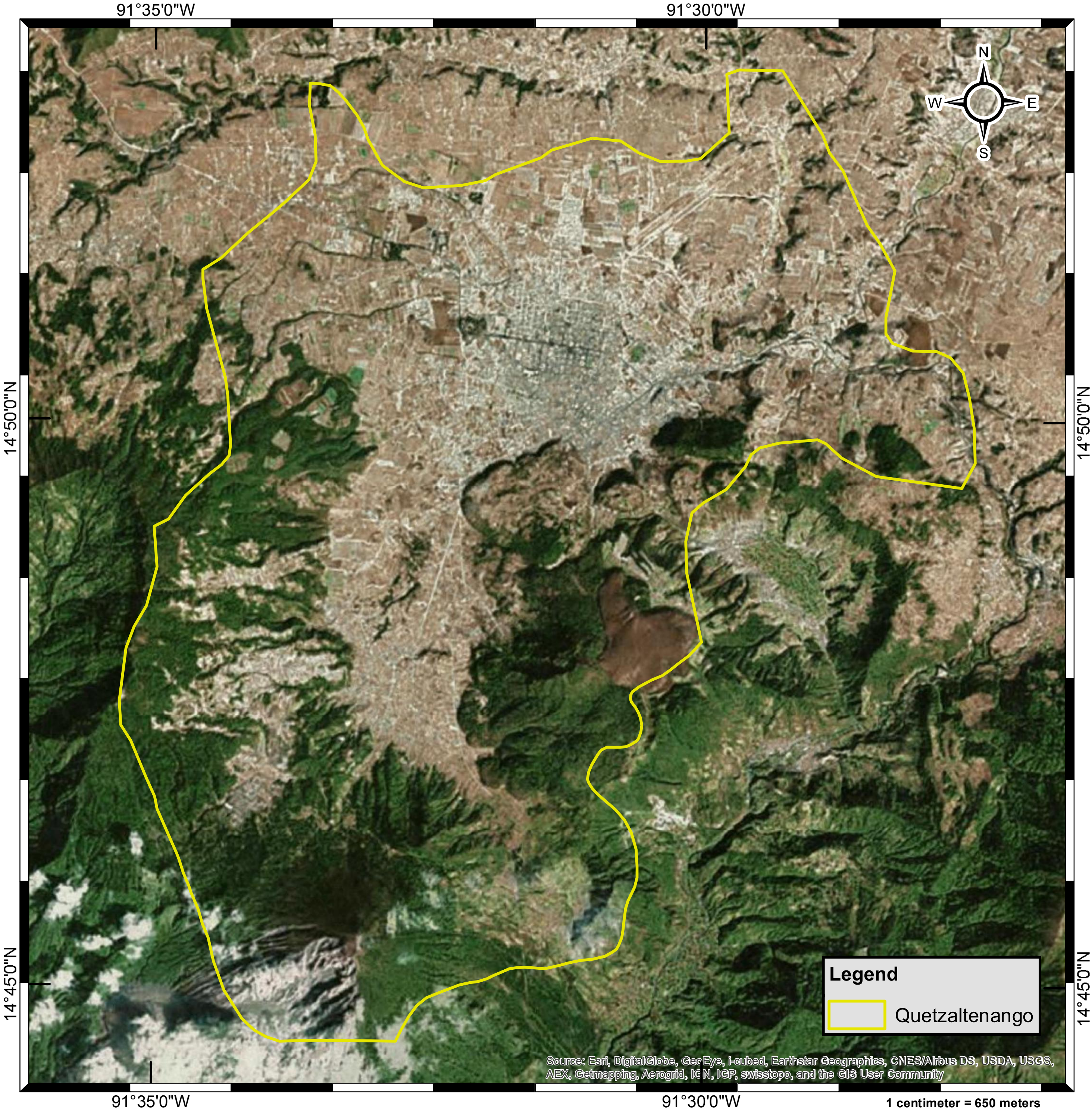
1:200,000

0 1.5 3 6 9 12
Kilometers

Municipality of Quetzaltenango, Western Highlands, Guatemala



1 centimeter = 650 meters

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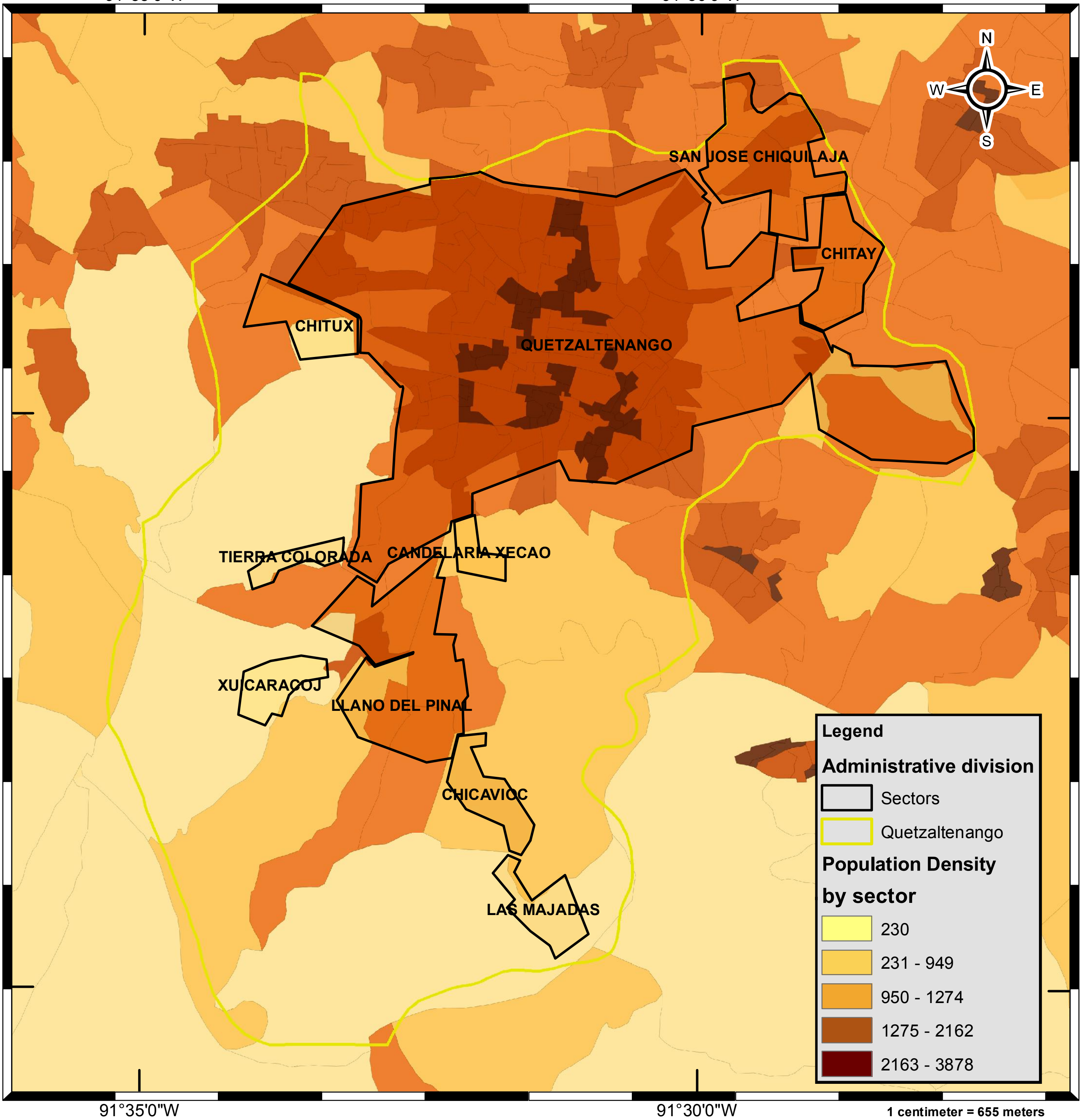
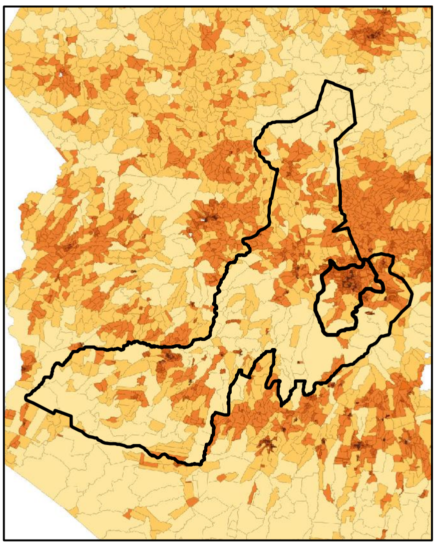
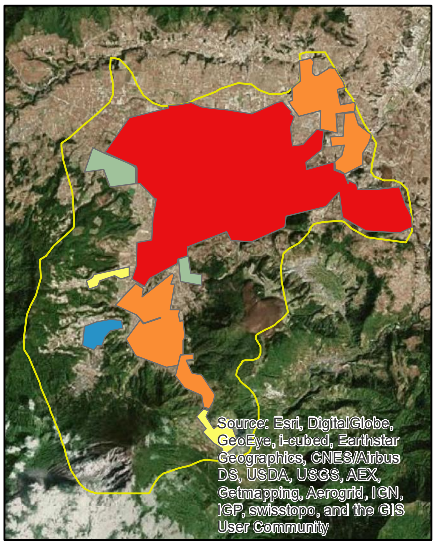
1:65,000

0 0.5 1 2 3 4
Kilometers

Population density by sector, Quetzaltenango, Guatemala







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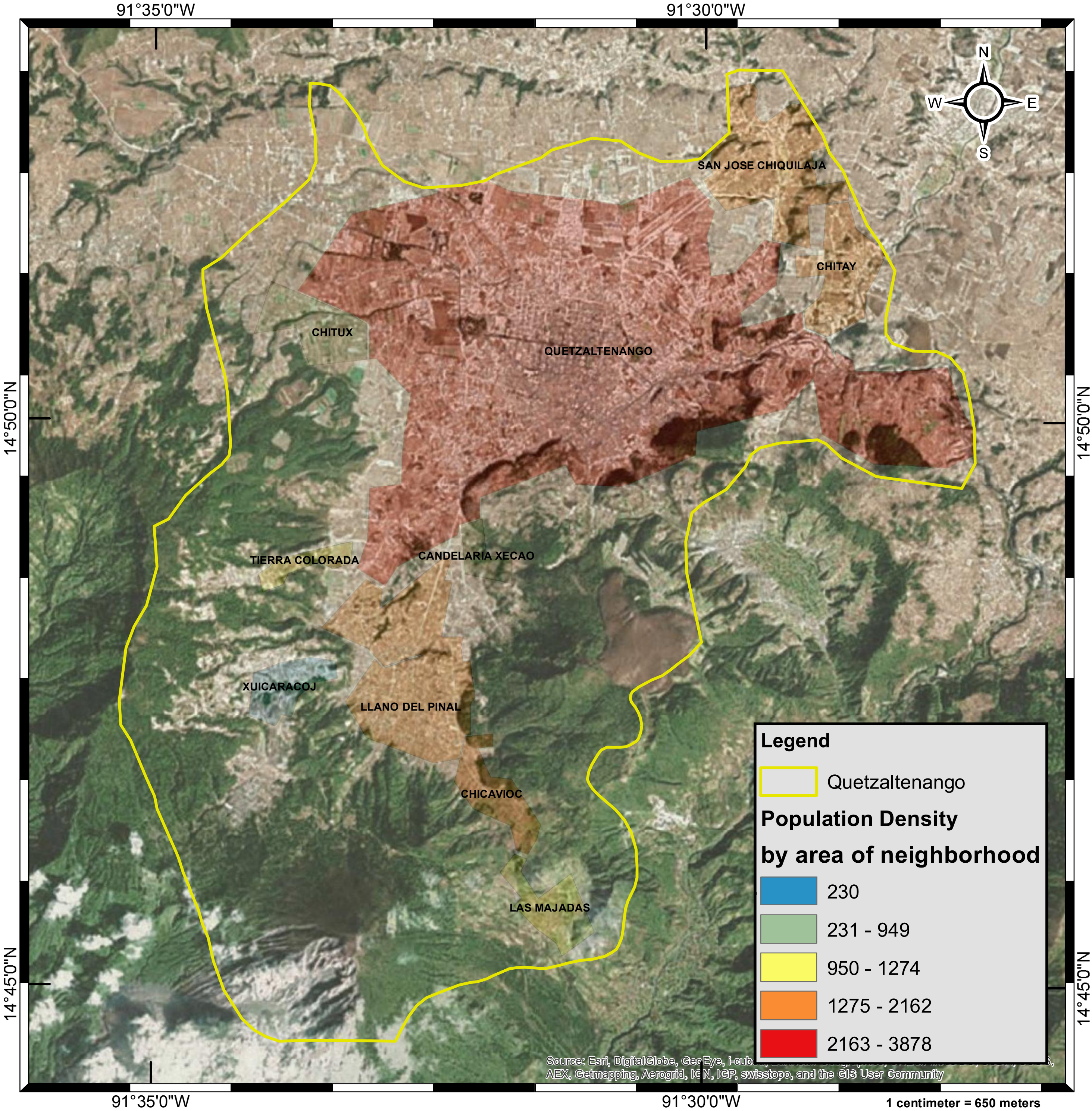
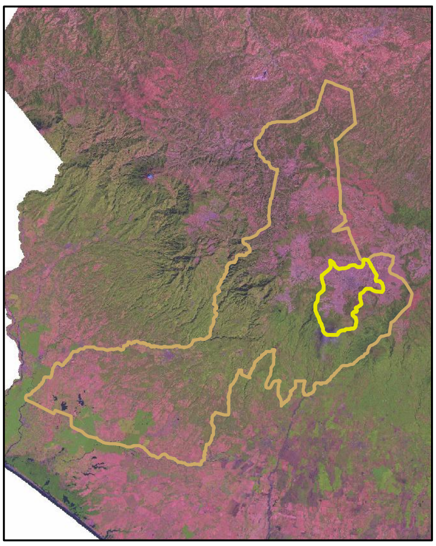
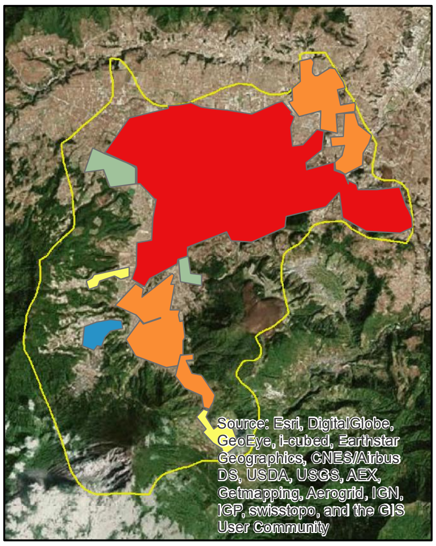
1:65,500

0 0.5 1 2 3 4
Kilometers

Population density by neighborhood, Quetzaltenango, Guatemala







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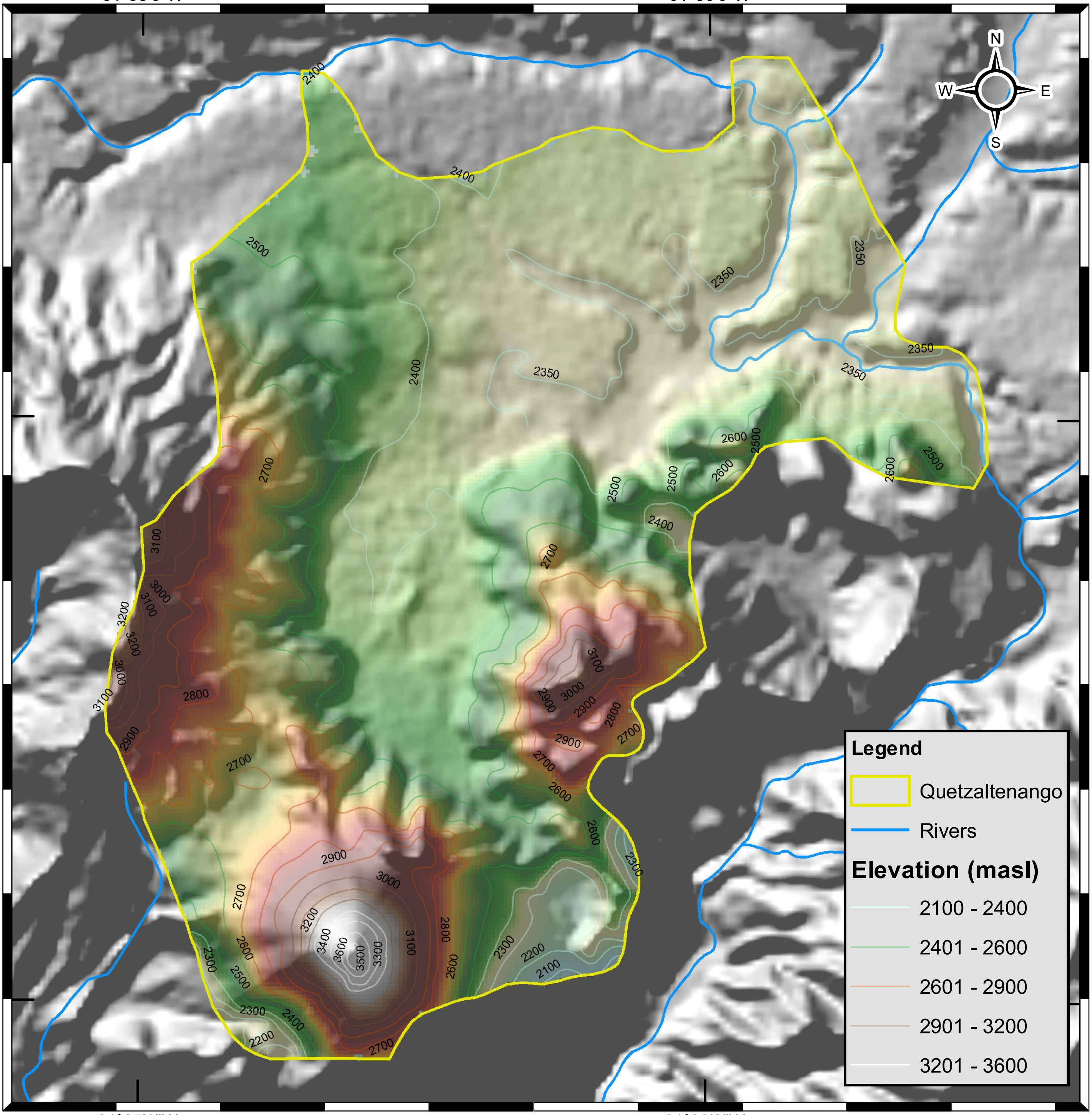
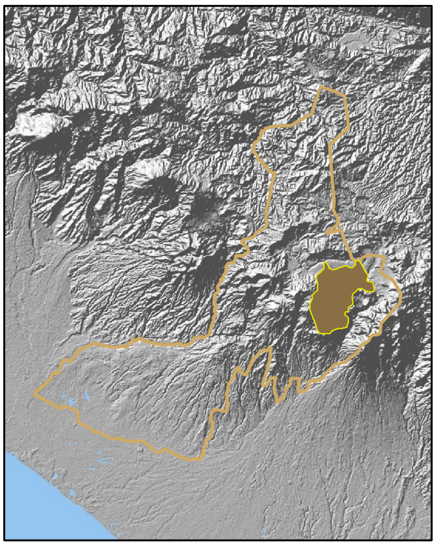
1:65,000

0 0.5 1 2 3 4
Kilometers

Topographic relief, Municipality of Quetzaltenango, Guatemala



1 centimeter = 650 meters



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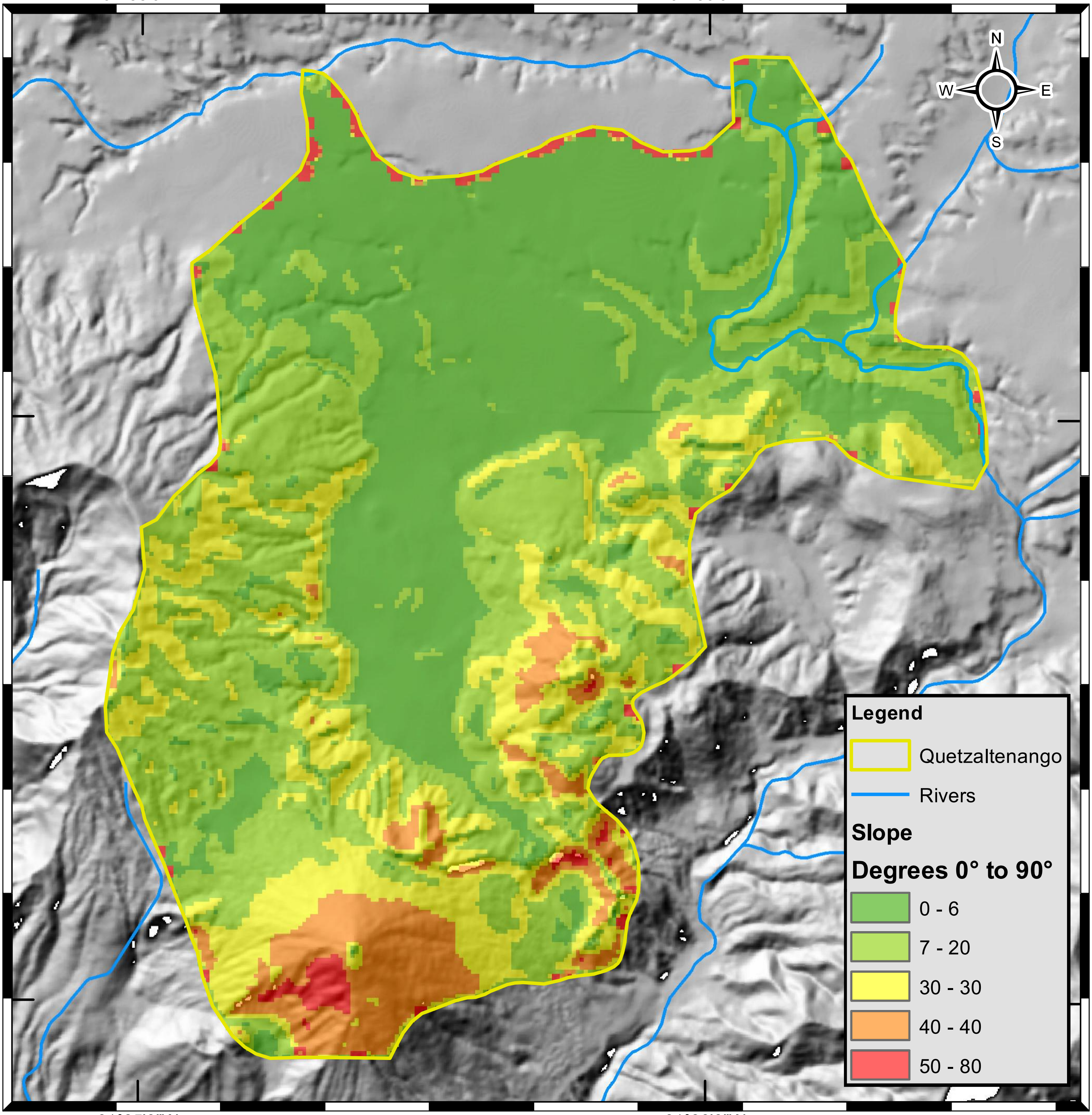
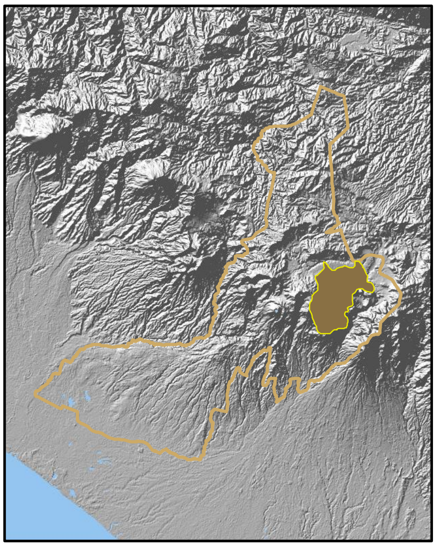
1:65,000

0 0.5 1 2 3 4
Kilometers

Natural slope, Municipality of Quetzaltenango, Guatemala



1 centimeter = 650 meters



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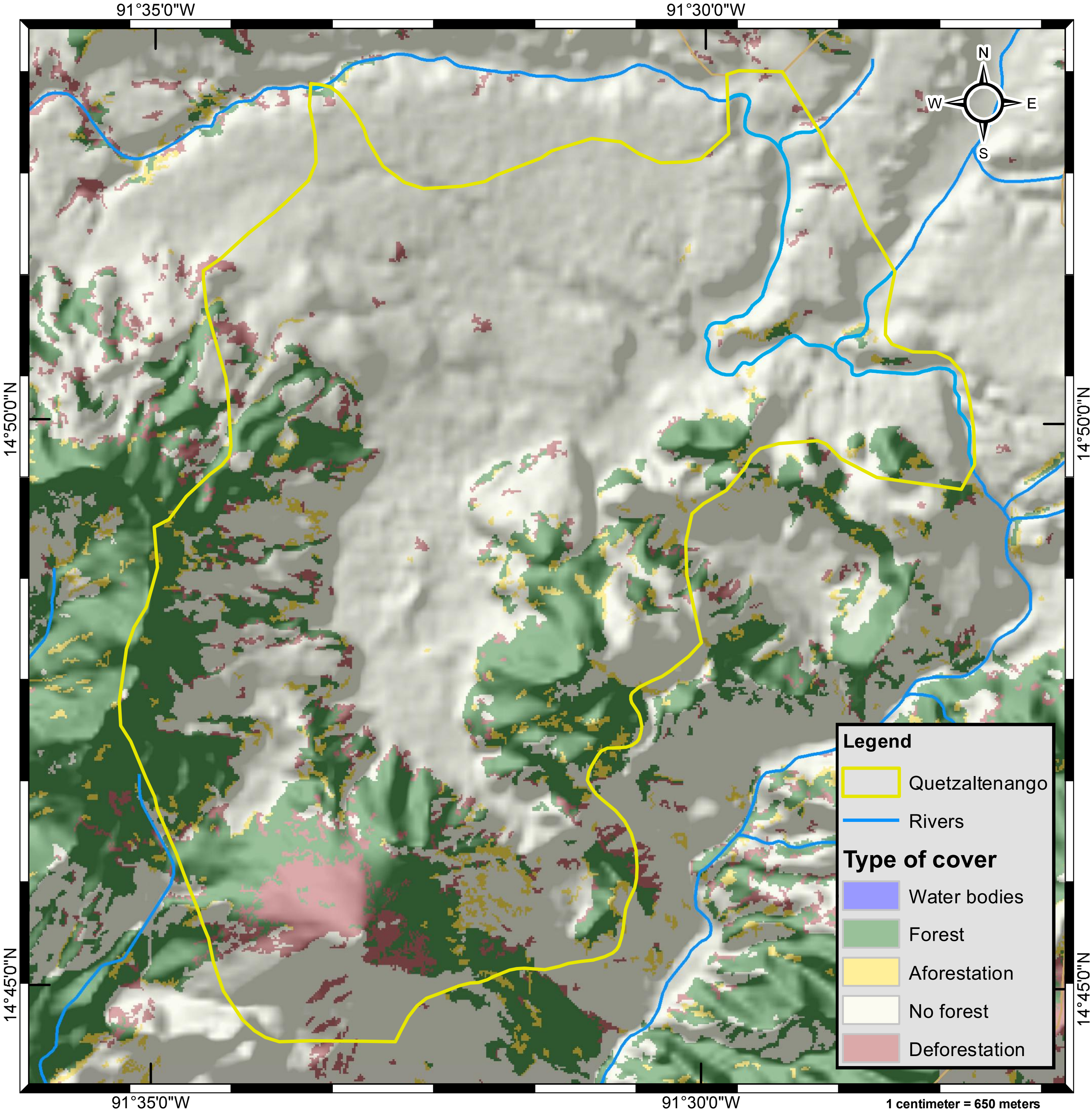
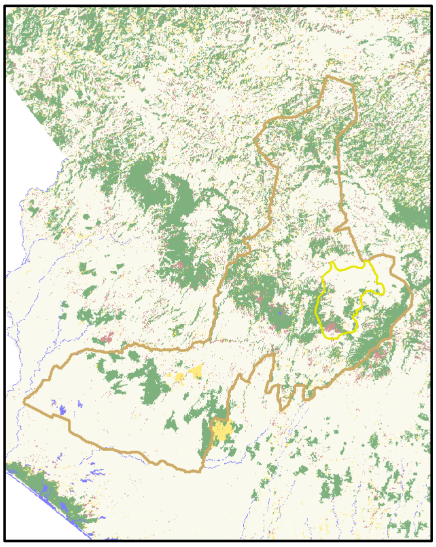
1:65,000

0 0.5 1 2 3 4
Kilometers

Land Cover mosaic 2005-2010, Quetzaltenango, Guatemala





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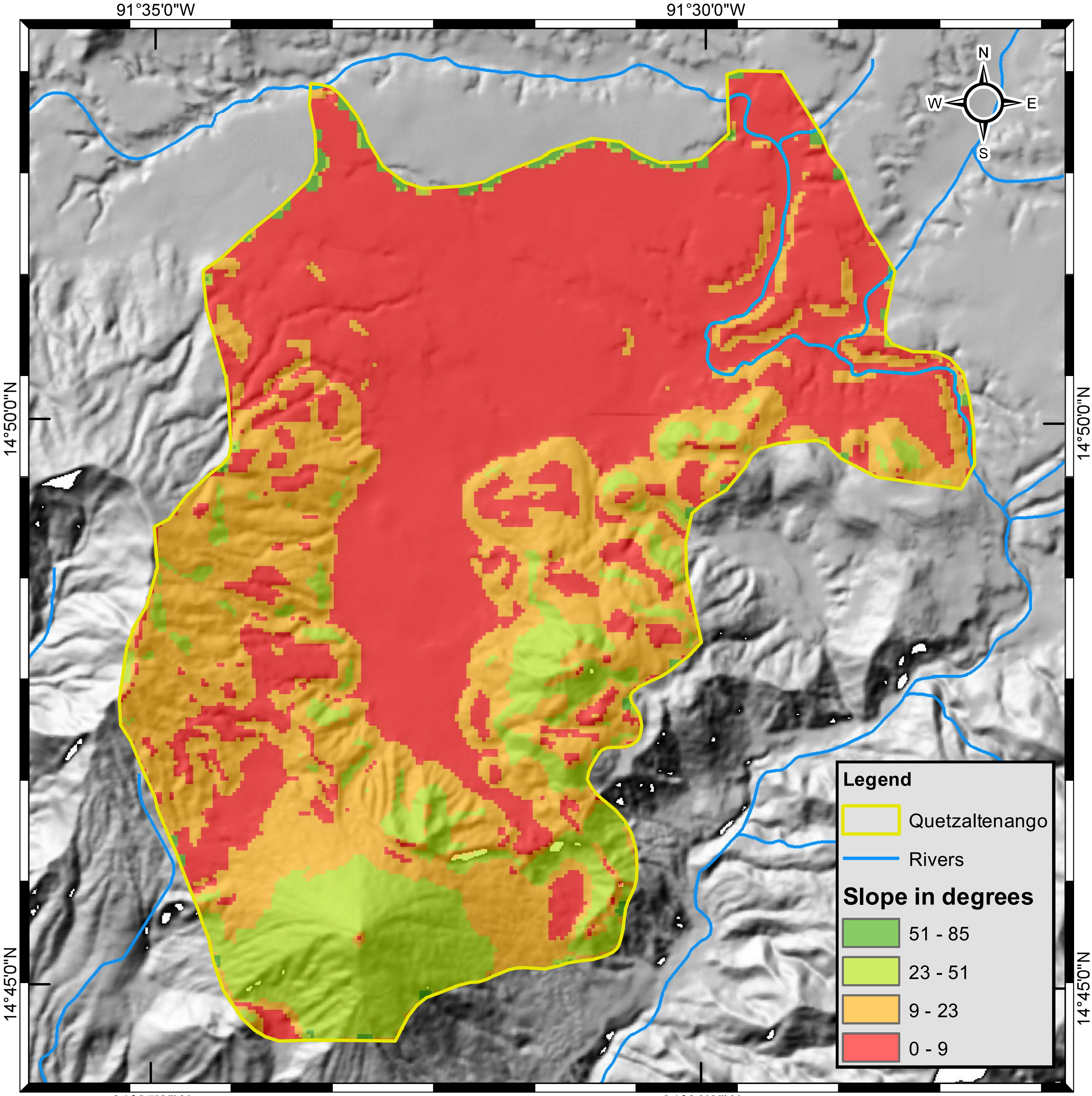
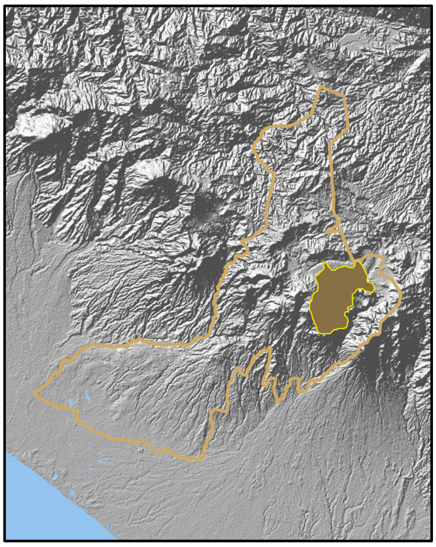
1:65,000

0 0.5 1 2 3 4
Kilometers

Reclassified Slope, Municipality of Quetzaltenango, Guatemala





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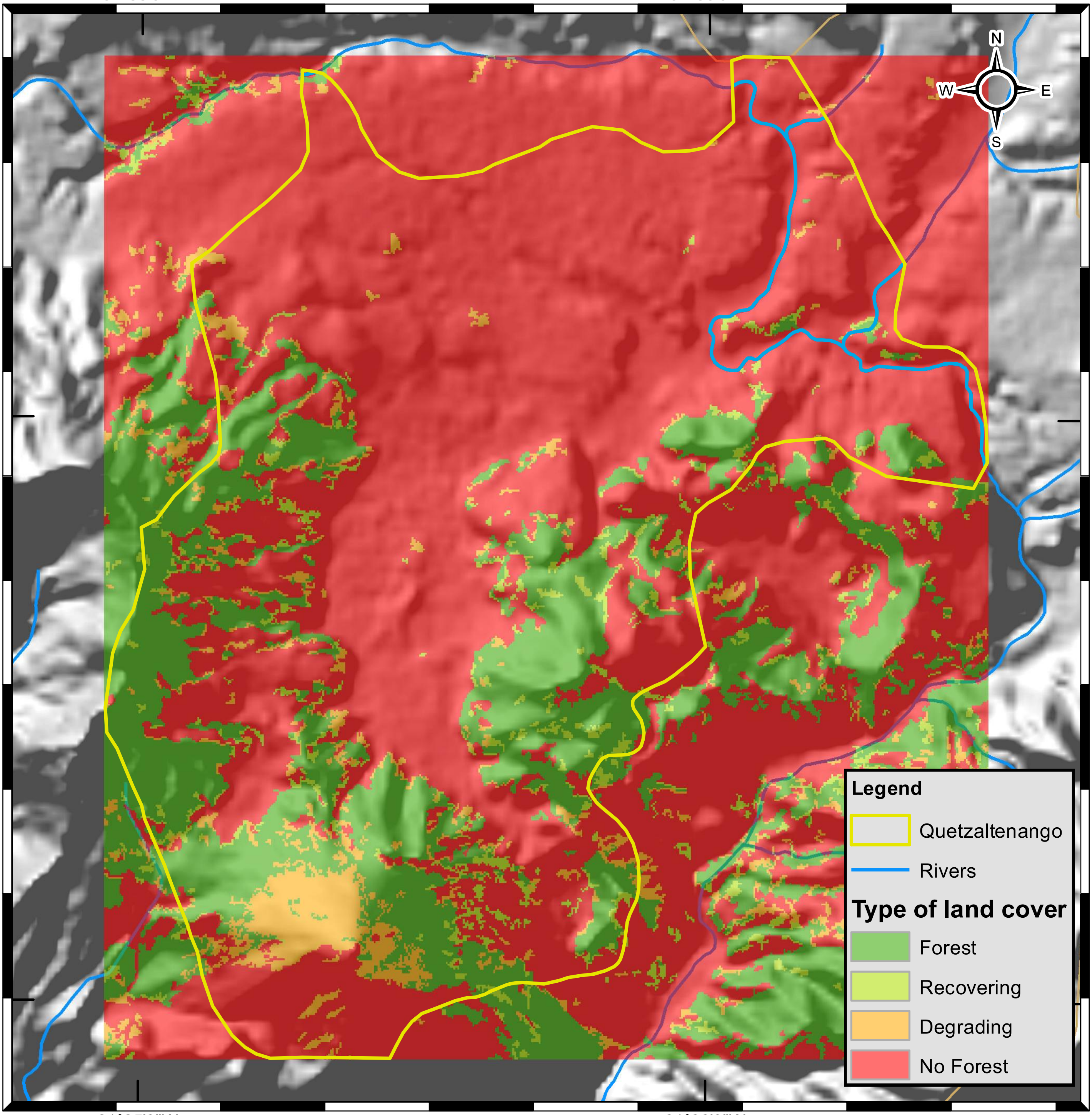
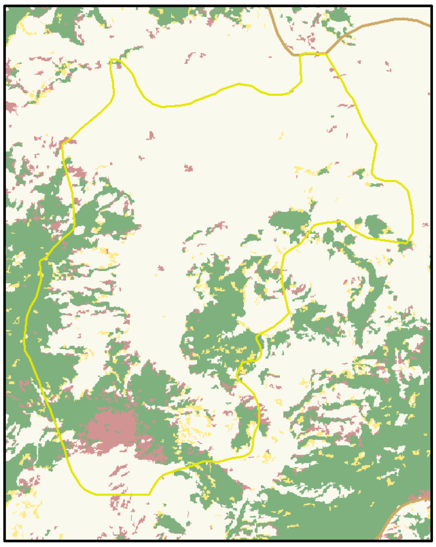
1:65,000

0 0.5 1 2 3 4
Kilometers

Reclassified Land Cover, Quetzaltenango, Guatemala



1 centimeter = 650 meters



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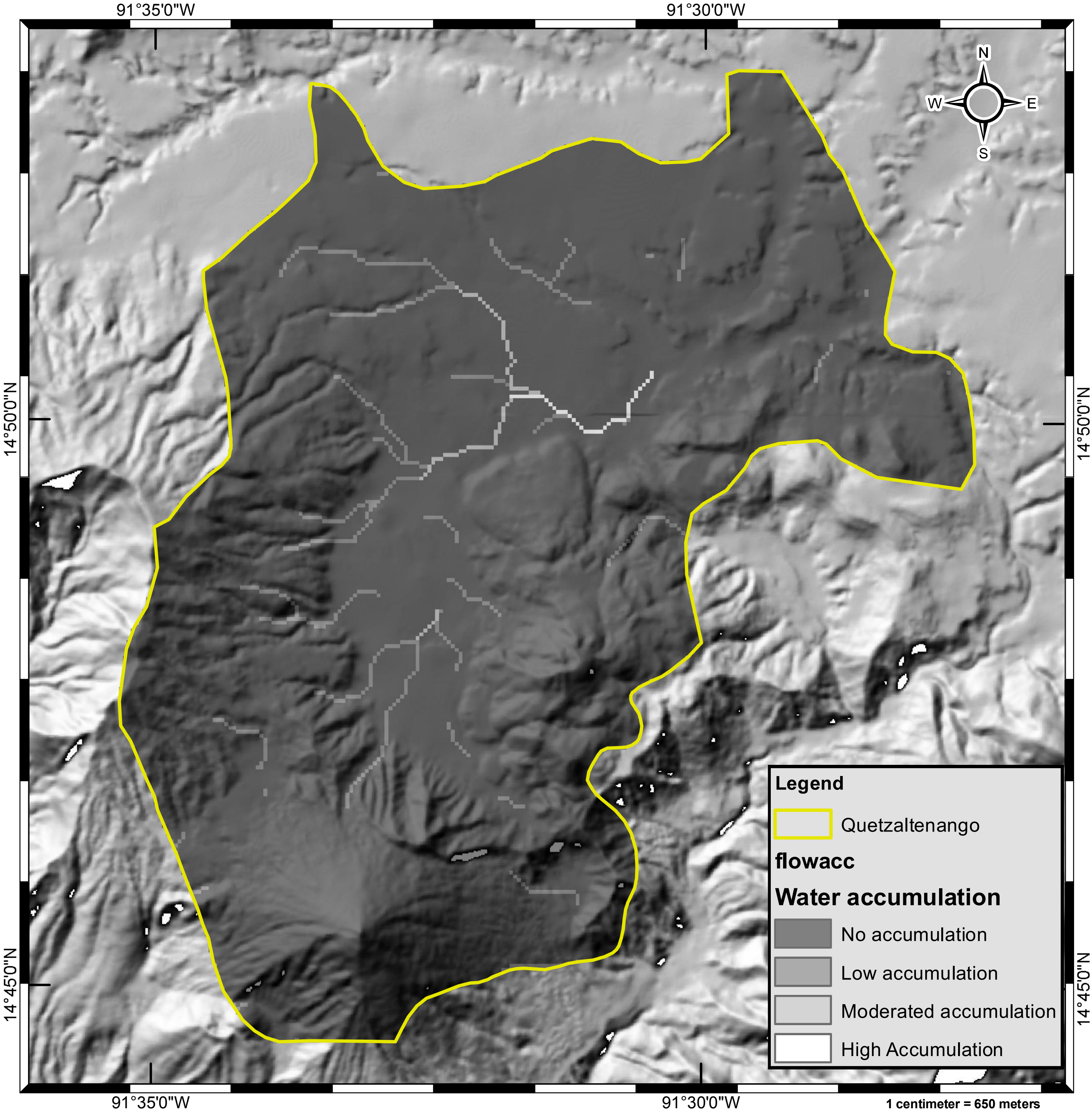
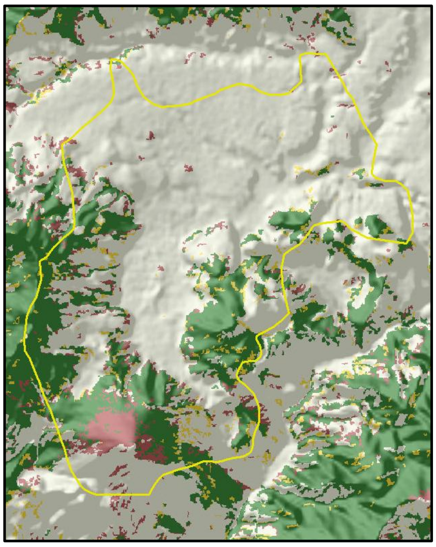
1:65,000

0 0.5 1 2 3 4
Kilometers

Water flow accumulation, Quetzaltenango, Guatemala





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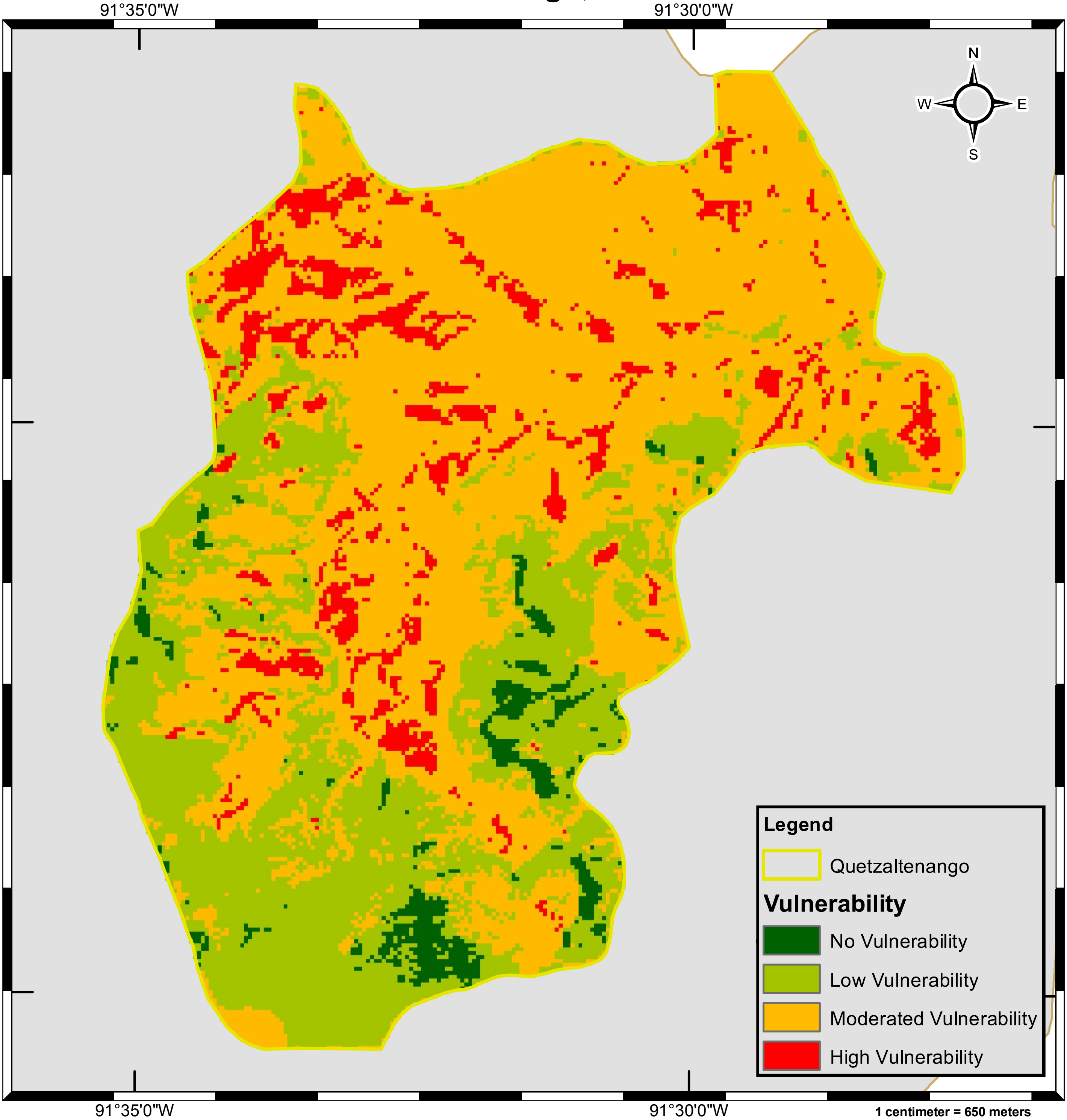
1:65,000

0 0.5 1 2 3 4
Kilometers

Weighted overlay analysis outcome, vulnerable areas to flooding Quetzaltenango, Guatemala



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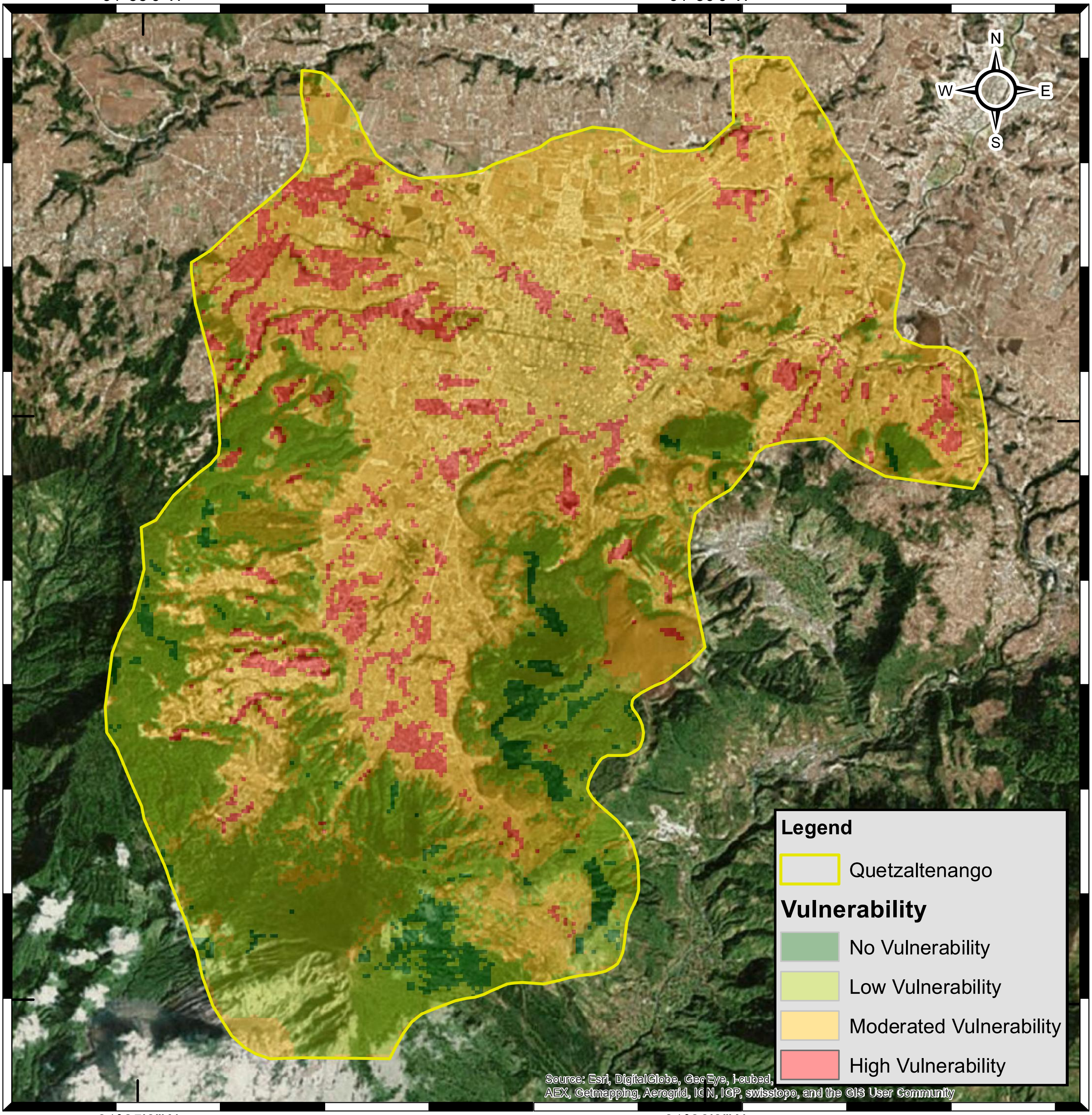
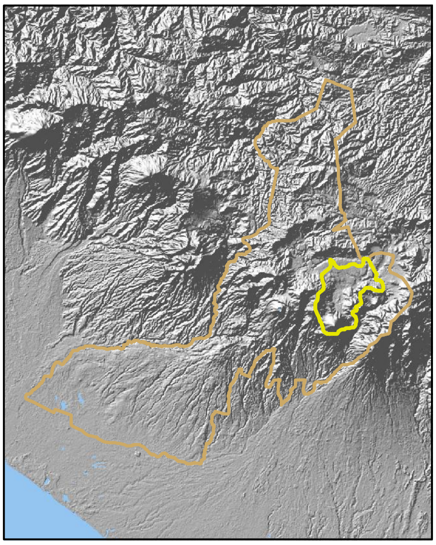
1:65,000

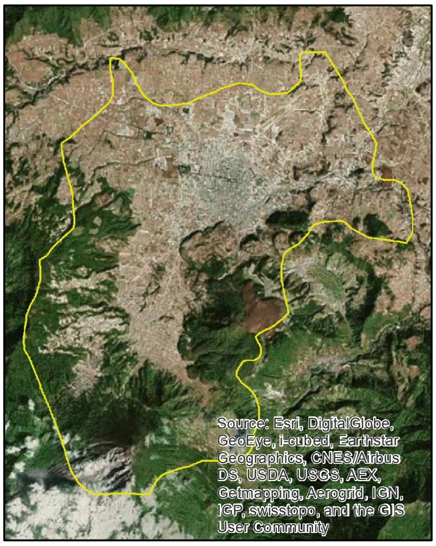
0 0.5 1 2 3 4
Kilometers

Vulnerability Map Quetzaltenango City, Guatemala



1 centimeter = 650 meters





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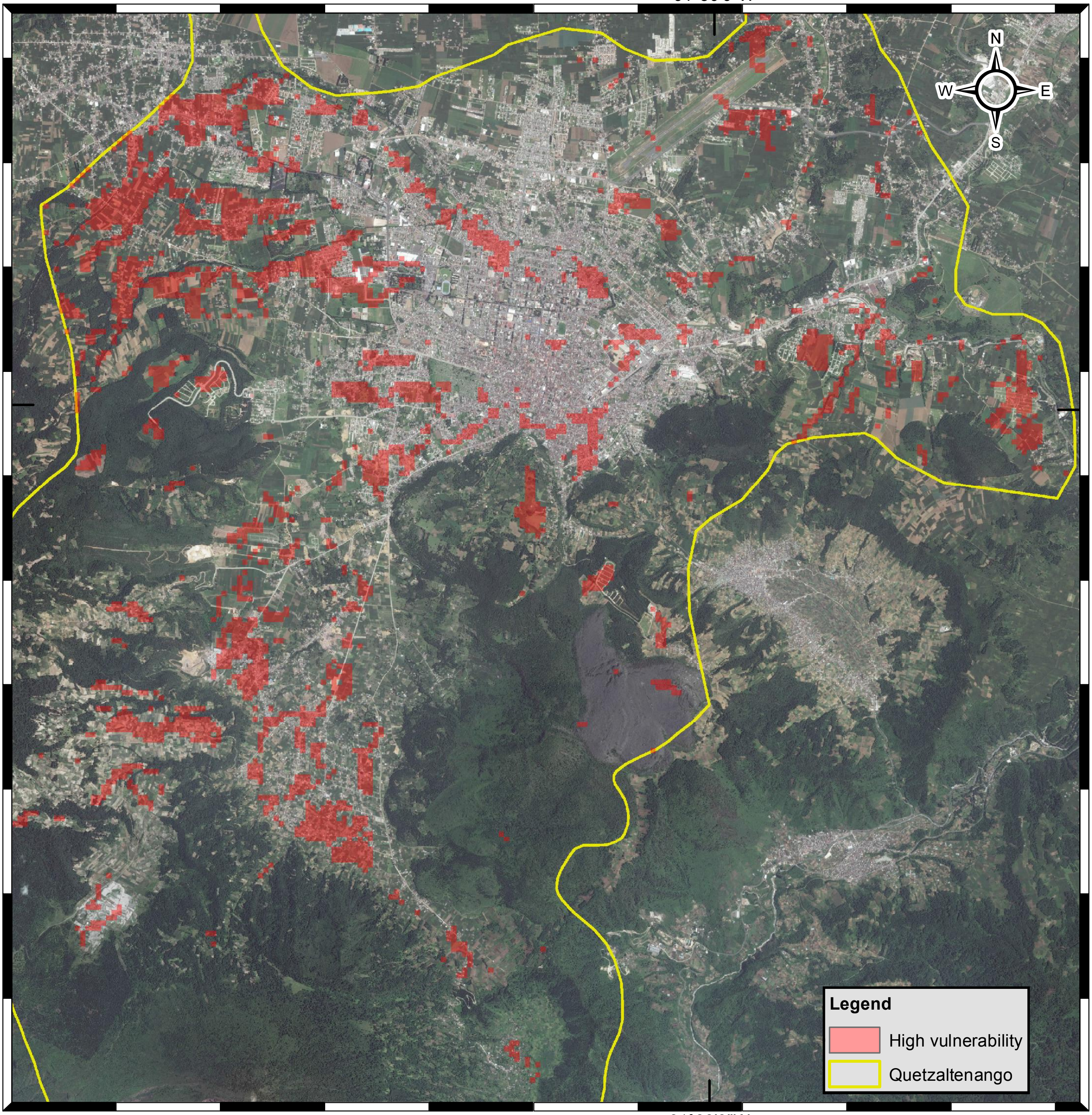
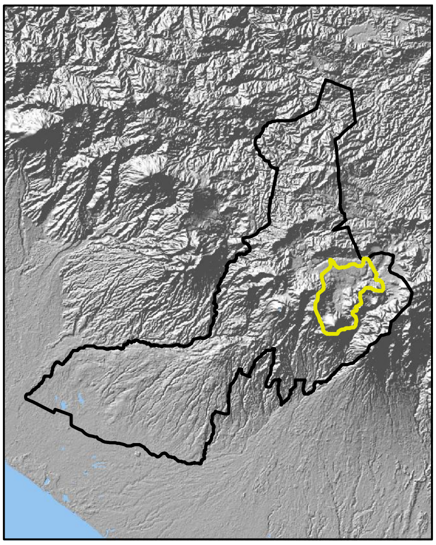
1:65,000

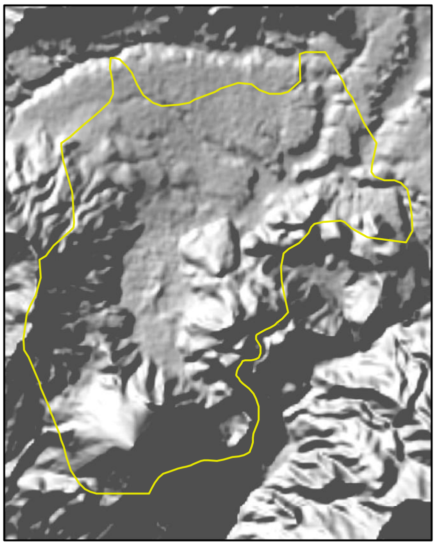
0 0.5 1 2 3 4
Kilometers

Areas with high vulnerability to flooding, Quetzaltenango, Guatemala



1 centimeter = 500 meters





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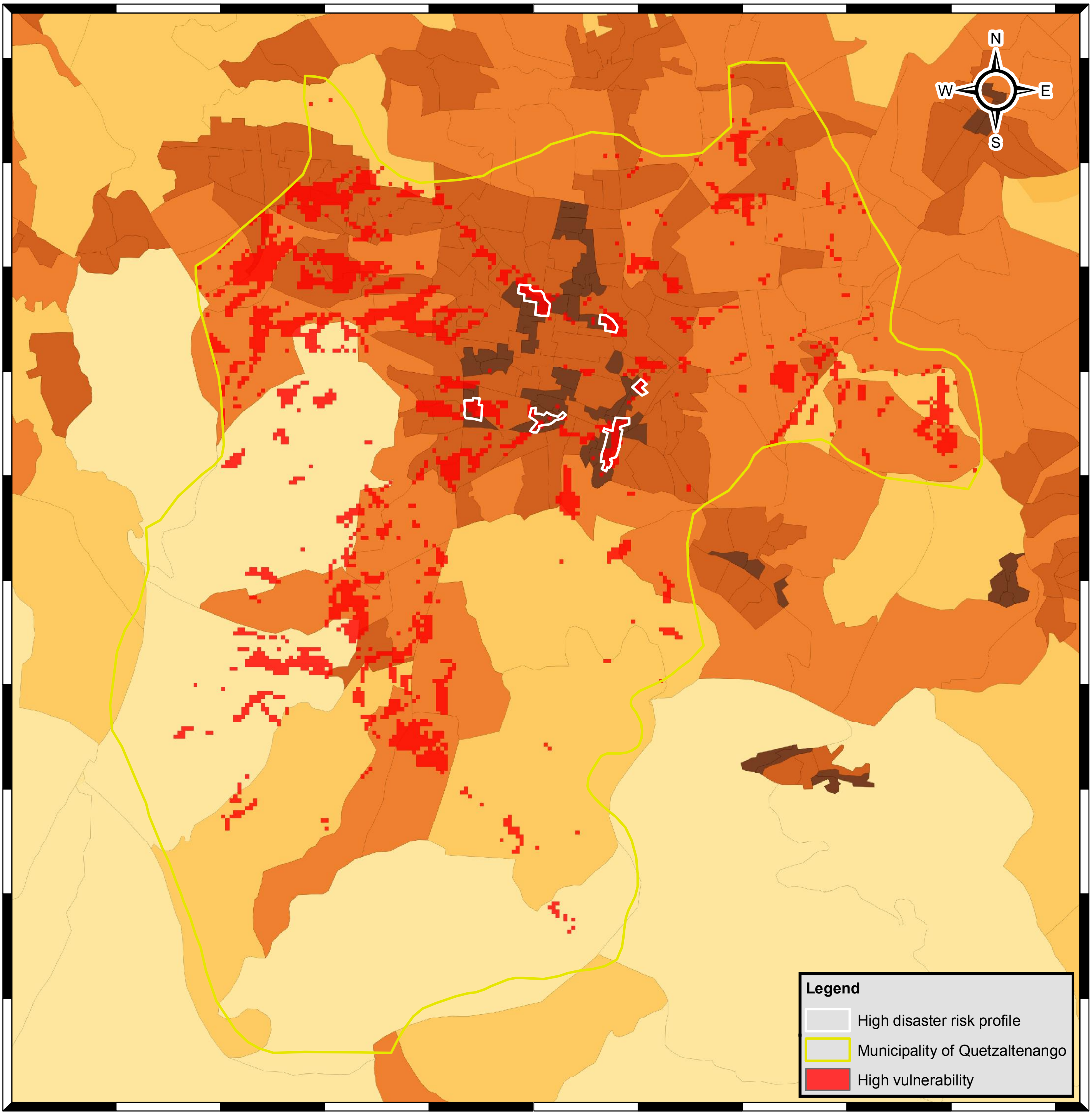
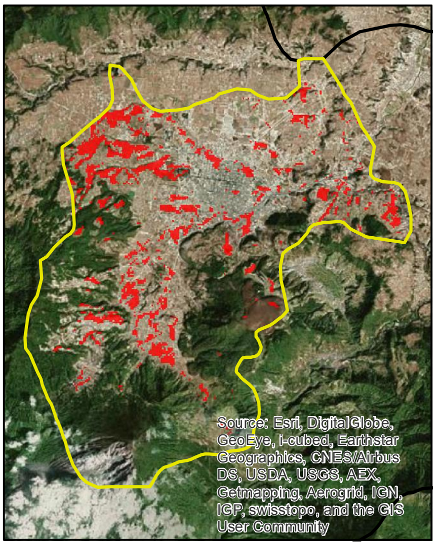
1:50,000

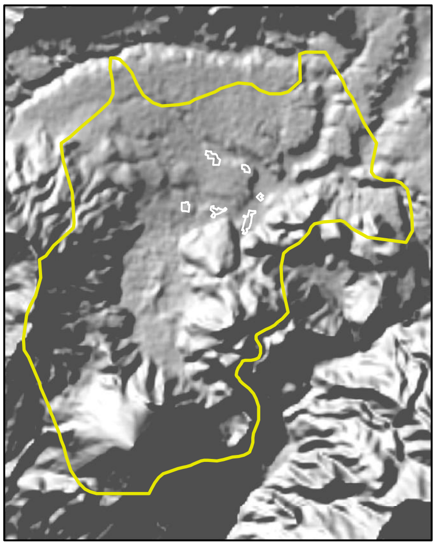
0 0.4 0.8 1.6 2.4 3.2
Kilometers

Areas with highest risk profile to flooding, Quetzaltenango, Guatemala



1 centimeter = 659 meters





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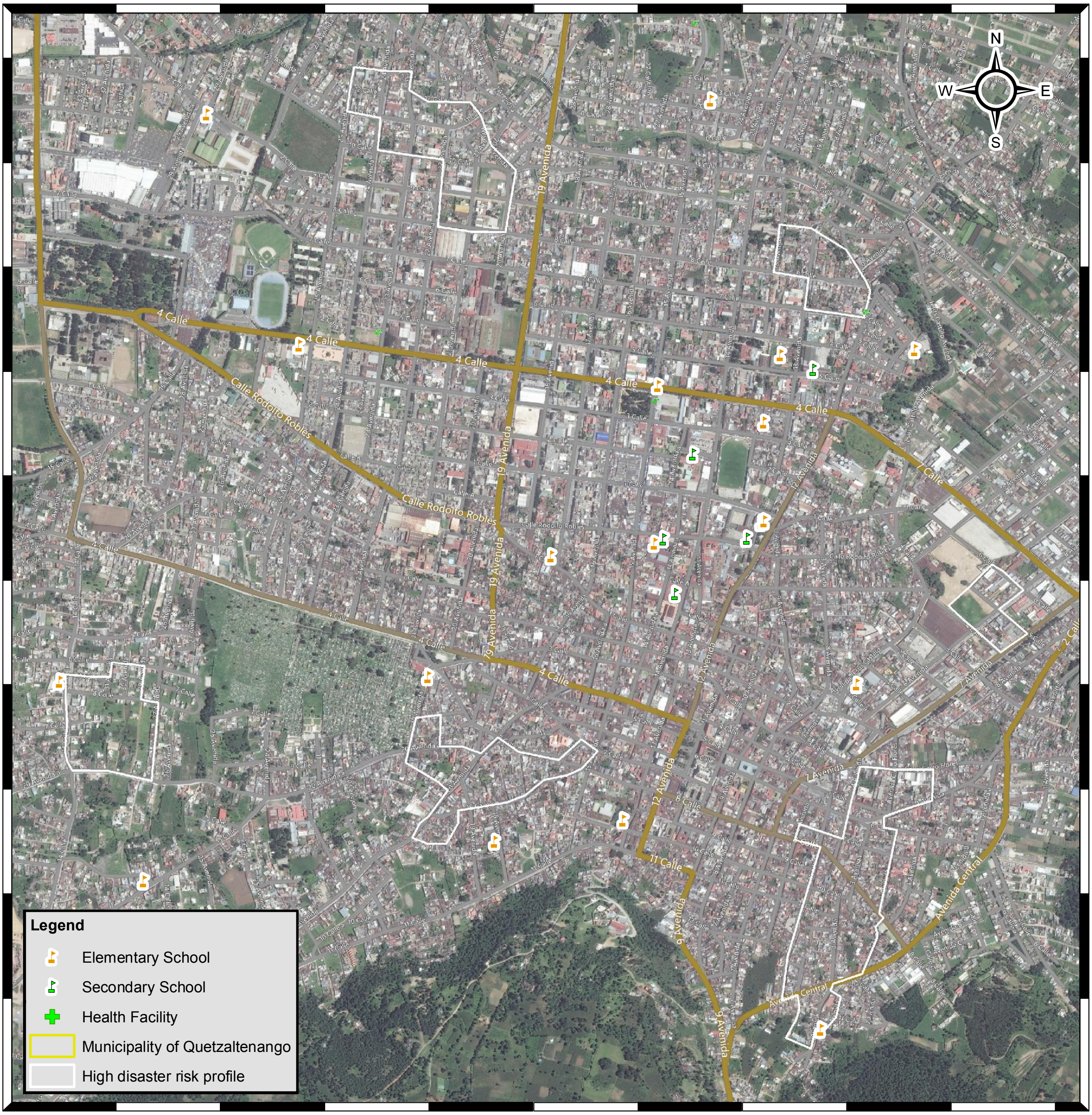
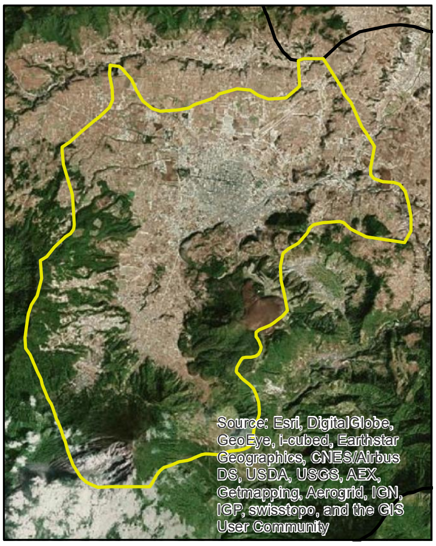
1:65,875

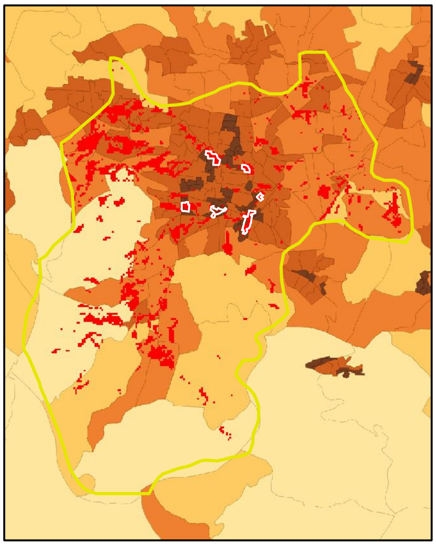
0 0.5 1 2 3 4
Kilometers

Flood impact on social infrastructure within high disaster risk areas, Quetzaltenango, Guatemala



1 centimeter = 125 meters





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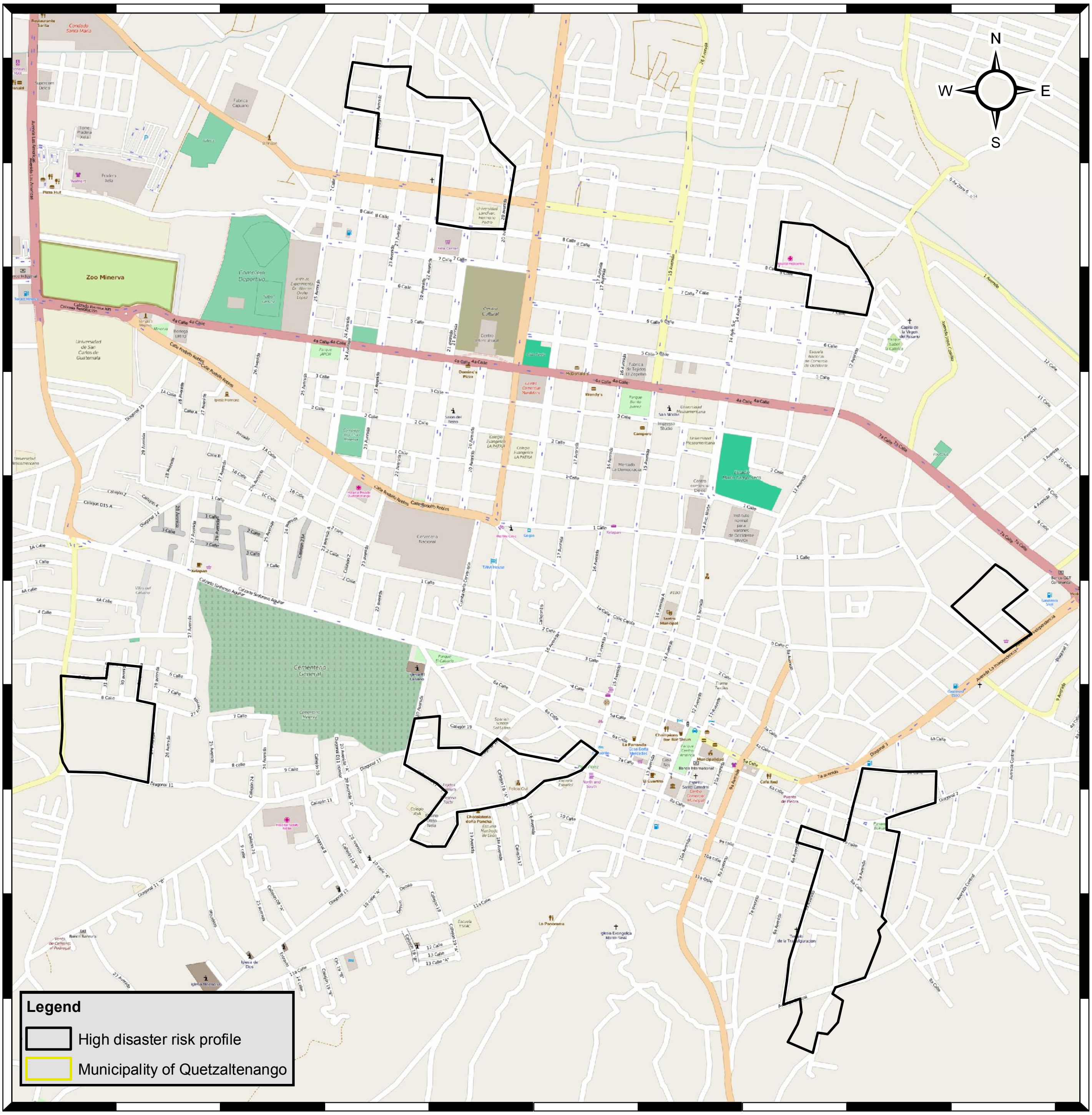
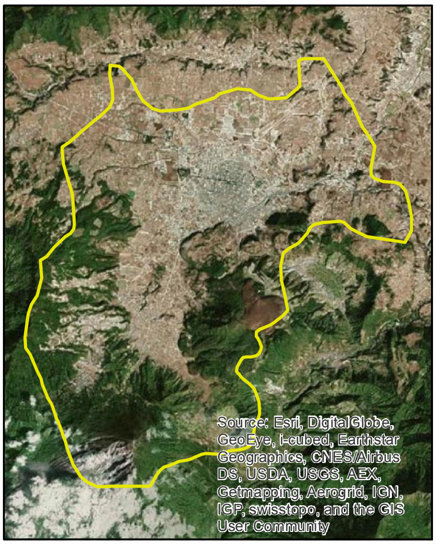
1:12,500

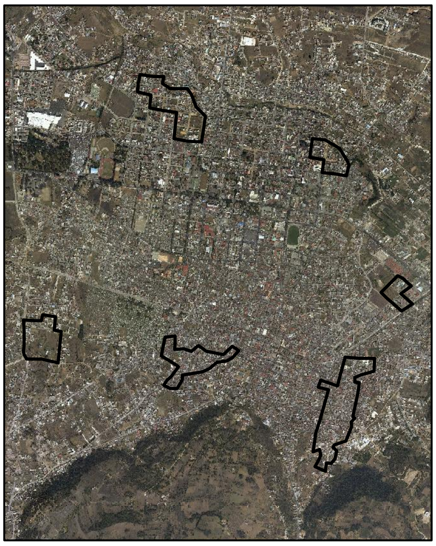
0 0.1 0.2 0.4 0.6 0.8
Kilometers

Areas with high disaster risk profile, Quetzaltenango, Guatemala



1 centimeter = 124 meters





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Projected Coordinate System: GTM

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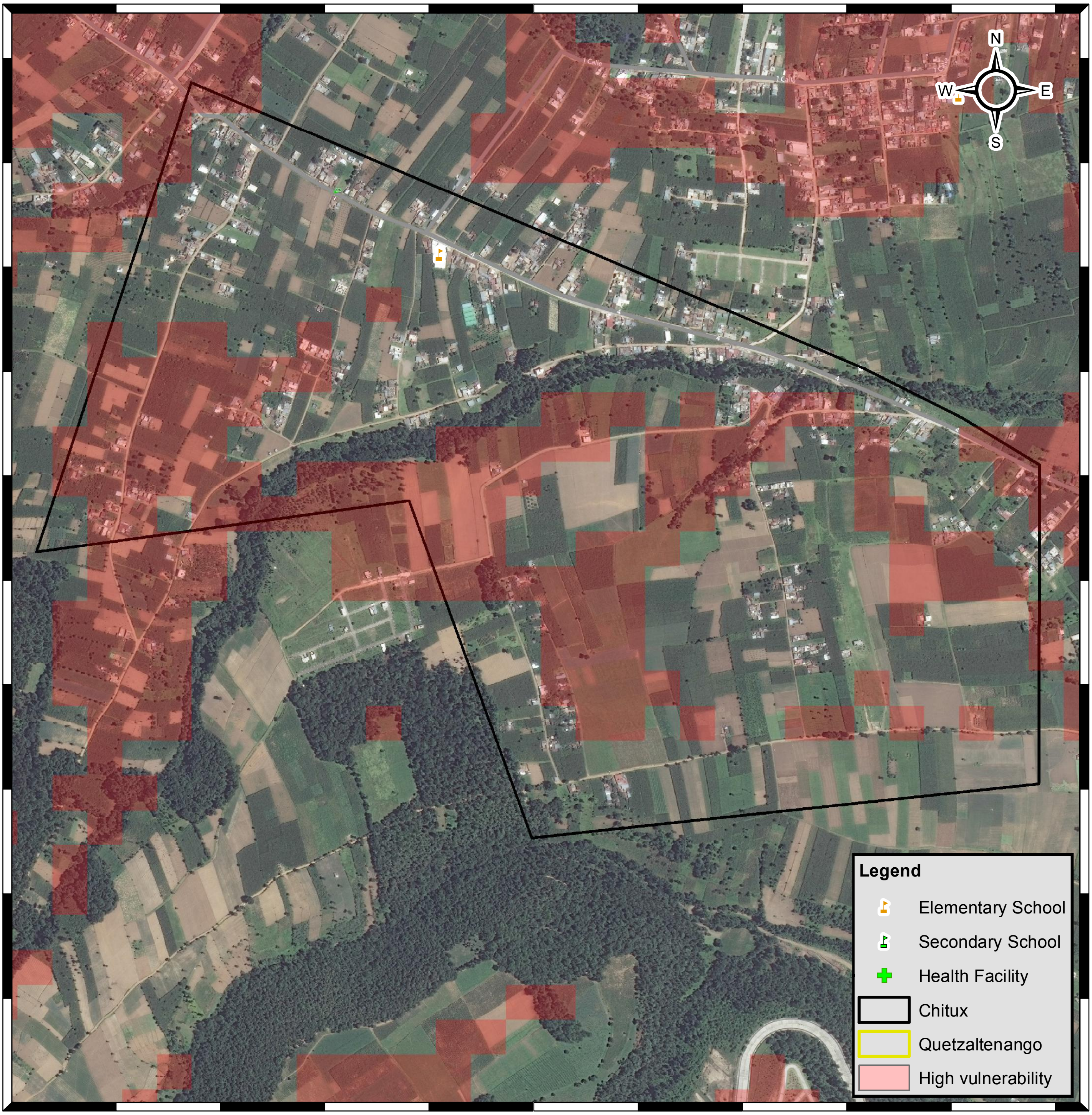
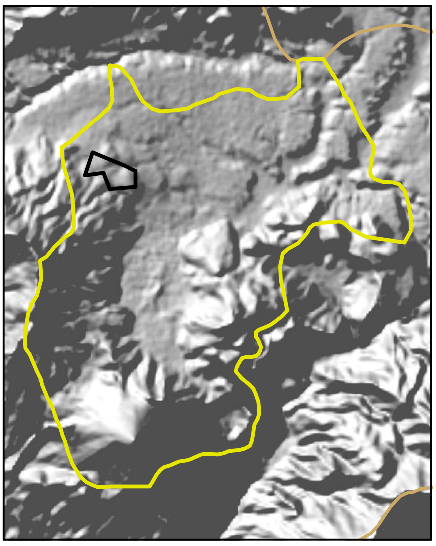
1:12,414

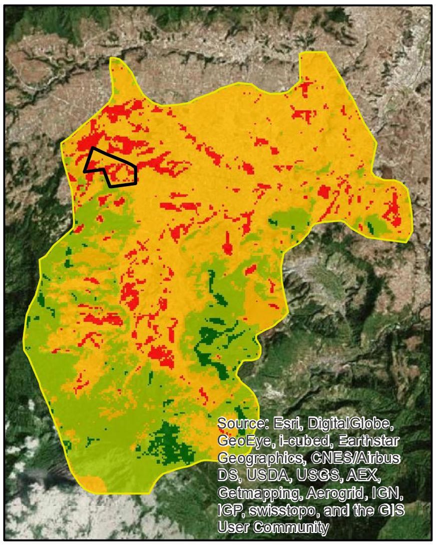
0 0.1 0.2 0.4 0.6 0.8
Kilometers

Flood impact on social infrastructure, Chitux neighborhood, Quetzaltenango, Guatemala



1 centimeter = 75 meters





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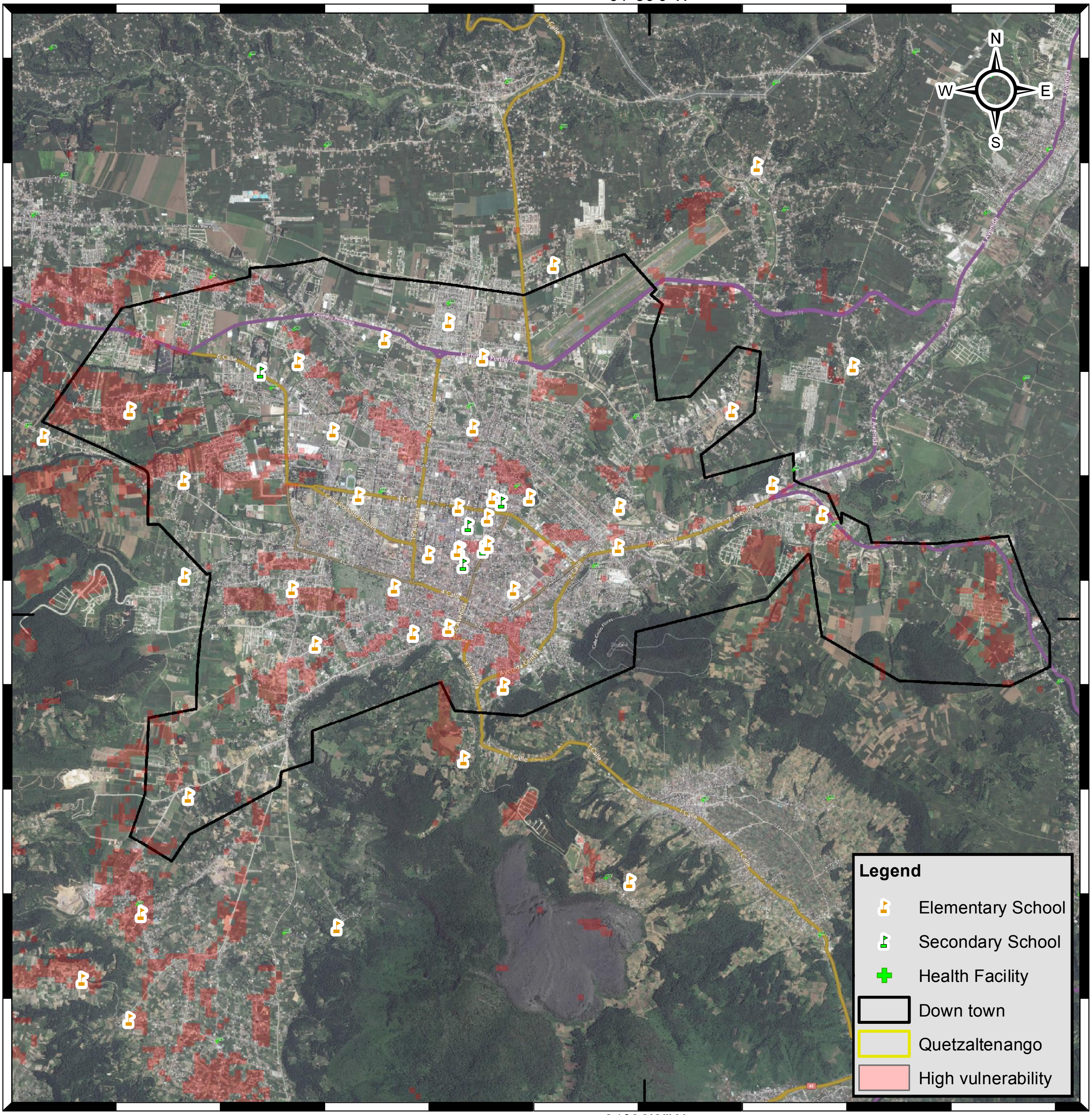
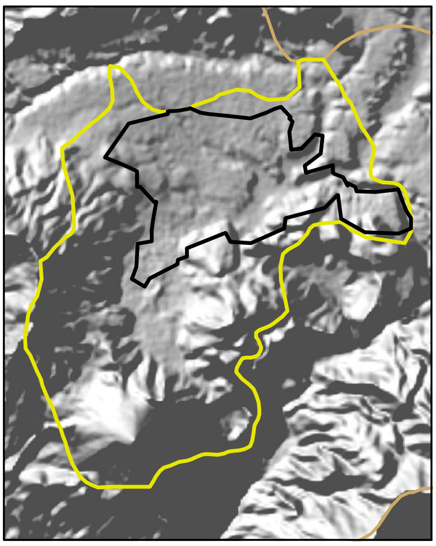
1:7,500

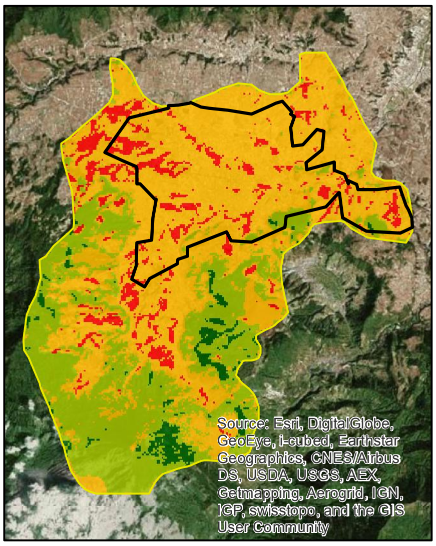
0 0.05 0.1 0.2 0.3 0.4
Kilometers

Flood impact on social infrastructure, Town Centre, Quetzaltenango, Guatemala



1 centimeter = 450 meters





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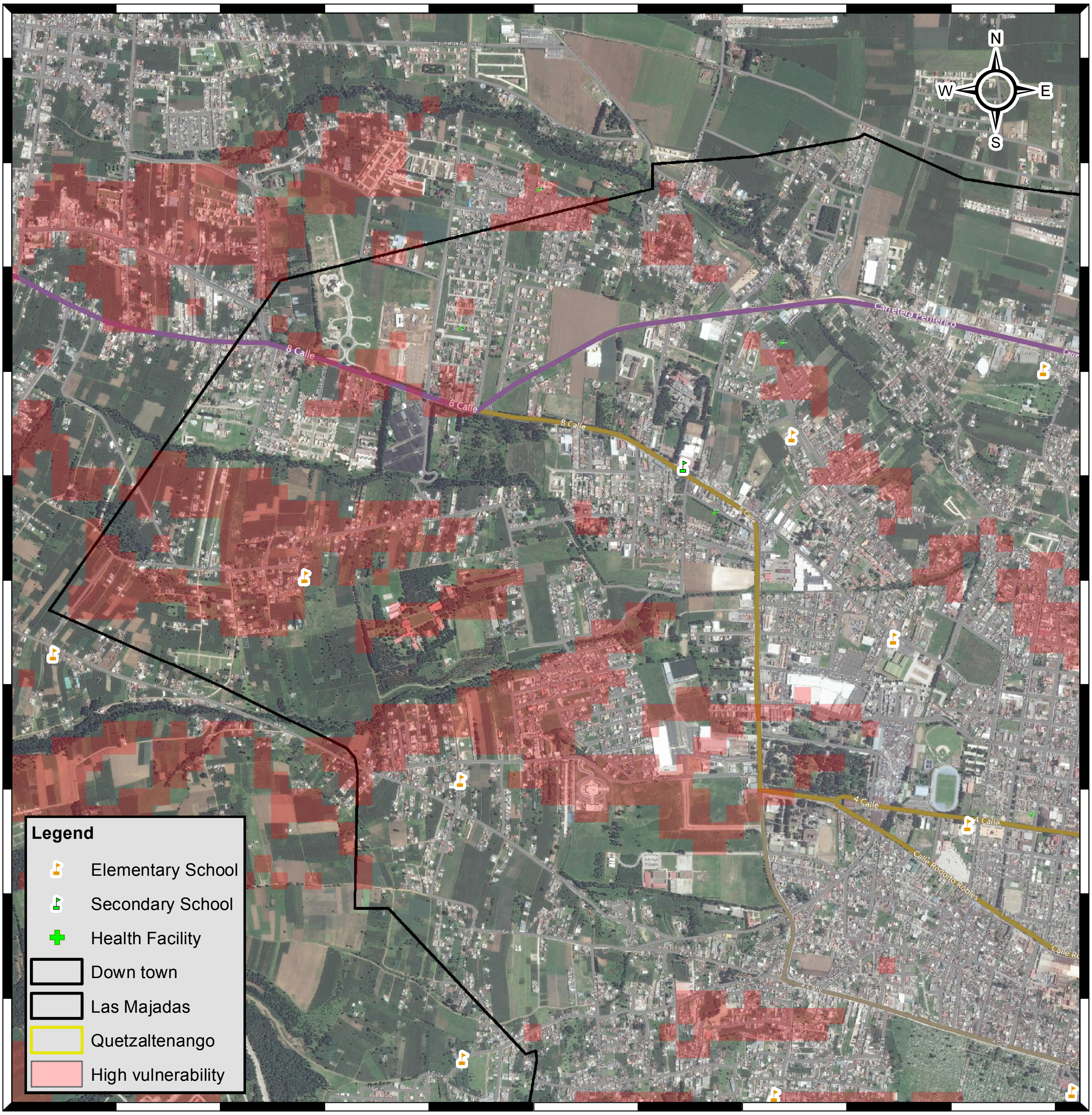
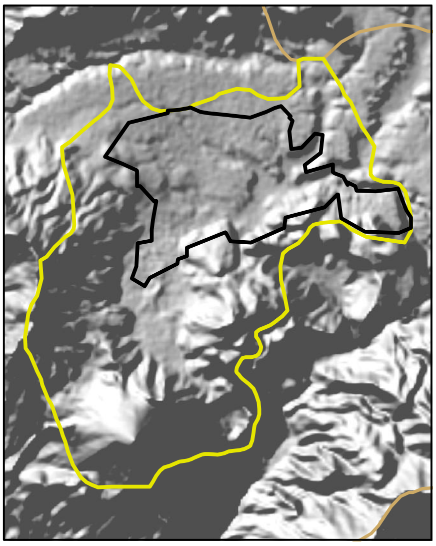
1:45,000

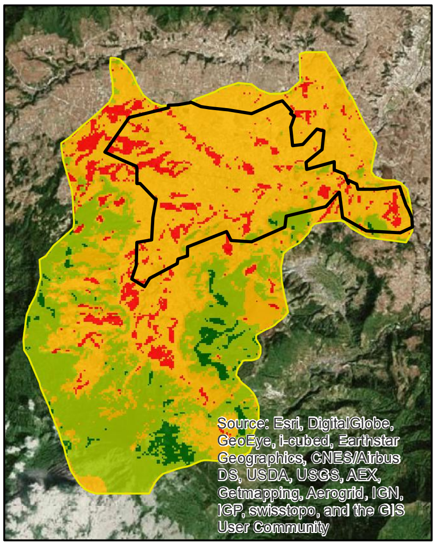
0 0.35 0.7 1.4 2.1 2.8
Kilometers

Flood impact on social infrastructure, Town Centre (Northwest side), Quetzaltenango, Guatemala



1 centimeter = 155 meters





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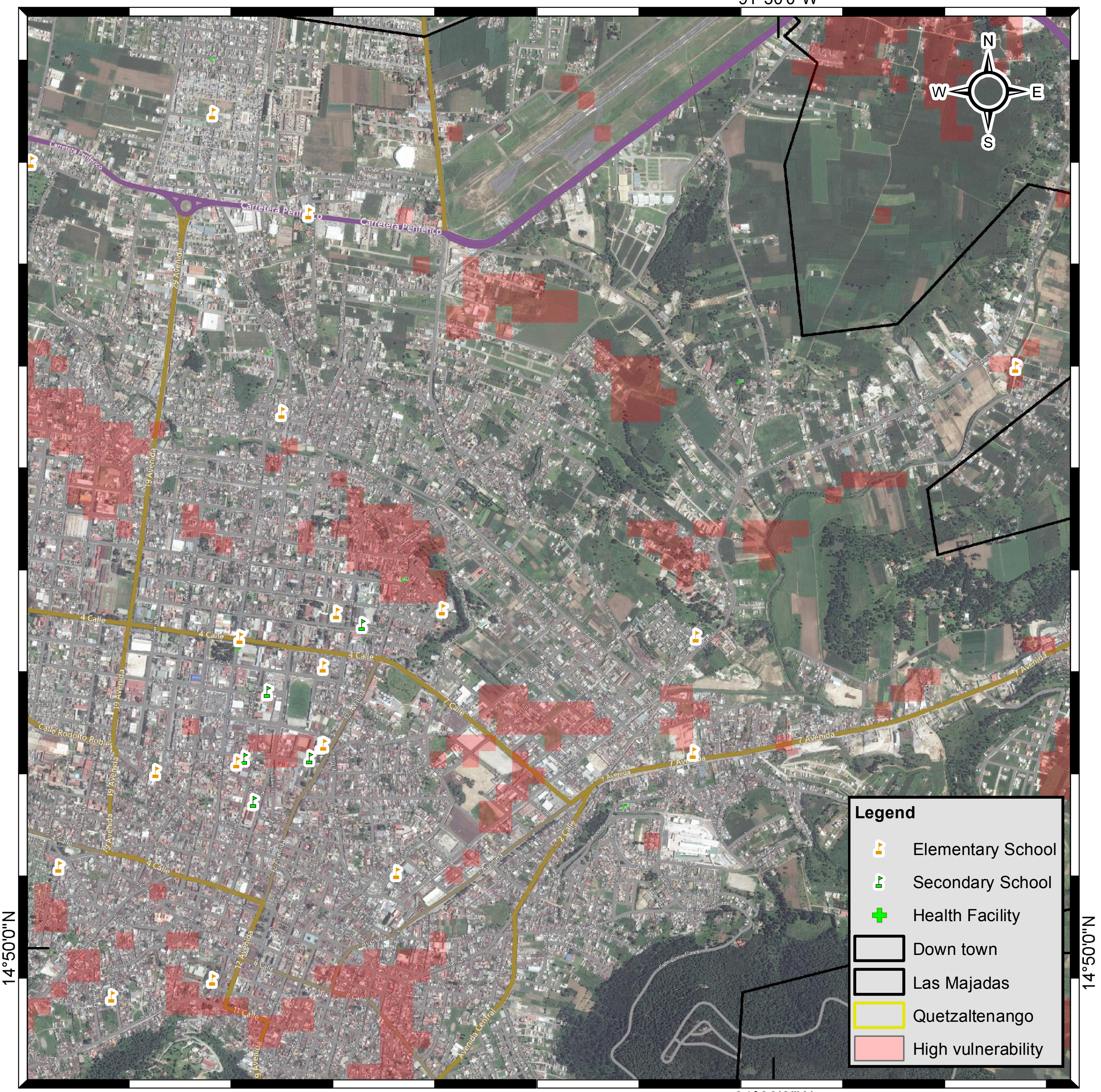
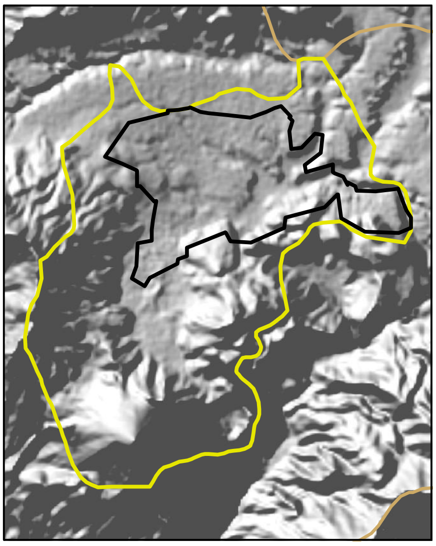
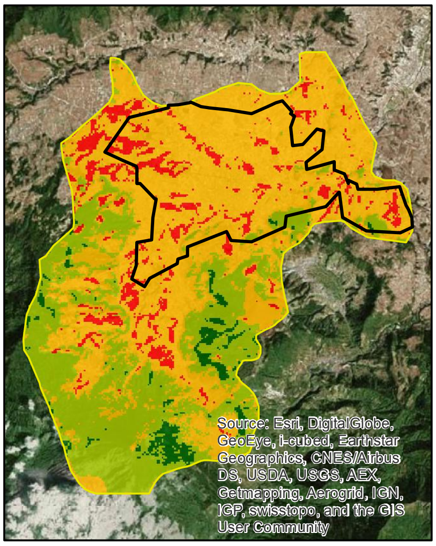
1:15,500

0 0.125 0.25 0.5 0.75 1
Kilometers

Flood impact on social infrastructure, Town Centre (Northeast side), Quetzaltenango, Guatemala







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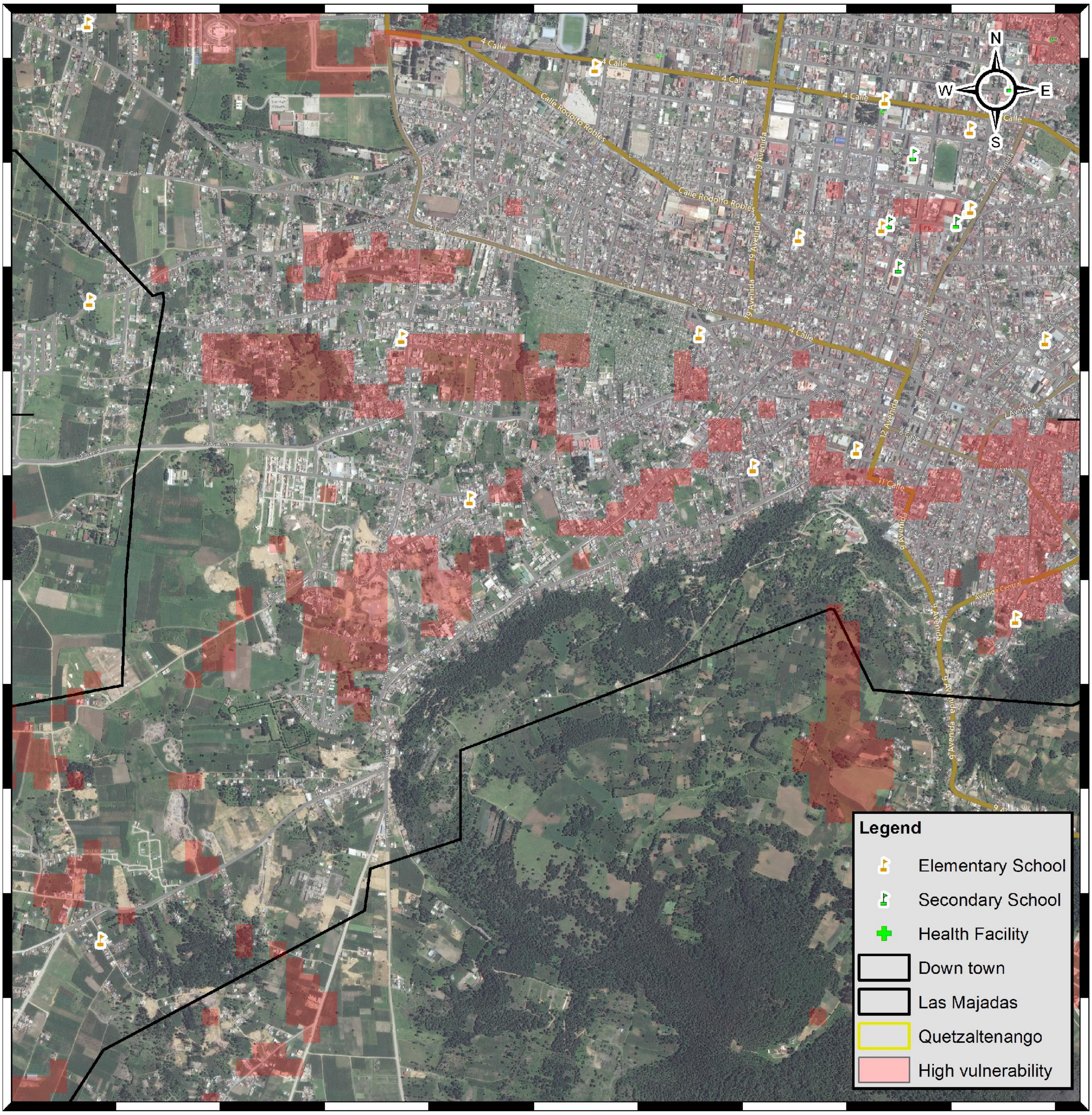
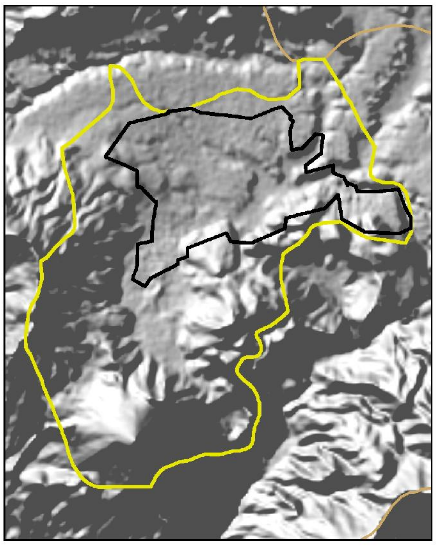
1:15,500

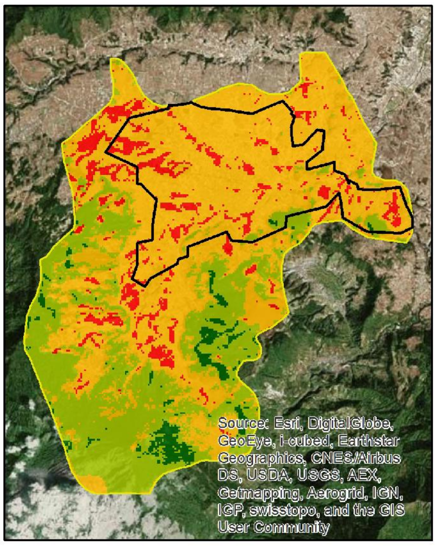
0 0.125 0.25 0.5 0.75 1
Kilometers

Flood impact on social infrastructure, Town Centre (Southern side), Quetzaltenango, Guatemala



1 centimeter = 155 meters





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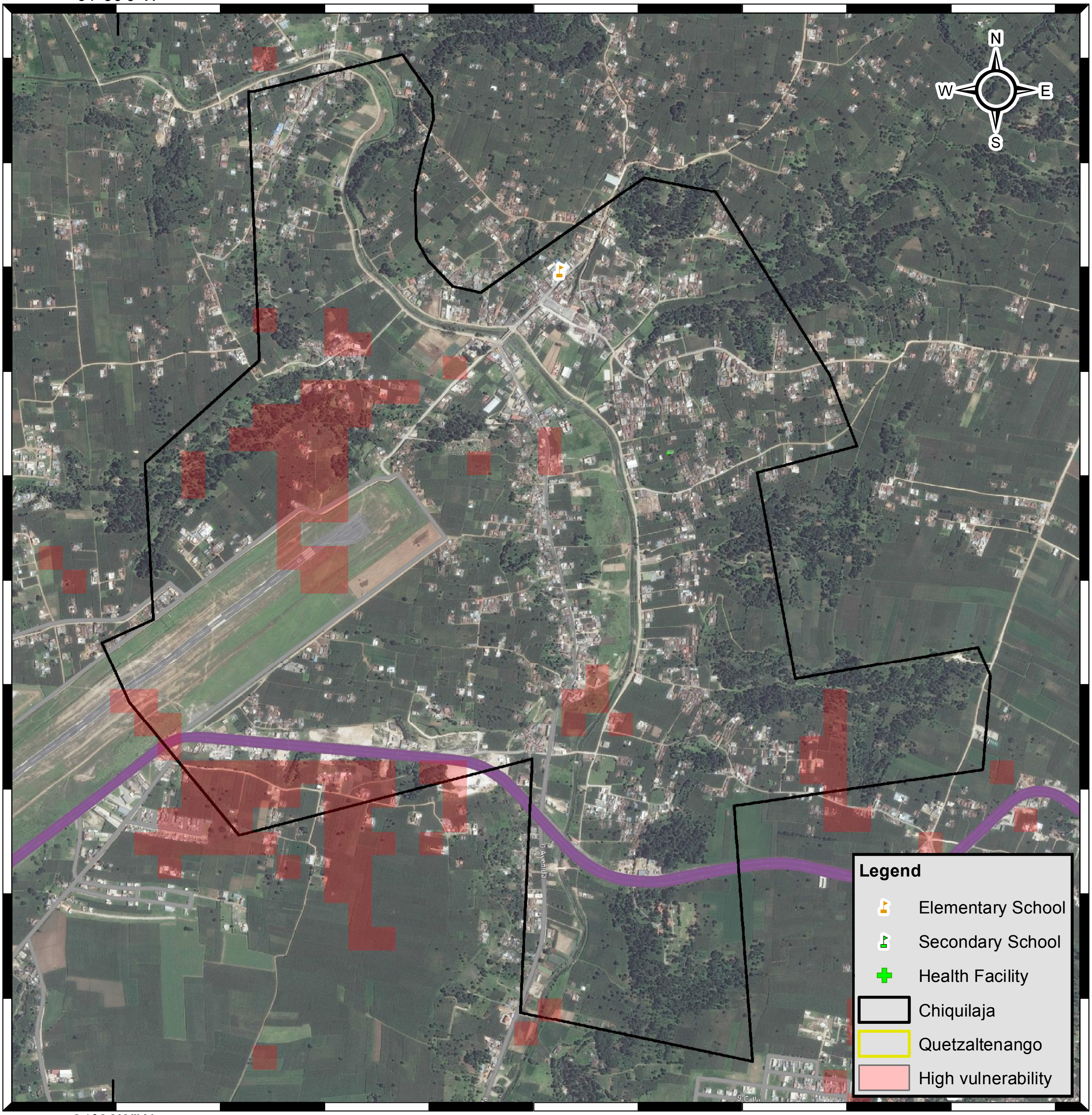
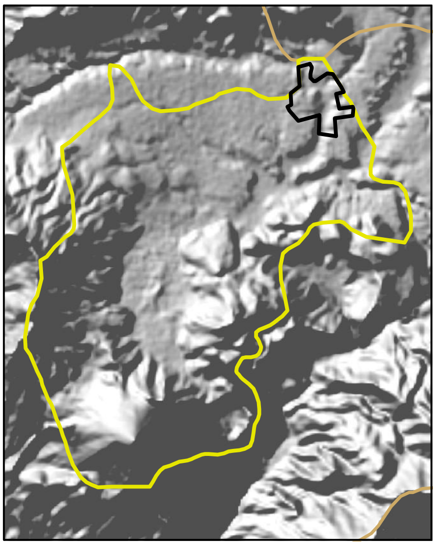
1:15,500

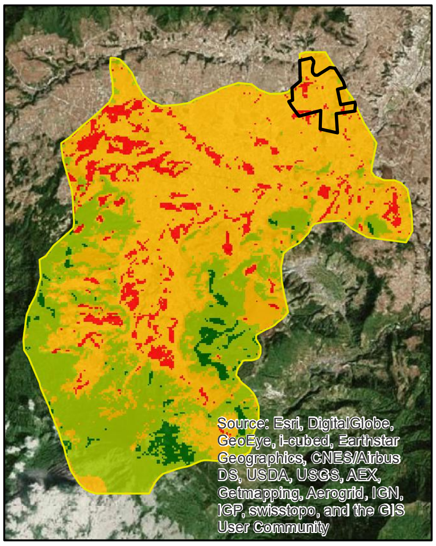
0 0.125 0.25 0.5 0.75 1
Kilometers

Flood impact on social infrastructure, Chiquilaja neighborhood, Quetzaltenango, Guatemala



1 centimeter = 110 meters





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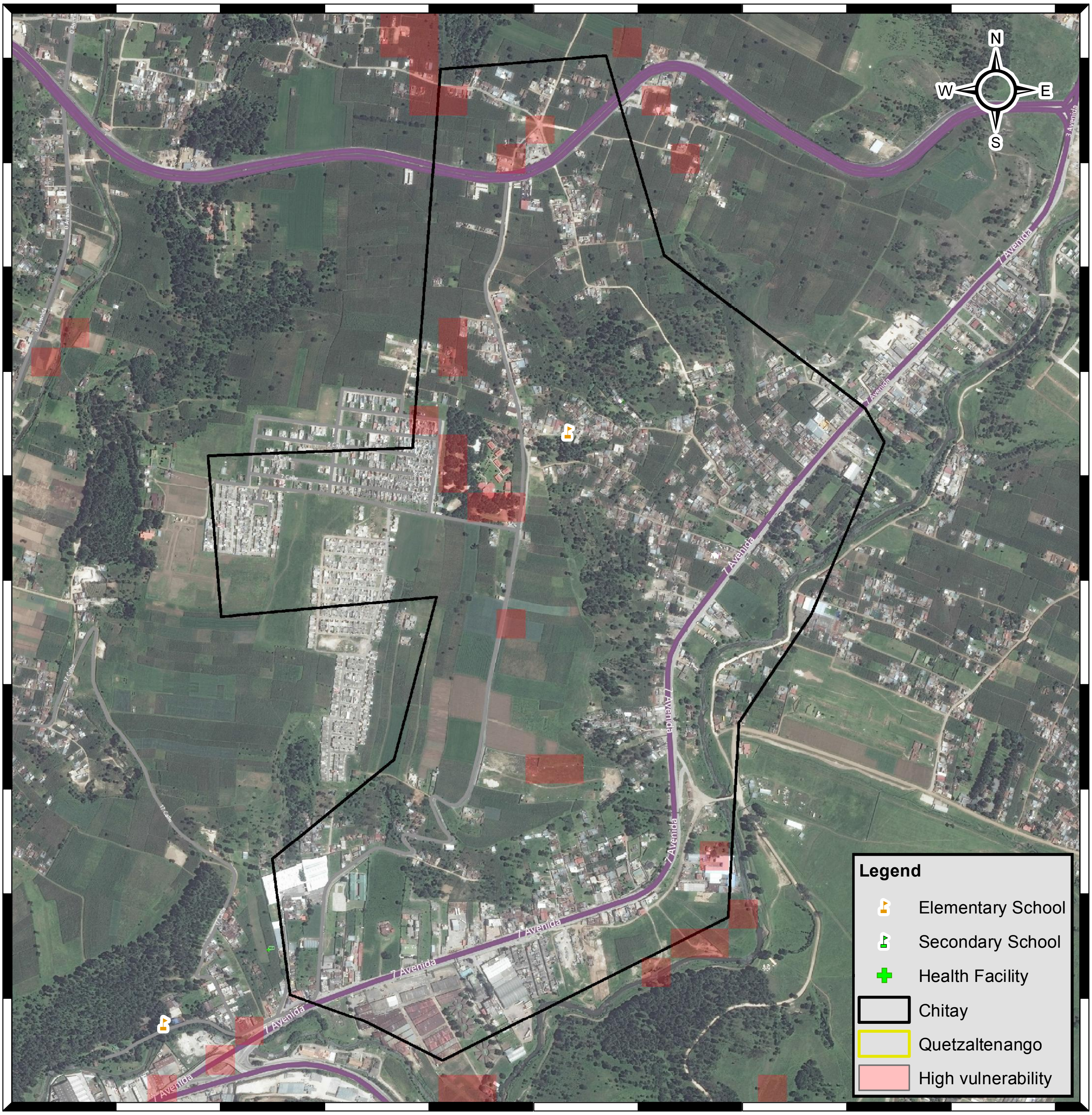
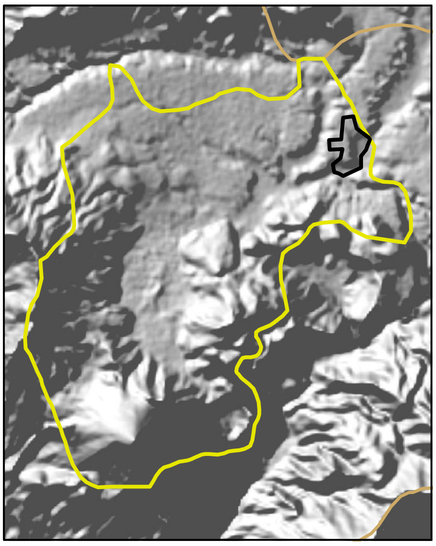
1:11,000

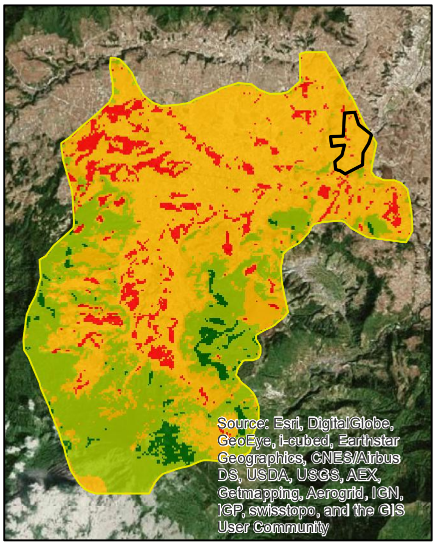
0 0.075 0.15 0.3 0.45 0.6
Kilometers

Flood impact on social infrastructure, Chitay neighborhood, Quetzaltenango, Guatemala



1 centimeter = 90 meters





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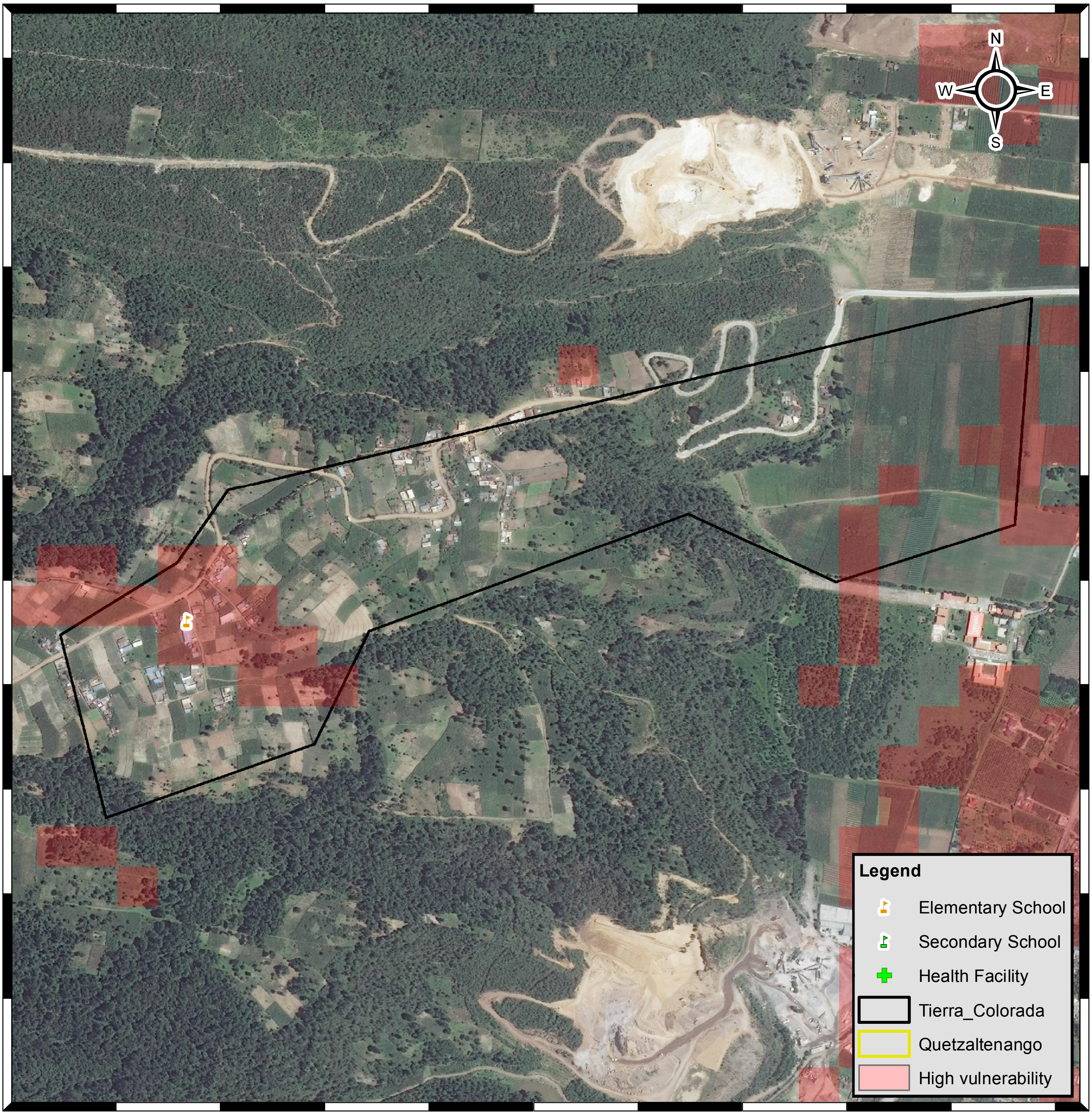
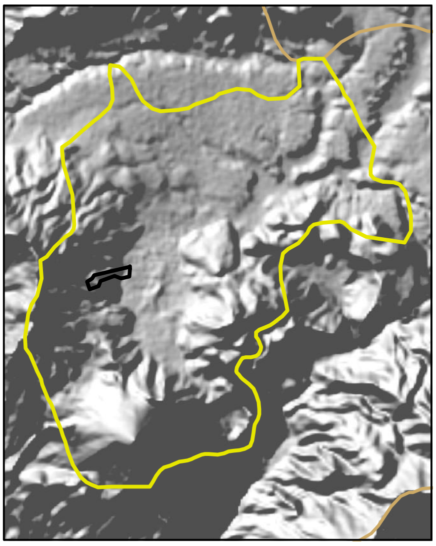
1:9,000

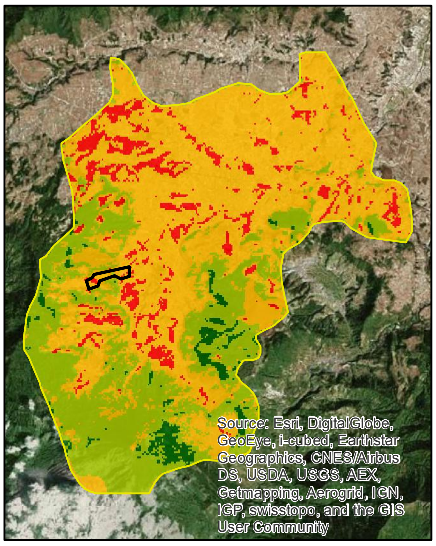
0 0.05 0.1 0.2 0.3 0.4
Kilometers

Flood impact on social infrastructure, Tierra Colorada neighborhood, Quetzaltenango, Guatemala



1 centimeter = 65 meters





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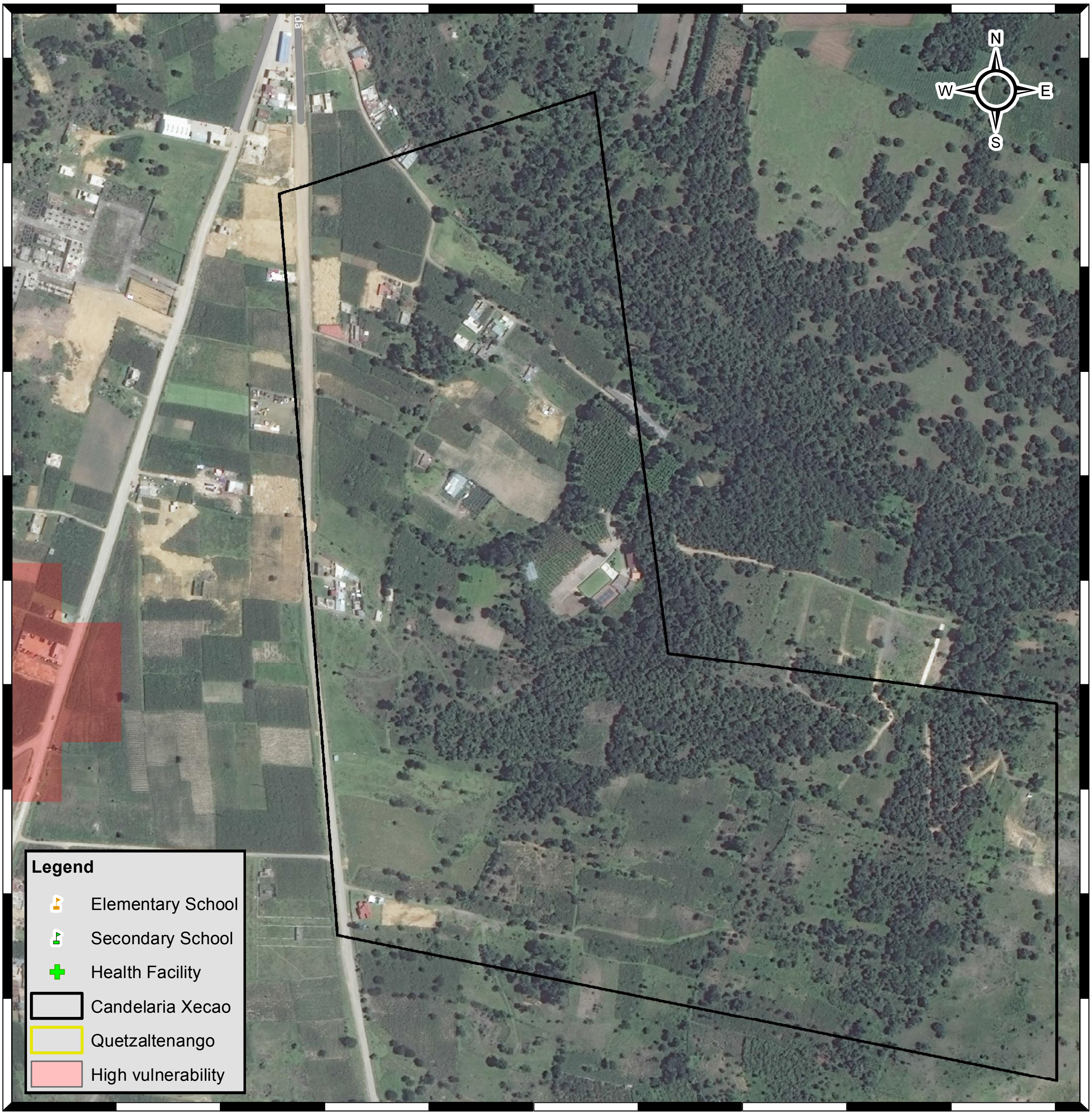
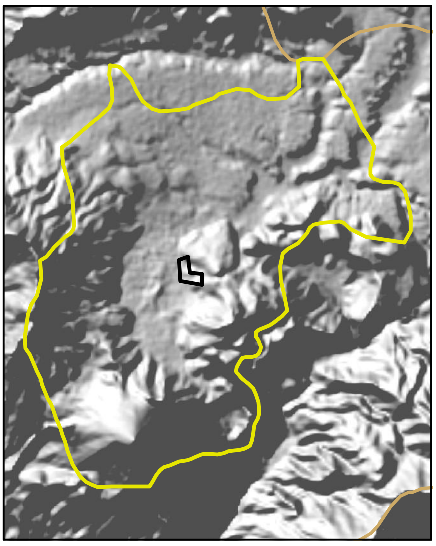
1:6,524

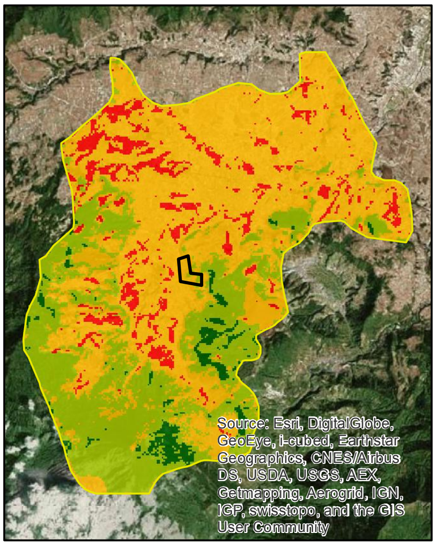
0 0.05 0.1 0.2 0.3 0.4
Kilometers

Flood impact on social infrastructure, Candelaria Xecao neighborhood, Quetzaltenango, Guatemala



1 centimeter = 44 meters





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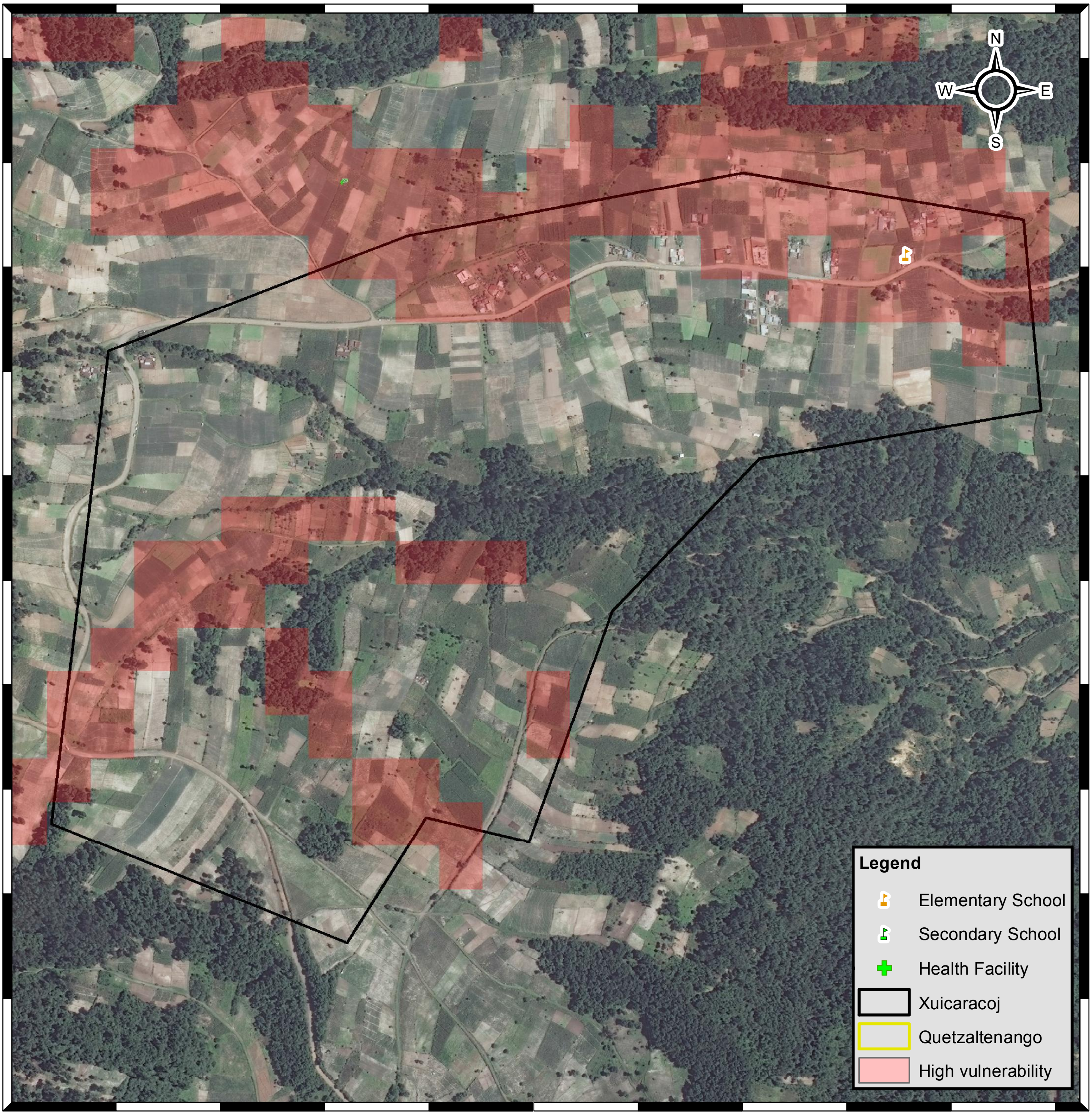
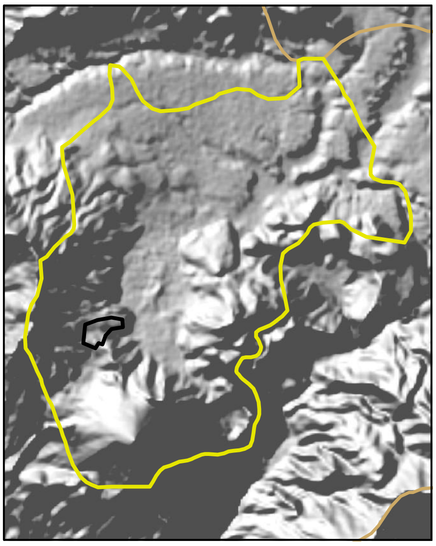
1:4,379

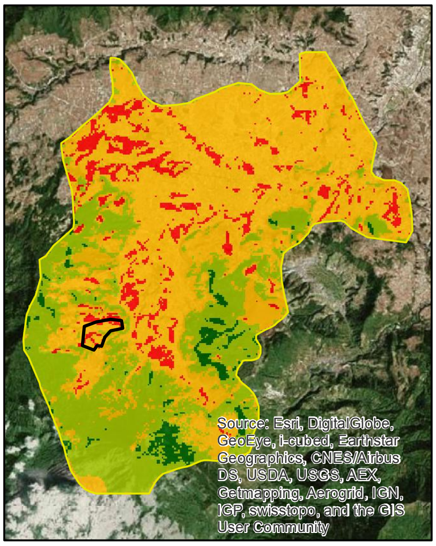
0 0.035 0.07 0.14 0.21 0.28
Kilometers

Flood impact on social infrastructure, Xuicaracoj neighborhood, Quetzaltenango, Guatemala



1 centimeter = 60 meters





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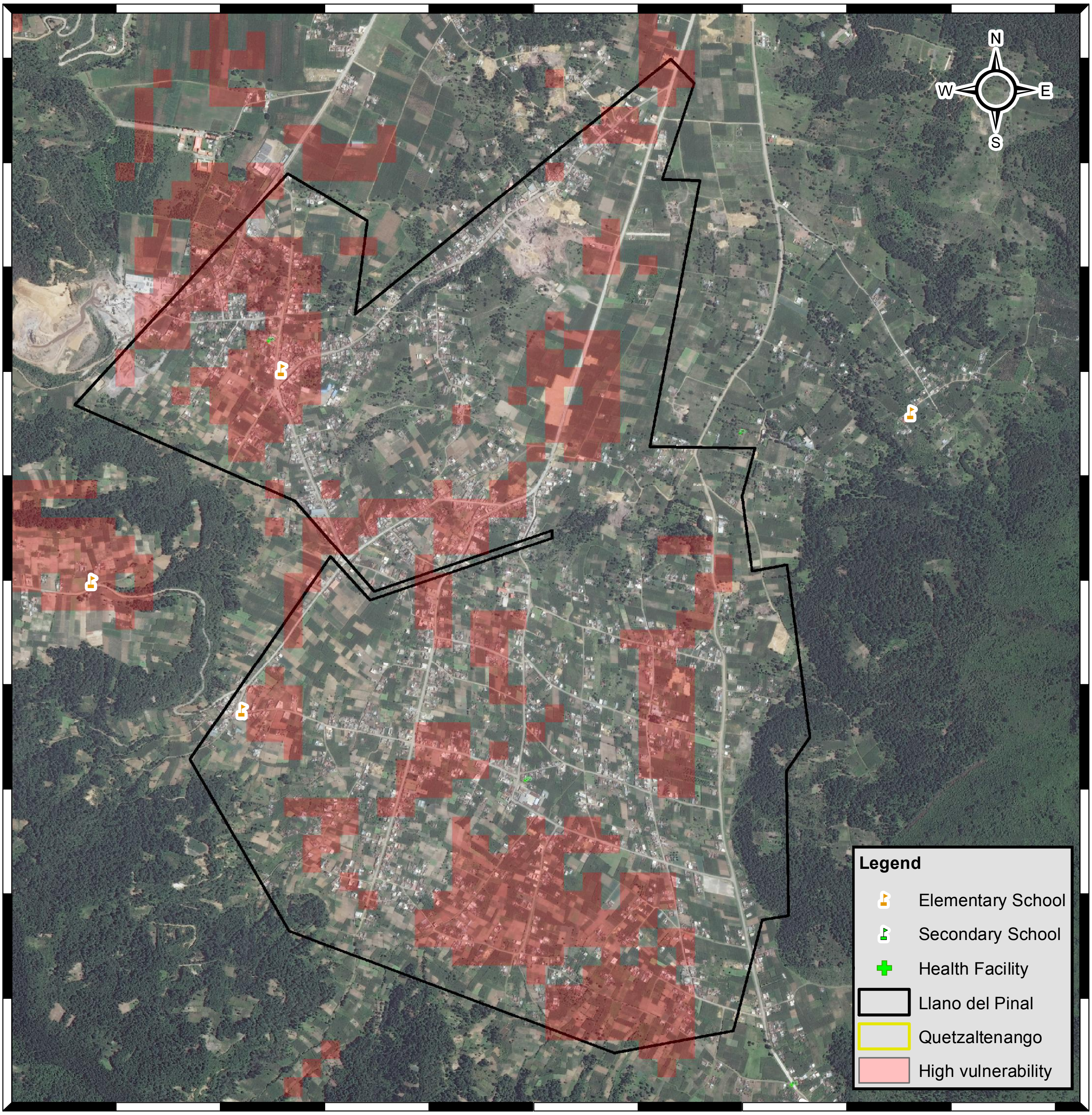
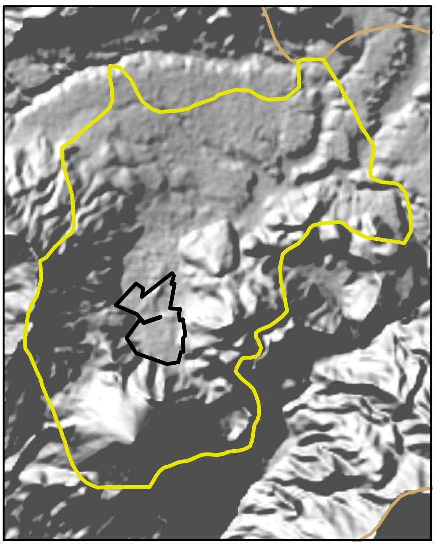
1:6,000

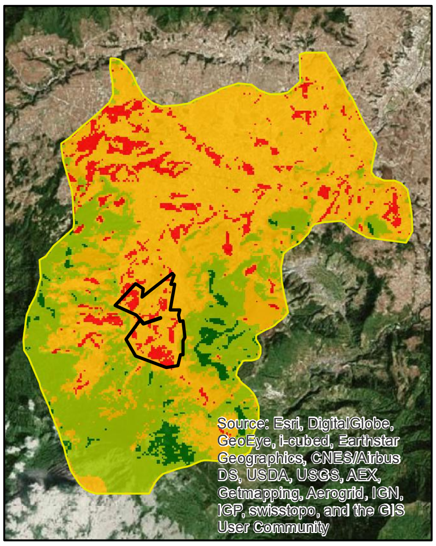
0 0.0475 0.095 0.19 0.285 0.38
Kilometers

Flood impact on social infrastructure, Llano del Pinal neighborhood, Quetzaltenango, Guatemala



1 centimeter = 140 meters





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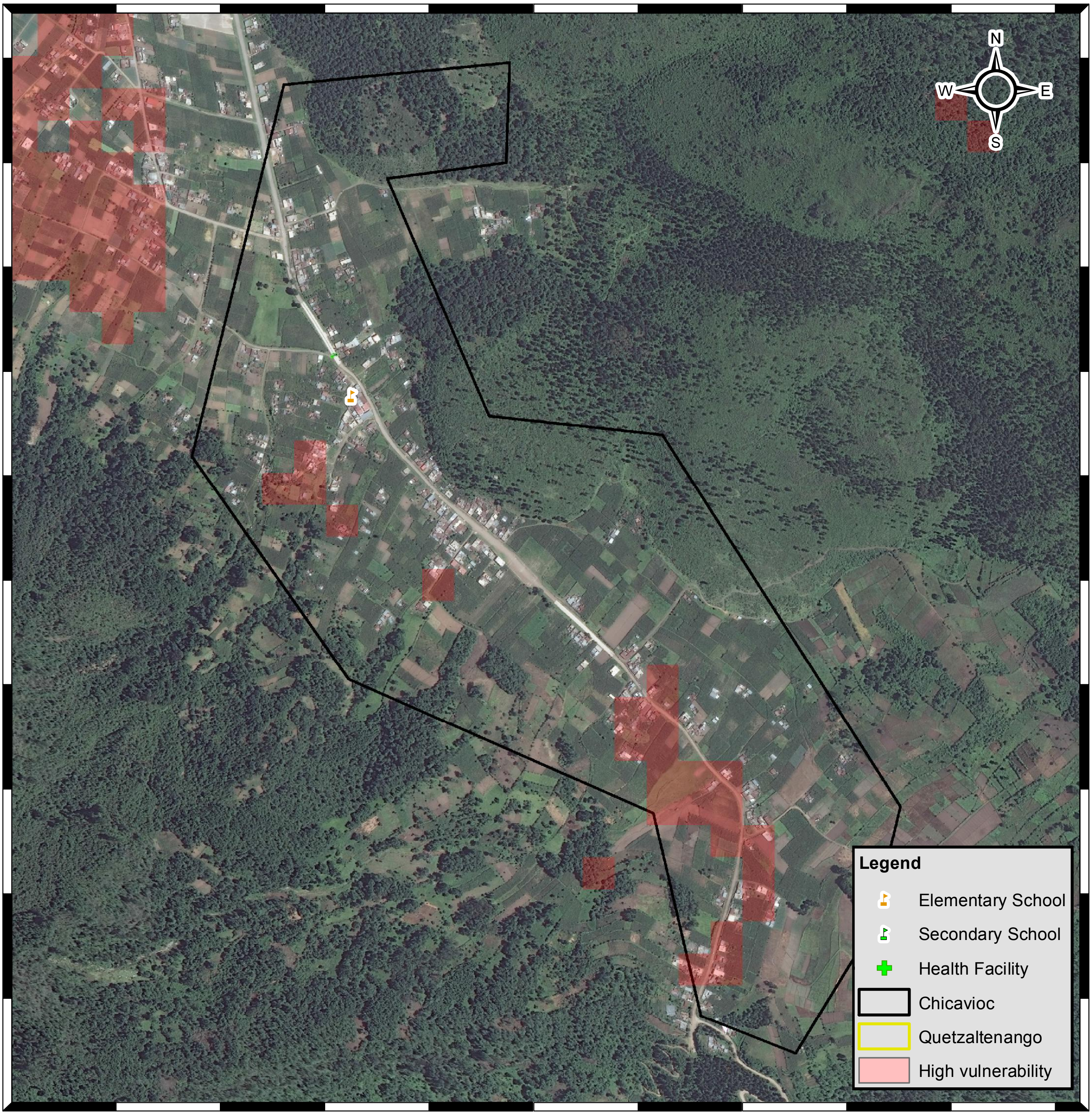
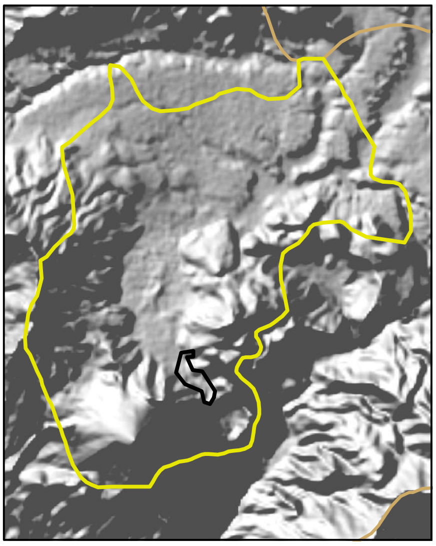
1:14,000

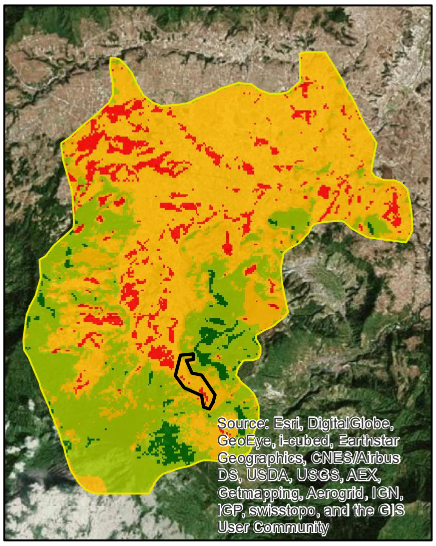
0 0.1 0.2 0.4 0.6 0.8
Kilometers

Flood impact on social infrastructure, Chicavioc neighborhood, Quetzaltenango, Guatemala



1 centimeter = 82 meters





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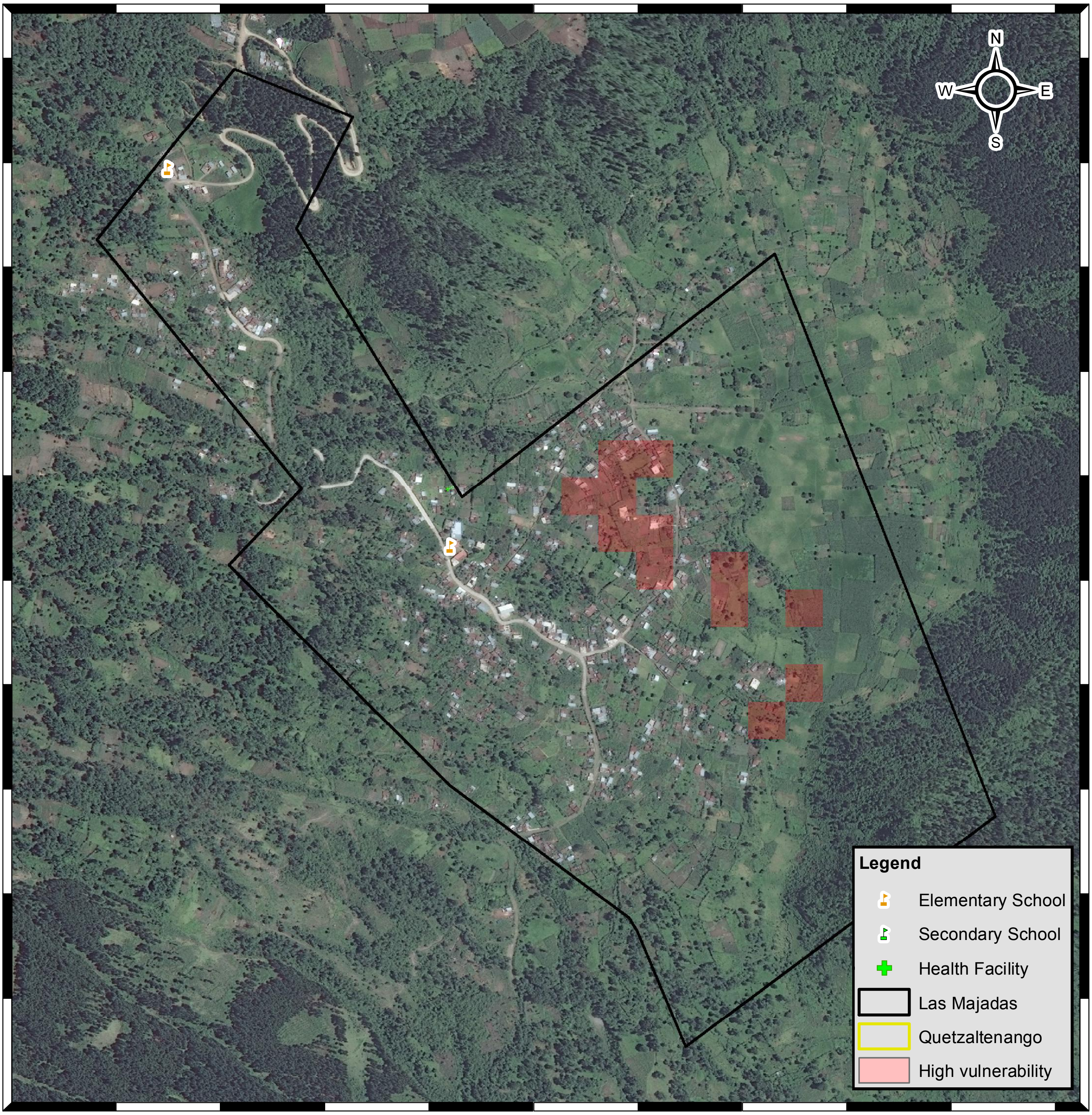
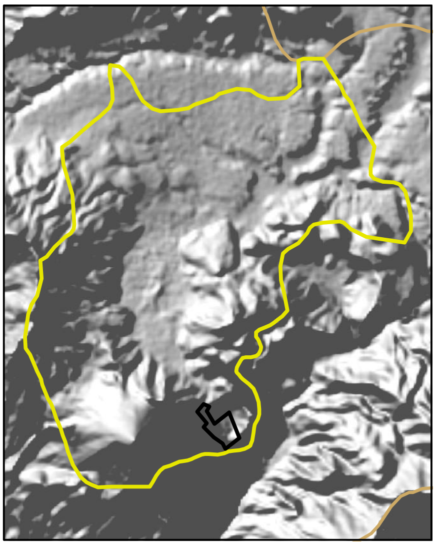
1:8,175

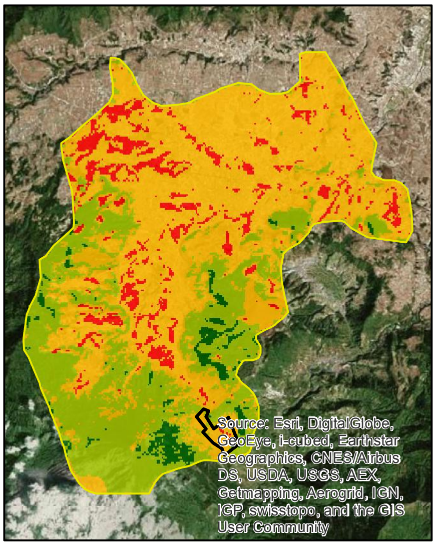
0 0.05 0.1 0.2 0.3 0.4
Kilometers

Flood impact on social infrastructure, Las Majadas neighborhood, Quetzaltenango, Guatemala



1 centimeter = 70 meters





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1:7,000

0 0.05 0.1 0.2 0.3 0.4
Kilometers