

# Interaction between land-use change, flooding and human health in Metro Vancouver, Canada

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**Abstract** Many regions of the world are experiencing an increase in frequency and intensity of floods. There has been increasing understanding among emergency preparedness and natural disaster planners that rapid urbanization is enhancing the risk from river flooding in urban areas. Many regions of Canada have been exposed to particularly severe floods over the course of the last few years, much of this due to land-use change. This study aims at understanding the risk of flooding for the City of Metro Vancouver, British Columbia, Canada, which is located in the Fraser River Delta. The paper presents a fast, efficient and reliable method that can be used to produce vegetation maps from advanced very high resolution radiometer images and SPOT vegetation maps. A 10-day maximum normalized difference vegetation index maps were produced to assess the dynamics of the urbanization process in Vancouver. Remotely sensed data show a significant decrease in vegetation cover in the Metro Vancouver City between 1984 and 2012. The proposed method can be used as an effective tool for raising early land-use change awareness and assist with flood risk management. Flood risk management has a substantial impact on human health and well-being in urban areas, and this flood risk information will be used to assess the impact of flooding and explore the complex relationship between land-use change, urbanization, flooding and impact on urban dwellers.

**Keywords** Land-use change · Remote sensing · Vegetation · Flood · Health

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## 1 Introduction

There is a growing body of evidence that the main driver of global climate change is the human population's needs for energy, food, goods, services and information and disposal of waste products from these activities. The significant increases in human population over the last 200 years has caused substantial and continuing impacts on land use on a large scale. These land-use changes have impacts on ecological systems and these in turn have impacts on the climate both locally and on a global scale. Climate is a well-established determinant of human health and well-being (Steffen et al. 2004).

Over half of the world's population lives now in urban based on the Global Health Observatory (GHO) report,<sup>1</sup> by the middle of the twenty-first century, "the urban population will almost double, increasing from approximately 3.4 billion in 2009 to 6.4 billion in 2050." Significant proportion of this population will be living in informal, unplanned or slum settlements with little infrastructure available to support a healthy lifestyle. The increasing burden of disease in such environments presents a challenge to all societies as coping with the consequences of poor health diverts resources that could be put to other uses and increases the vulnerability of population.

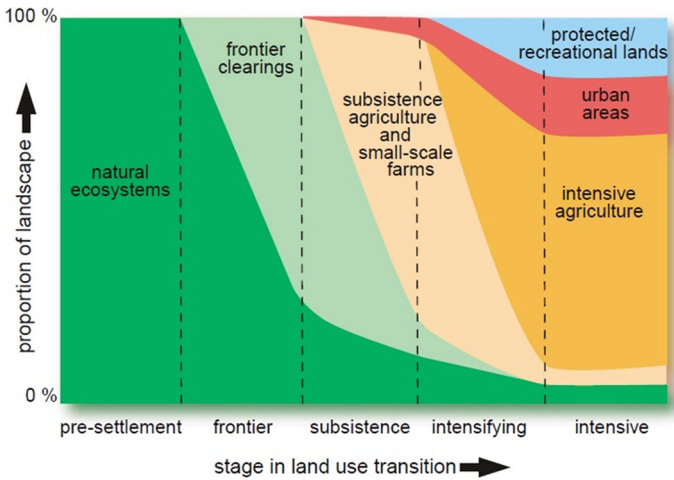
Many low-lying coastal, river delta megacities, already stressed by rapid population growth and economic, social, health and cultural preferences, are now increasingly vulnerable to climate change, particularly as a result of the more frequent extreme weather events such as heat waves, heavy rainfall and high winds. In addition, the threat of rising sea levels (Arkema et al. 2013) as well as more intense storm surges makes coastal cities more vulnerable to adverse conditions that the human populations need to cope with by a combination of mitigation measures and adaptation strategies in order to increase resilience and decrease vulnerability to these events. Coastal megacities are extremely complex environments in which a large number of factors can impact individual and population health. Climate change is a factor that decision-making bodies need take into consideration in order to ensure ongoing urban health, well-being and sustainability.

Land-use activities, most of which involve converting natural landscapes for human use, have changed a large percentage of the planet's land surface. Deforestation, expanding built environments, intensifying farmland production, damming and diverting watercourses for energy or irrigation projects are human actions which are changing the world's land use in essentially irreversible ways (DeFries et al. 2004). Built environments, in particular, increase vulnerability to extreme events such as heavy rainfall due to the diminished absorptive capacity of the land.

Figure 1 shows land-use transitions. Transitions in land-use activities that may be experienced within a given region over time have been shown in the figure. As with demographic and economic transitions, societies appear also to follow a classification of different land-use managements: from resettlement natural vegetation to boundary clearing, then to subsistence agriculture and small-scale farms, and as a final point to intensive agriculture, urban areas and protected recreational lands (Foley et al. 2005). Different parts of the world are in different transition phases, based on their social and economic conditions and ecological environment. Land-use practices vary across the world; the ultimate outcome is however mostly the same: the acquisition of natural resources for direct human needs happens at the cost of disrupting environmental conditions and ecosystem cycles.

According to the fourth assessment report by the Intergovernmental Panel on Climate Change (IPCC 2007), one of the effects of climate change is an increase in the magnitude

<sup>1</sup> [http://www.who.int/gho/urban\\_health/situation\\_trends/urban\\_population\\_growth\\_text/en/](http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/).



**Fig. 1** Land-use transitions (DeFries et al. 2004)

and frequency of extreme hydrologic events. A number of studies in the Canadian context concur with the findings of IPCC (2007). In particular, a study completed by Environment Canada (EC 2007) on four selected river basins in Ontario using a modeling exercise indicates that the impacts of future climate change on the frequency and magnitude of precipitation, stream flow and associated flooding risks will increase in that part of Canada. With the increase in magnitude and frequency of extreme hydrologic events, combined with rapid urbanization and land-use change, catastrophic events like the Calgary flooding in 2013 will happen again. The impact of these events on physical infrastructure and personal property, along with the disruption of socioeconomic activities has significant short- and long-term consequences for these communities. The physical, mental and spiritual well-being of the population living in such communities is not exempt and needs to be considered in any future mitigation and adaptation measures.

Exposure and vulnerability of the urban environment to climate extremes change with temporal and spatial scales and depend on many factors such as the overall health of the population, the local economy, social infrastructure, environmental conditions, geography, demographics, cultural content, institutional organization and governance. Individuals and communities are exposed and vulnerable based on inequalities expressed through different levels of wealth and education, disability and health status, as well as gender, age, class and other social and cultural characteristics (IPCC 2012). Monitoring the locations and distributions of land-cover changes is important for establishing links between policy decisions, governing actions and subsequent land-use activities.

The goal of the research presented in this paper is to show the link between the progressive urbanization and risk of flooding using the City of Vancouver, British Columbia, Canada (Fig. 2) as a case study. The Lower Fraser and Estuary Watershed are already facing increased risk of flooding due to urbanization (Brandes and O’Riodan 2007). Both regions are at present experiencing population increase which further contributes to the increase in flood risk. This study illustrates the process of establishing a relationship between an impervious area and vegetation cover making use of remote sensing techniques. Using two sensors of NOAA-AVHRR and SPOT-VGT helped us to

cover longer terms of vegetation monitoring for the city of Metro Vancouver. Results of this study have a direct application in land-use planning for future urban development.

Once the link between urbanization and vegetation cover is established, it will be possible (1) to predict the future urbanization trends and (2) to determine vulnerable areas to the risk of flooding. Reduction in the uncertainty, mainly in land-use change, is aimed at developing and implementing healthy urbanization policies and addressing major human health challenges generated by changing climate (Nirupama and Simonovic 2006).

The rest of the paper is organized as follows. In Sect. 2, the Vancouver case study is presented. The discussion of land-use change impacts on flood frequency is presented in Sect. 3. The methodology based on the use of remote sensing that has been employed in the study is presented in Sect. 4. Finally, the results, summary and conclusions of the study and further research work are outlined in Sect. 5.

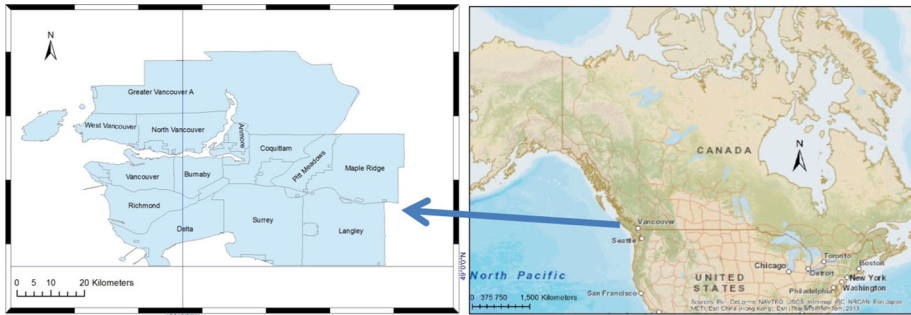
## 2 Study area

Over last several decades, Metro Vancouver has achieved a significant level of socio-economic development. In that period, Metro Vancouver economic expansion has outperformed the results of federal Canadian economy. As a consequence, according to census information (Statistics Canada 2012), employment in Greater Vancouver reached 1.1 million in 2006, and that represents the fastest pace of job growth among Canada's three largest metropolitan areas. Rapid socioeconomic development has been shadowed by two parallel trends that directly affect local natural resources: considerable population growth and rapid urbanization. In 2011, Metro Vancouver had a population of 2,476,328, while the regional district has a land area of 2,882.55 km<sup>2</sup> and a population density of 856.2 people/km<sup>2</sup> (Statistics Canada 2012). In contrast, Metro Vancouver population in year 1981 was 1,169,831 (Fig. 3) that shows increase in more than 100 % (Statistics Canada 2012).

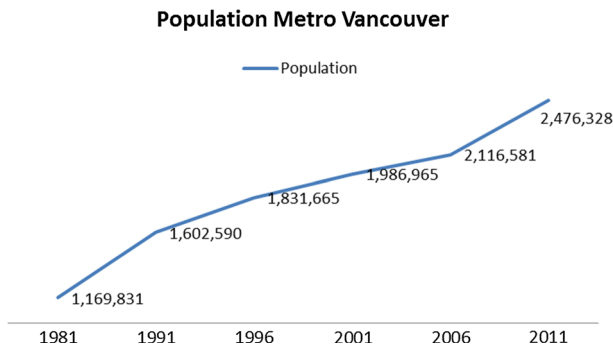
In addition, Metro Vancouver has experienced significant effects of changing climate conditions. The Fraser River is the largest river on the west coast of Canada, draining approximately one quarter of British Columbia. Flooding is a potential impact of climate change in Vancouver which is located in the Fraser River Basin. The leading cause of inland floods is heavy rainfall, but they can also be created by snowmelt and dam-break flows. Intense precipitation may also cause standing water to accumulate in urban areas, as the capacity of drainage is exceeded (UN/ISDR 2004).

Vancouver is exposed to multiple types of hydro-meteorological climate hazards including storm surges, tsunamis, sea-level rise, and coastal and riverine flooding. Urbanization and climate change will intensify the problems associated with these hazards in urban coastal megacities as the frequency and magnitude of events increases. Changes in the physical system have direct and indirect impacts on economic, social, health and organizational activities (Peck and Simonovic 2013). For instance, consider the flood hazard. Riverine flooding directly affects water quality, which in turn may affect the health of a population and therefore impact the economy. Some areas within a city may experience larger impacts than others based on the magnitude of hazard (Peck and Simonovic 2013).

In the OECD 2012 report, Vancouver is rated 15th for exposed assets, with USD \$55 billion at risk, and 32nd in terms of population at risk, with 320,000 people exposed to negative impacts of climate change. Vancouver's coastal infrastructure at risk includes



**Fig. 2** City of Metro Vancouver in the province of British Columbia in Canada



**Fig. 3** Population growth in Metro Vancouver

highways, sewer systems, waste treatment facilities, shipping and ferry terminals, and Vancouver’s International Airport.<sup>2</sup>

### 3 The impacts of land-use change on flood frequency

Flood prediction and modeling generally involves three main phases: (1) rainfall prediction; (2) description of the rainfall-runoff transformation; and (3) hydrologic and hydraulic routing of the runoff to obtain the water level. Flood routing is important in the design of flood protection measures in order to assess the impact of the proposed measures on the modification of flood peak and its timing (Singh and McCann 1980). Land-use change plays an important role in both, phase (2) and phase (3), and therefore is addressed in the paper as one of the main inputs for flood risk management activities (design or protection measures, emergency management and others).

The increase in atmospheric temperature will increase in the capacity of the atmosphere to hold water and accelerates several of the processes involved in the redistribution of moisture in the atmosphere. These changes suggest that flood-generating processes linked to the atmosphere are on the increase (Simonovic 2012). However, warming also alters many other aspects of the global water cycle. Rising temperature results in (1) increased

<sup>2</sup> <http://coastalcitiesatrisk.org/wordpress/>.

evaporation, (2) change in spatial and temporal precipitation patterns and (3) change in surface storage of water, including snowpack generation, snowmelt, river ice breakup and glacial melt.

One of the main causes of ecosystem change is change in land use. Floods represent around 40 % of the total number of natural disasters worldwide (Waroux 2011). Floods vary in time and space primarily due to climate variability. Future forecasts of long-term variations of floods stay inconclusive. Over the past decades, an upward trend of reported floods has been observed; however, it is not clear whether this trend reflects a real increase in flood events or only increase in reporting and registration of floods. There has been an increase of 20 % in heavy precipitation in USA and Europe in past 50 years, which can play an important role in increasing flood frequency (Waroux 2011). It is important to note that floods may result from a mixture of causes. For example, the huge storm-related coastal flood that hit the east coast of the UK and the Netherlands in 1953 coincided with inland flooding due to heavy precipitation (Waroux 2011).

Deforestation may increase river flooding by affecting soil structure and volume, decreasing infiltration rates, and reducing water storage. The long-term effects of land clearance and agricultural development are challenging to monitor. There are some estimates that vegetation clearance reduces actual evapotranspiration by over 400 mm/year in the humid tropics and 200 mm/year in mid-latitudes (Paker 2000).

Floods are natural phenomena in the Metro Vancouver City. Flood control and prevention is a major part of urban planning and much is already being done in many jurisdictions. However, the complete elimination of flood damage is not possible. Generally, most people are accepting of the inevitability of floods that are larger than expected, and that many human activities can magnify both, the size and the impact of flooding. Flooding may originate in (1) the rapid input of large quantities of water; (2) high tides and onshore winds that can create both sea and estuarine floods; and (3) blockages within the drainage network (Simonovic 2012).

#### 4 Data and method

Local governments have many land-use management policies for increasing community resilience: critical and public facilities policies, development regulations, building standards, planning processes, land and property acquisition, and public information. Land-use planning and management leads to communities where people and property are kept out of the areas exposed to hazards, where development is designed to be resilient to natural forces, and where the mitigative capacity of natural environmental systems is not diminished. In many countries, land-use planning and management are not governed by the federal or state policies. These levels of government look unwilling to take a role in land-use management and they communicate to local governments conflicting signals about exposure to hazards advocating risk reduction and transfer rather than risk assumption and elimination (Simonovic 2012). One of the key factors in land-use management is vegetation monitoring.

The surface of the earth has been significantly changed by human activities. This has affected local and regional water stabilities and river regimes. These impacts are either direct, by manipulation of water resources, or indirect, through the effects of forest clearance and agriculture. Paker (2000) estimates that 20 % of the land area of the globe has been severely reformed by human activities. Some modifications have increased the flood hazard. Elimination of the natural vegetation tends to reduce evapotranspiration

losses and exposes the soil surface to the full kinetic energy of the falling rain, causing breakup of the soil crumbs, clogging pores, reducing infiltration capacity, maybe even forming impermeable patches (Simonovic 2012).

Making both quantitative and visual comparisons of land-use change and vegetative domains in the City of Metro Vancouver allowed us to generate more useful and reliable results for predicting future flood scenarios. For predicting and protecting land-use change in coastal cities which located in river deltas, we need more efficient study methods and shorter processing time—compared to conventional methods. Currently, remote sensing is one of the best tools that help researchers to reach the goal which has direct impact on flood forecasting.

#### 4.1 Remote sensing

Normalized difference vegetation index (NDVI) is based on the fact that healthy vegetation has a low reflectance in the visible portion of the electromagnetic spectrum due to chlorophyll absorption and other pigments, and a high reflectance in the near infrared (NIR) because of the internal reflectance by the mesophyll spongy tissue of a green leaf (Campbell 1987). NDVI can be calculated using pixel's reflectance values of red (visible) band and the NIR band of a satellite sensor as:

$$\text{NDVI} = (\text{NIR} - \text{VIS}) / (\text{NIR} + \text{VIS}) \quad (1)$$

NDVI values range from  $-1$  to  $+1$ . Because of the high reflectance in the NIR portion of the electromagnetic spectrum, healthy vegetation is represented by high NDVI values between 0.05 and 1. Conversely, non-vegetated surfaces (such as water bodies) yield a negative NDVI value. Bare soil areas have NDVI values which are closest to 0 due to the high reflectance in both the visible and NIR portions of the electromagnetic spectrum (Lillesand and Kiefer 1994).

In order to study the vegetation cover in Metro Vancouver, 10-day composite NDVI data are derived from the sensor VEGETATION on board the SPOT satellite platform which was assimilated from the “Vlaamse Instelling Voor Technologisch Onderzoek” (SPOT-VGT 2011) for 1998–2012. Also, the Advanced Very High Resolution Radiometer (AVHRR) images have been used for 1984, 1991 and 1995.

The SPOT-VGT S10 (10-day composite) NDVI composites have a spatial resolution of  $1 \text{ km}^2$  and were derived from primary SPOT-VGT products; the composites were corrected for reflectance, scattering, water vapor, ozone and other gas absorption using the procedures described by Achard et al. 1994 and Duchemin 2000.

NOAA-AVHRR images have been taken by the local area coverage Advanced Very High Resolution Radiometer (LAC AVHRR) aboard the National Oceanic and Atmospheric Administration (NOAA) 14–16 satellite was preprocessed using Environment for Visualizing Images software called ENVI. ENVI software is a software application used to process and analyze geospatial imagery. It is commonly used by remote sensing professionals and image analysts.

For temporal analysis, a 28-year period was chosen in order to study the long-term effects of urbanization on the vegetation cover. This research was limited to 28 years due to the failure to access any data records prior to 1984. Preliminary examination of AVHRR data collected from the NOAA satellite database (NOAA 2013) shows that a number of images have severe cloud contamination and/or missing passes. Of the 60 images collected during 1984–1997 (April–September), 7 raw AVHRR images were selected for years 1984–1991 and 1995.



The maximum value compositing (MVC) procedure as described by Holben (1986) was used to merge NDVI values over the course of 10 days. MVC is a procedure used in satellite imaging, which is used for vegetation studies. It requires that a series of multi-temporal geo-referenced satellite data be processed into NDVI images. On a pixel-by-pixel basis, each NDVI value is examined, and only the highest value is retained for each pixel location. After all pixels have been evaluated, the result is known as an MVC image (Holben (1986)). The resulting surface reflectance value for each pixel thus corresponds to the date with the maximum NDVI value in a 10-day period. MVC for the synthesis of daily NDVI values was found to be a reliable way for sensing changes in vegetation cover (Lanfredi et al. 2003).

Typical NDVI values range between 0.1 and 0.8 for vegetated areas, with a higher (composite) NDVI value corresponding to denser, greener vegetation. The temporal evolution of NDVI values is considered to be an effective way to analyze the impact of (1) natural seasonal variations, (2) extreme climatic events and (3) human activities on ecosystems (Telesca and Lasaponara 2006). The temporal evolution of NDVI values for the period 1998–2012 was analyzed in Metro Vancouver, British Columbia, Canada. Average, decadal NDVI values on farmland were calculated by spatial aggregation of the 1.1-km<sup>2</sup> pixels.

#### 4.2 Assessment of climate change caused flood impacts on human health

The potential health impacts of floods can be both direct and indirect. These impacts strongly depend on the type of flood event and the environmental, ecological, social and economic conditions which prevail in affected area. Direct health impacts normally include immediate loss of life and physical injuries. Secondary health effects are due to infectious/communicable diseases (types and varieties dependent on geographic location), which compromised healthcare access for individuals suffering from non-communicable chronic diseases and mental health conditions (Waroux 2011). The time frames and magnitude of each category are also time dependent with infectious complications in general, occurring early, the effects on non-communicable disease and mental illness occurring somewhat later or even extending into long-term health issues. These long-term consequences, particularly mental health related, are beginning to attract more attention. Floods have the potential to cause a much larger impact on health and well-being of human populations than that was previously appreciated (Tapsell and Tunstall 2008).

In high-income countries such as Canada, the infectious diseases risk is generally considered low. The greatest risk is related to the possibility of waterborne diseases as a result of drinking water contamination, but experience has shown that in larger urban areas where water treatment and wastewater infrastructure is well maintained, the risk is low. Communities with less well-developed infrastructure are clearly at higher risk during extreme weather events as demonstrated by the Walkerton, Ontario experience (Schwartz and McConnell 2009). Flood-related morbidity in high-income countries is more heavily weighted to loss of access to health care for people with chronic, non-communicable conditions such as dialysis and ongoing cancer care. As more resources are also being diverted to keep the frail elderly in the home, access for the caregivers is becoming increasingly important during a flood event.

It is being recognized that longer-term consequences, such as the presence of mold, post-flooding, have a detrimental effect on human health (WHO 2009). In addition, mental health conditions, such as post-traumatic stress disorder (PTSD) and depression, contribute significant burden of disease during and following episodes of flooding.



In developing countries, in general, people are at a higher risk of infectious diseases due to the endemic presence of a wide variety of infectious conditions in many locales that are prone to flooding. Non-communicable diseases also contribute significantly to the burden of disease in the pre-disaster state, so lack of ongoing healthcare provision is still a significant factor when severe flooding occurs. Mental health conditions likely contribute significantly to the burden of disease but there are few studies to indicate the magnitude of the problem. Additional factors, such as environmental degradation, poverty, poor housing, warfare and political factors, combine to increase the health burden brought on by floods and sea-level rise (Waroux 2011).

## 5 Results and discussion

### 5.1 RS techniques that applied for extracting the vegetation

Using ENVI software, geometric corrections for all the images were performed in two subsequent stages using ephemeris data and ground control points. In the ground control point method, polynomial transformation was employed and root mean square (RMS) error values averaged around 0.8 pixels. The resulting images had a nominal spatial resolution of 1.1 km<sup>2</sup>.

During each year of the study, images were collected from the same 10-day period for August, and the ones that had the least cloud contamination were selected to produce NDVI images. From these images, 10-day maximum NDVI monthly composites were subsequently generated. In order to validate SPOT-VEG maps, they were later compared to similar NOAA-AVHRR NDVI maps. After validating the NDVI images, min/max NDVI and long-term NDVI images were obtained based on maximum value composite (MVC) using ENVI software.

### 5.2 Vegetation maps and trend

As previously mentioned, preprocessing was applied to the input data in order to obtain the 10-day NDVI images. Figure 4 shows the vegetation condition for the years 1984, 1991, 1995, 2000, 2005 and 2012. NDVI varies between 0 and 1. The value closer to one represents the higher percentage of vegetation cover. Significant decrease in vegetation is visible in central and eastern parts of the city in last 28 years.

Figure 5 shows vegetation trend between years 1984 and 2012. From 1994 to 1997, NOAA AVHRR are used; from 1998 to 2012, SPOT-VEG sensor data. There are a few extreme drops in vegetation condition in years 1991, 2002 and 2005 which are caused by cloud contamination of the images.

## 6 Conclusion and discussion

Over the last three decades, urbanization has taken place everywhere. From the conservation point of view, the urban planning is essential for development of urban areas. In the Fraser River Delta where the City of Metro Vancouver is located, severe land-use change took place over the last three decades. The vegetation cover change affects the river flows, leading to possibility of floods. Due to increased impervious area, precipitation responds

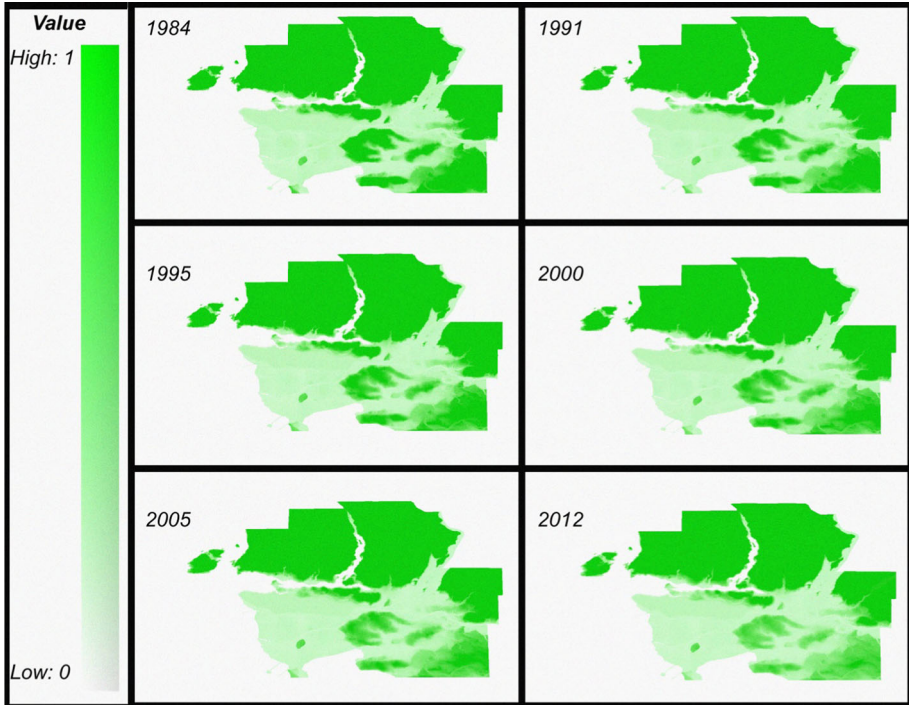


Fig. 4 Vegetation condition

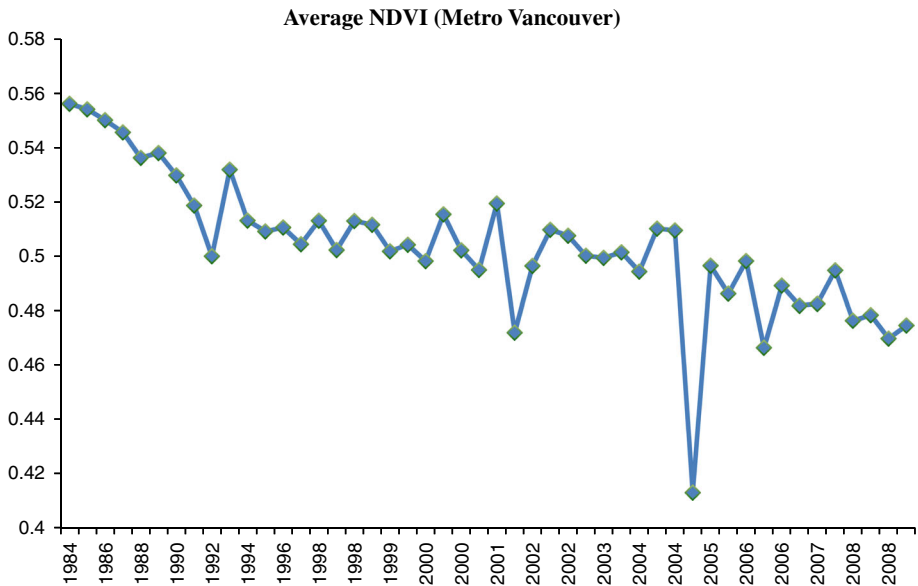


Fig. 5 Vegetation trend between 1984 and 2012, Metro Vancouver

quickly, reducing the time to peak and producing higher peak flows in the drainage channels. Deforestation and urbanization are continuing.

With the help of remote sensing technology, the Metropolitan Vancouver area could be studied efficiently in less time compared to conventional methods. To update the land-use database in the watershed, more recent and higher-resolution satellite imagery will be required together with the land-use classification. The case study is an example of how remote sensing technology can help in understanding the development pattern in the area and its affect's on the flood regime. Therefore, this technology can help the authorities in developing the conservation policies with respect to land use. In summary, vegetation monitoring and conservation have direct impact on human health and flood emergency management in coastal mega cities located in river deltas. It is time to increase the capacity of megacities to successfully adapt and cope with risks posed by the effects of climate change.

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