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Coastal urban climate resilience planning in Quy Nhon, Vietnam

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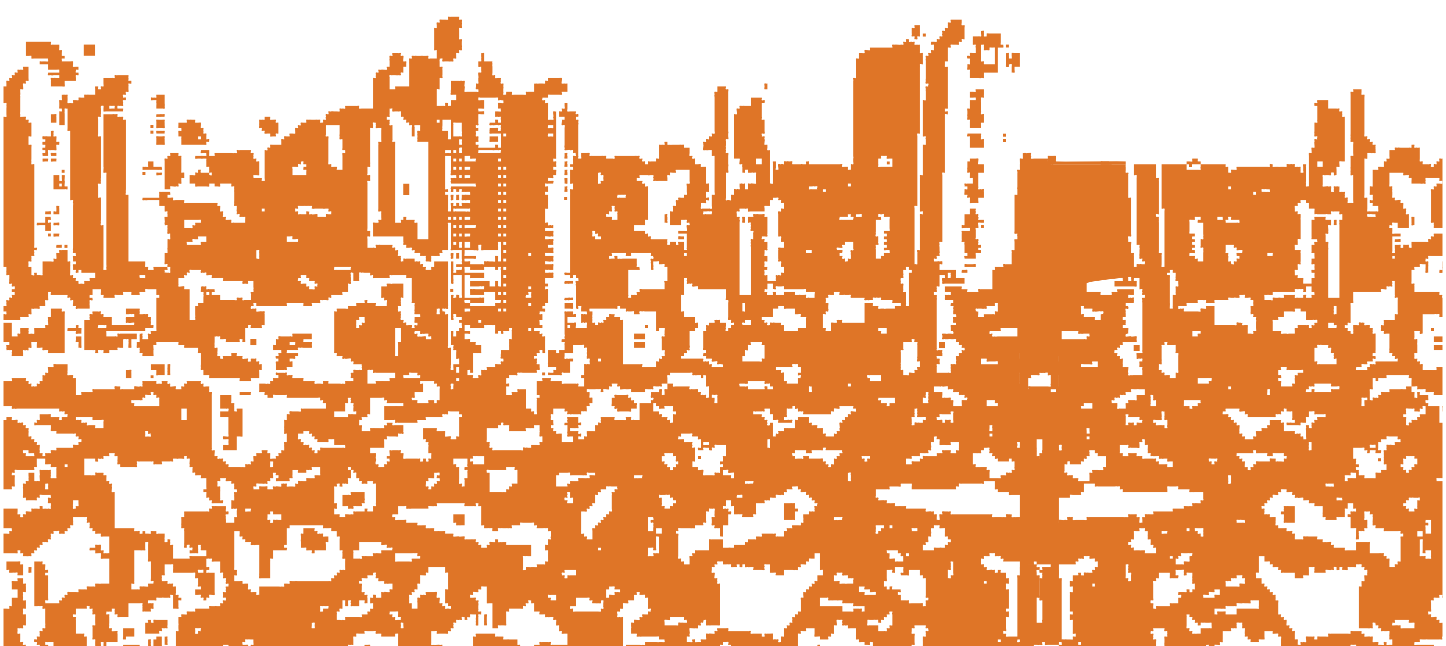

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Abstract

Climate change, sea-level rise and associated events such as shoreline erosion, coastal flooding and water pollution could affect coastal areas in a variety of ways. New approaches to understanding urban planning and land, water, waste and ecosystem management are needed.

In this working paper, we have used a series of Landsat satellite images from 1973 to 2013 to detect changes in urban areas and shoreline modifications of Quy Nhon City, Vietnam. Results show that the changes are significantly associated with anthropogenic activity. We also used logistic regression to test the relevant spatial variables involved in the urban expansion process.

Our study reveals that urban planning is a spatial decision-making process, which requires a multi-disciplinary research approach. It should take into account a range of factors from social aspects to the natural conditions of the urban territory, which is required to consider city development in a global context.

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Acronyms

ACCCRN	Asian Cities Climate Change Resilience Network
CC	Climate change
CCCO	Climate Change Coordination Office
CPC	City People's Committee
DARD	Department of Agriculture and Rural Development
DOC	Department of Construction
DONRE	Department of Natural Resources and Environment
ENSO	El Niño Southern Oscillation
ETM	Enhanced Thematic Mapper
IMHEN	Institute of Meteorology, Hydrology and Environment
IPCC	Intergovernmental Panel on Climate Change
MLR	Multiple logistic regression
MSS	Multispectral scanner
LDCM	Landsat Data Continuity Mission (Landsat 8)
TM	Thematic Mapper
VNU	Vietnam National University

1 Introduction

Climate change is one of the most challenging global issues facing humanity. The impacts of climate change and its associated events such as shoreline erosion, sea-level rise, coastal flooding and water pollution will affect coastal areas in a variety of ways. Alongside the effects of climate change, confronting existing challenges about environment and development are also of concern (Romero-Lankao, 2008; Romero-Lankao and Dodman, 2011). However, addressing the additional stressors of climate change and sea-level rise may require new approaches to urban planning and land, water, waste and ecosystem management along the coast.

As a country located in southeast Asia, with 3,260 km coastline spanning 15 degrees of latitude, Vietnam has a varied topography and diverse climates. It is also situated along the northwest Pacific Ocean typhoon route, exposing the country to an average of seven typhoons per year, particularly in central parts (World Bank, 2011). Given that a high density of the country's population and economic activities are located in the coastal lowlands, analysing spatial and temporal changes in urban areas and shoreline modifications, therefore, is an important aspect of coastal city planning. This is particularly true as there is a lack of sufficient and high-quality data for urban climate-resilience research in Vietnam, which creates increasingly serious challenges.

The city of Quy Nhon has expanded into areas that are prone to flooding and other storm-related risks (DiGregorio, 2013). In the context of climate change and sea-level rise, and as local authorities, investors and urban planners confront these risks, they have focused their attention on flood-proofing site plans, constructing and upgrading flood-related infrastructure such as the East dyke system and building concrete shorelines in many places near the coast. However, the uncertainties of climate change mean that costly infrastructure built now may not be able to protect new urban areas in the future. Therefore, understanding the city plan, development plans and shoreline modification are essential to supporting urban climate resilience planning in Quy Nhon.

This working paper aims to examine different approaches to urbanisation and shoreline modification through three research questions:

- Where are urbanisation and shoreline modifications taking place? Where they are likely to take place in the future?
- What problems are caused by urbanisation and shoreline modification in the context of climate change planning?
- From local perspectives, what are possible solutions for climate-resilience planning in Quy Nhon?

2 Background

2.1 Case study area: city of Quy Nhon

Situated beside the Thi Nai lagoon, Quy Nhon City has undergone dramatic changes in its land-use patterns due to very rapid urbanisation and industrialisation. The physical growth of the city was caused by the development of residential and industrial activity around the city, particularly since the 1960s.

Quy Nhon is the capital of Binh Dinh Province and is also under its administrative jurisdiction. The city has a total area of 285.5 km^2 and a population of over 280,000 people (Quy Nhon sub-Office of Statistics, 2013). It includes 16 wards and five communes. Established in 1898 as a small trading town, Quy Nhon's first period of rapid growth occurred between 1964 and 1974, the period of the American war. After the war, government policies encouraged refugees to return to their home areas through resettlement and incentive programmes and the creation of 'new economic zones' which included clearing forested areas for agriculture (DiGregorio, 2013).

In the last several years, the city has experienced a boom in industrialisation and urbanisation. Massive multi-core international, national and provincial investments have included building the Nhon Hoi bridge and port, upgrading the Quy Nhon fishing port, upgrading national road 19, constructing the Phu Tai industrial area, and establishing the An Phu Thinh and Bui Thi Xuan residential areas.

Economically, these investments have provided new infrastructure and residential areas, and have helped in building a broad and highly diversified modern industrial base. However, these activities have put dramatic pressure on the urban environment and threaten the preservation of the surroundings of the Thi Nai Lagoon. Unplanned conversion of land and reclamation of water bodies for residential, transportation and industrial purposes may exacerbate the flood risk in downstream of the Ha Thanh and Con rivers and desertification in Phuong Mai Peninsula. They may also push the city's growth towards unsustainable development. This has become one of the most significant issues faced by the local authorities. Future sustainable urban management requires a deep understanding of the city's development path and city planning.

2.2 Climate change and sea-level rise in Quy Nhon

Several climate change and sea-level rise scenarios in Quy Nhon have been developed by the Vietnam Institute of Hydrology, Meteorology and Environment (IMHEN, 2011) including A1F1 (fossil-fuel intensive, high emissions), B2 (medium emissions) and B1 (low emissions). According to these scenarios, and to results from climate change studies in Quy Nhon, the city is projected to be strongly affected by climate change within specific parameters.

2.2.1 Sea-level rise

In the high-emission scenario A1F1, sea level in Binh Dinh is predicted to rise by 83–87cm by the year 2100, which would threaten the survival of coastal cities like Quy Nhon. However, even with medium emissions (B2), a rise of 61–74cm is predicted, and with the low emissions scenario, an estimate of 52–65cm is projected (Table 1). The areas anticipated to be affected by flooding are located in the lowest parts of the city in Nhon Binh, Nhon Phu and Quang Trung wards and a small part of Phuong Mai Peninsula (Climate Change Working Group of Quy Nhon city, 2010). Each of these areas have high concentrations of low-income earners working as farmers and fishermen (Van and Thai, 2011).These areas – with about 70,000 inhabitants in 2012 (Quy Nhon Sub-office of Statistics, 2013) – will be most exposed to the hazards that will affect the sustainable development of the city, requiring the government to improve its services and infrastructure. As sea-level rise is uncertain – especially when associated with climate change – it is critical that decision makers embed climate change scenarios into city planning processes so that they can mitigate the local community's exposure to its effects.

Table 1. Scenarios for sea-level rise in Quy Nhon

	High-rise scenario (A1F1)		Medium-rise scenario (B2)		Low-rise scenario (B1)	
Year	**Predicted rise (cm)**	**Areas flooded (km^2)**	**Predicted rise (cm)**	**Areas flooded (km^2)**	**Predicted rise (cm)**	**Areas flooded (km^2)**
2020	8–9	25.16	8–9	25.14	8–9	25.12
2050	26–30	28.86	23–27	28.50	22–26	28.4
2070	45–53	31.63	37–44	30.78	34–42	30.43
2100	79–99	35.85	59–75	34.20	51–66	33.18

2.2.2 Temperature

Table 2 shows the mean temperature variation in Quy Nhon from a dataset of 50 years in comparison with the baseline period from 1980 to 1999. According to the data, the range of temperature variation in Quy Nhon (absolute value) in the winter is much higher than in the summer, however the variation does not change notably over each year. However, calculating the decadal variation of monthly mean temperature shows that the mean temperature in January remained unchanged during three decades from 1961 to 1990 at 23ºC but increased by 0.6ºC from 1991–2000 and decreased a bit in the decade of 2001–2010. Mean temperatures in July also remained almost unchanged at 29.6ºC in the decade 1961–1970 then increased by 0.2ºC per decade in 1971–1990, but from 2001–2010, it increased to 30.2ºC.

The results from IMHEN's developed models show that by the end of the 21st Century, annual mean temperatures in Vietnam could increase by between 1.1–1.9ºC (scenario B1), 1.6–2.8ºC (B2) and 2.1–3.6ºC (A2). Accordingly, the average temperature in Binh Dinh Province would tend to rise, with the fastest increase from March to May and the lowest increase from June to August. Specifically, up to 2050, the annual mean temperature according to the high-, medium- and low-emission predictions would increase by around 1.3ºC, 1.2ºC and 1.1ºC respectively. By 2100, an increase of annual mean temperature according to each scenario is projected at 2.9ºC, 2.3ºC and 1.5ºC.

Table 2. Temperature variance 1961–2010

Year	January	July	Yearly	Year	January	July	Yearly
1961	–0.4	0.1	–0.1	1986	–0.9	0.0	–0.4
1962	–0.8	–0.8	–0.8	1987	0.2	0.9	0.1
1963	–1.8	–0.1	–0.8	1988	0.8	0.1	0.0
1964	1.4	–1.9	–0.5	1989	0.1	–0.5	–0.5
1965	–1.4	0.0	–0.3	1990	0.4	0.3	0.0
1966	1.0	–1.1	0.1	1991	1.1	–0.5	0.0
1967	–1.3	–0.3	–0.6	1992	–1.2	–0.3	–0.1
1968	–0.3	–0.5	–0.5	1993	–0.2	0.1	–0.1
1969	1.7	–0.3	–0.1	1994	0.1	0.5	0.4
1970	–0.7	–0.4	–0.2	1995	0.5	–0.4	–0.1
1971	–0.7	–0.5	–0.9	1996	–0.2	–0.4	–0.3
1972	–1.0	0.3	–0.2	1997	–0.3	0.5	0.4
1973	0.9	–0.3	0.0	1998	2.3	–0.3	0.8
1974	–0.8	–0.4	–0.4	1999	0.5	0.3	0.1
1975	–0.1	–0.1	–0.1	2000	0.8	–0.6	–0.2
1976	–1.2	–1.1	–0.7	2001	1.1	0.9	0.4
1977	–0.7	0.1	–0.7	2002	0.7	1.4	0.4
1978	0.3	–1.0	–0.2	2003	–0.2	–0.3	0.4
1979	0.9	0.1	0.1	2004	0.2	–0.4	0.0
1980	0.6	0.1	–0.1	2005	–0.4	0.0	–0.1
1981	–0.6	0.0	0.2	2006	–0.2	0.3	0.3
1982	–0.6	0.7	0.1	2007	0.2	–0.4	–0.1
1983	–0.2	–0.3	–0.2	2008	–0.1	0.0	–0.3
1984	–1.6	–0.9	–0.4	2009	–0.8	0.1	0.1
1985	–0.2	–0.4	0.0	2010	1.2	–0.5	0.3

Source: (IMHEN, 2011)

2.2.3 Rainfall

The Climate Change Working Group of Quy Nhon city (2010) shows that rainfall is predicted to increase during the long rainy season (September to November) and decrease in the short rainy season (March to May). The largest predicted increase in rainfall should be September to November with 11.3–19.2 per cent and the largest decrease should be March to May with 5.5–9.3 per cent. Up to 2100, annual rainfall is predicted to increase from 2.3–3.9 per cent in all scenarios from medium (B2) to high (A2) and highest (A1FI). All scenarios predict that annual mean rainfall will increase by approximately 0.6 per cent by 2020 (Van and Thai, 2011).

2.2.4 Extreme weather projections

Recent studies show that in recent decades, storms have tended to move southward and occur later in the year. According to the IPCC, the occurrence and patterns of storms should change along with climate change; therefore, storms should occur with more frequency, higher intensity and with a longer storm season (Van and Thai, 2011).

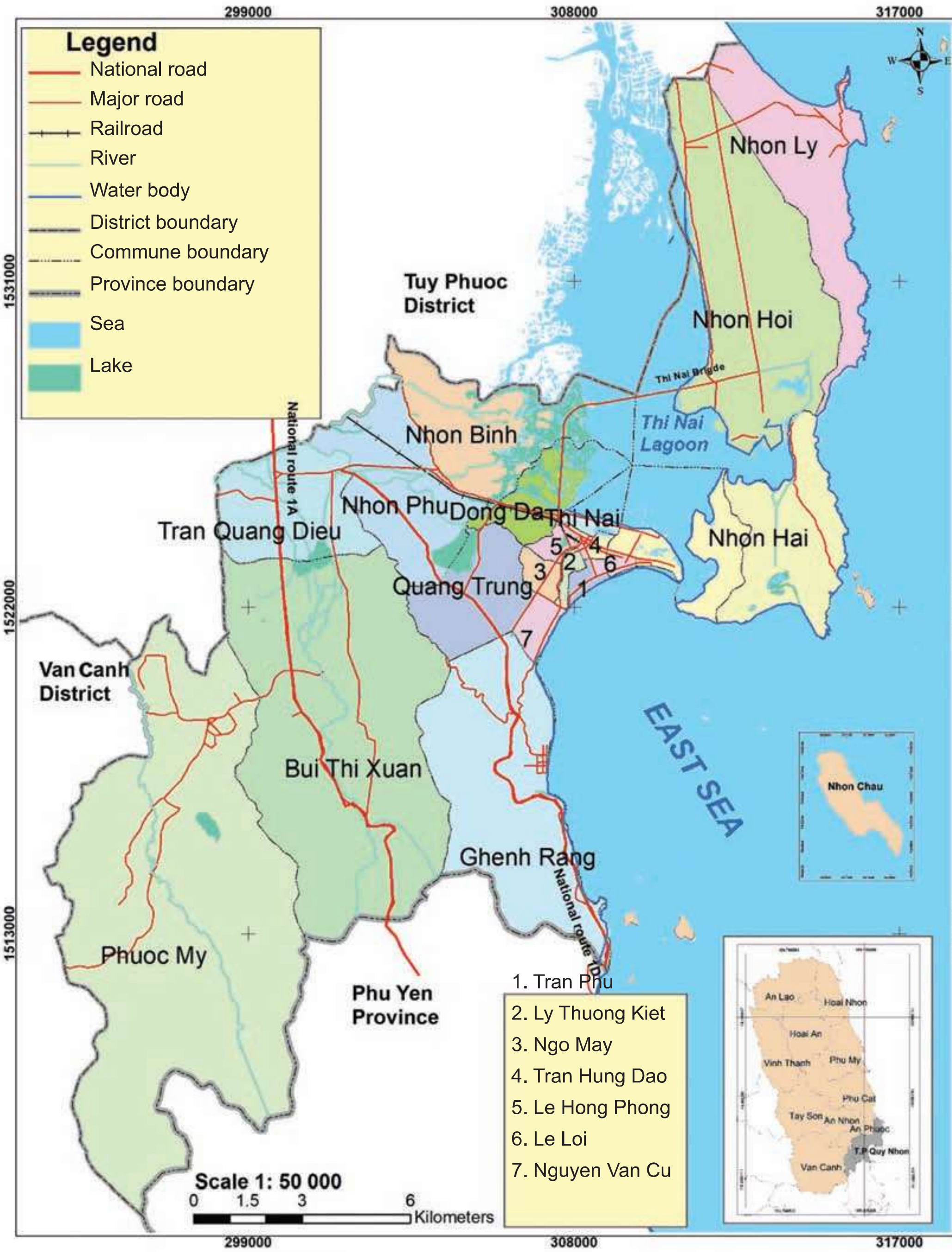
A recent study indicates that the climate phenomenon, the El Niño Southern Oscillation (ENSO) phenomenon, has been more active recently (Li *et al*., 2013). It states that 'the unusually high ENSO activity in the late 20th Century is a footprint of global warming' as ENSO is characterised by warmer ocean temperatures in the Pacific Northwest – a phenomenon that can cause major floods and extreme weather across the ocean. Consequently, as a coastal city lying on the eastern-most part of the Indochina Peninsula, Quy Nhon is very exposed to the likely effects of climate change, and therefore is increasingly at risk.

Observed data at Quy Nhon's hydrological meteorological station shows the cyclical impact of warm-phase ENSO has tended to increase during the last decades of the 20th and early 21st centuries (occurring on average every two to four years) in comparison to the first half of the 20th Century. The maximum temperature of several months in the summers of 1986, 1987, 1992, 1998, 2003, 2005 and 2007 was 1–1.5ºC higher than the monthly mean and 3.2–4.7ºC higher than the annual mean compared to previous years. Rainfall in Quy Nhon also strongly fluctuates. Compared with the average, rainfall tended to increase in 1955–1964, then markedly decreased in 1965–1984 and increased again in 1985–2004. In addition, rainstorms and floods in Binh Dinh historically haveoccurred in late October, but in recent years, due to the anomalous variations in rainfall, floods came very early in 2000 and 2005 and very late in 2001; sea level and flood peaks were often higher than before (Climate Change Working Group of Quy Nhon city, 2010).

2.3 City development and urban planning

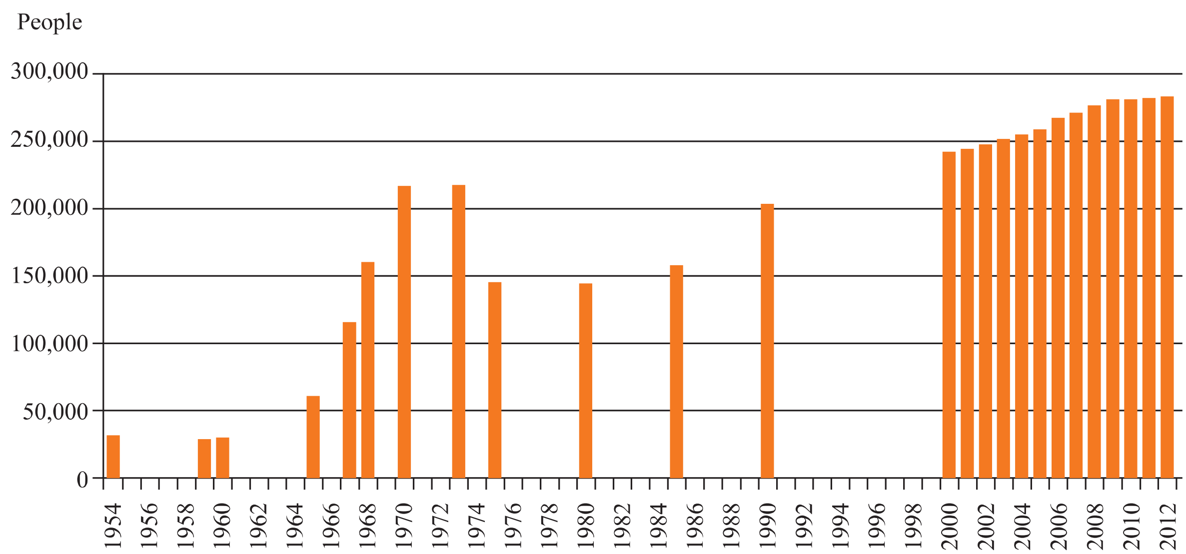
The development of Quy Nhon after Doi Moi in 1986 (the economic renovation or reform process) has been remarkable. From a small city with eight wards, six communes and 160,000 inhabitants in 1986, Quy Nhon has added two more wards, Bui Thi Xuan and Tran Quang Dieu, to the old Phuoc Long Commune of Tuy Phuoc District. In 1998, several city wards were divided, and Nhon Binh and Nhon Phu communes became city wards. In 2006, the city's administrative boundaries expanded into Phuoc My Commune. The city's current administrative map is presented in Figure 1.

Figure 1. Administrative map of Quy Nhon



The city's population grew from about 60,000 people in 1965 to nearly 220,000 in 1973 (Bang and Hieu, 1998). After the end of the war in 1975, there was a large migration of refugees, who moved out of Quy Nhon to the 'new economic zones'. As result, the population dropped after 1975, but grew again at a steady pace after 1983. The evolution of the city's population can be seen in Figure 2.

Figure 2. Quy Nhon population 1954–2012

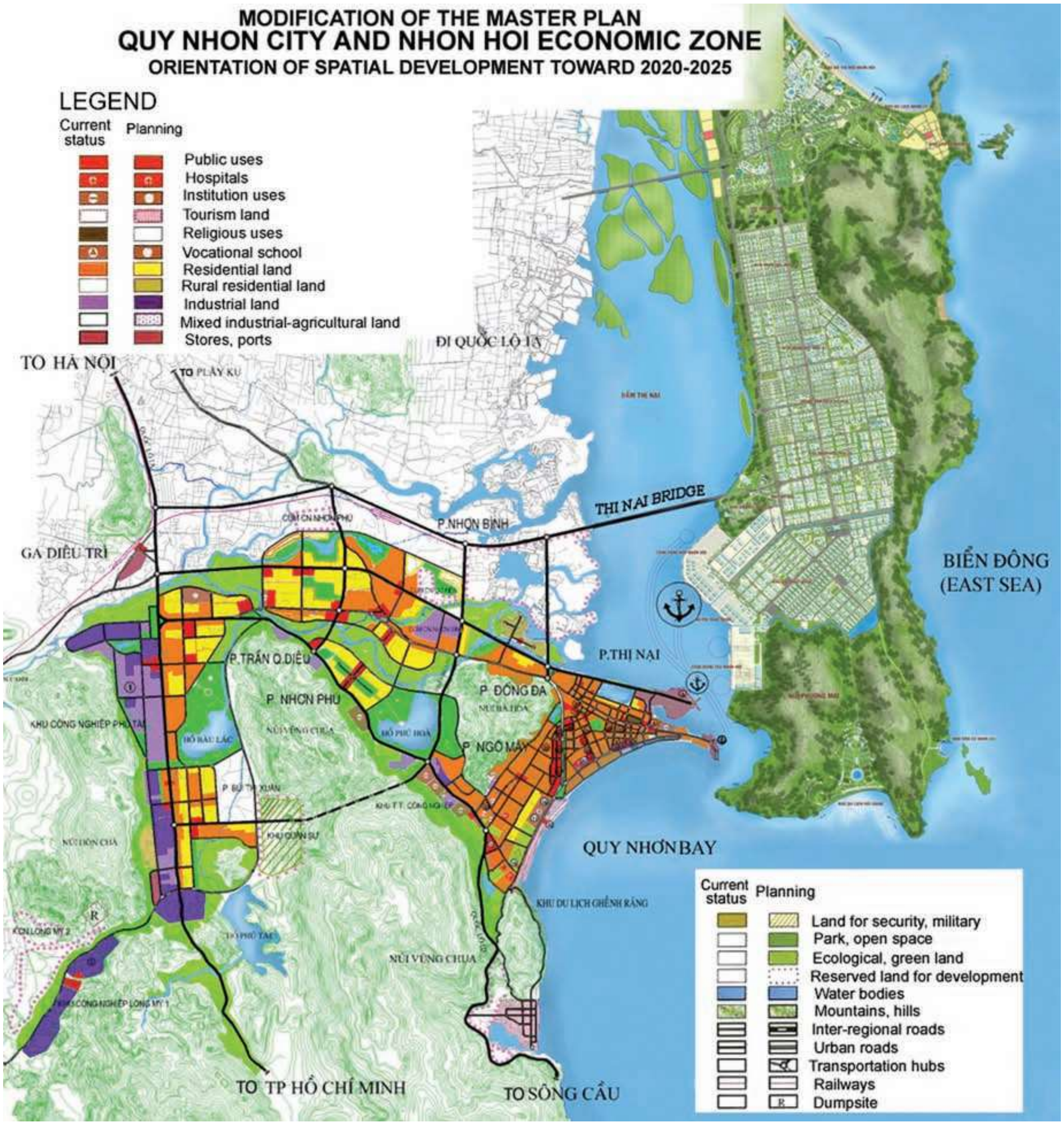


Source: (Bang and Hieu, 1998; Quy Nhon Sub-office of Statistics, 2013).

The master plan of Quy Nhon City to 2020 was approved by Decision No 98/QD –TTg dated 1 June 2004 (The Prime Minister of Vietnam, 2004). According to the plan (Figure 3), the expansion of Quy Nhon is based on several criteria:

- To improve the efficiency of land use, urban areas will expand into unused areas or areas with less efficient land use, such as some parts of other urban areas in the central (12 wards, 5686ha), north (Nhon Binh and Nhon Phu, 2787ha) and west (Tran Quang Dieu and Bui Thi Xuan, 6058ha).
- To expand the city towards Long My (Tuy Phuoc) with 6942ha for an industrial zone with a dedicated residential area, and also towards Nhon Hoi on the Phuong Mai Peninsula with integrated economic complexes consisting of a deep seaport and its services, trading services, tourism and an urban residential area with a total estimated area of 12,000ha.

Figure 3. Master plan of Quy Nhon 2020–2025



Source: Binh Dinh Planning and Construction Verification Centre (The Prime Minister of Vietnam, 2004).

The master plan of Quy Nhon City to 2035 and vision towards 2050 was approved by Decision No 1703/QD-TTg on 23 September 2013. The detailed plan has not yet been released. The plan aims:

- To turn Quy Nhon into the central city of the coastal central region with economic development based on industry, seaport, services and tourism by 2035.
- To turn the city into the national marine economic centre with economic development based on services, industry, tourism and the seaport and particularly focusing on services and the seaport by 2035.
- To turn Quy Nhon into an important city in Vietnam and Southeast Asia by 2050. The city will play an important role in the central region with economic development based on tourism, services, the seaport and industry with a special focus on tourism, services and the seaport. The city will receive substantial international investment and cooperation in medicine, education, tourism, environment and highly qualified human resources by 2050.

3 Data and methodology

Quy Nhon has large-scale plans for development and growth, but it also faces possibly severe impacts due to climate change. So this study's objectives – to understand the consequences of shoreline modification and urbanisation in a context of climate change – are very important.

A number of different methodologies were used in this study, as explained in this section.

3.1 Data collection

Satellite remote-sensing imagery provides the advantages of broad area coverage, systematic observations and the ability to use standardised and repeatable analyses to characterise the Earth's surface. In short, remote-sensing imagery offers opportunities for monitoring change over a time period at a particular location (Herold *et al*., 2006; Seto and Christensen, 2013). For Quy Nhon, a time series of cloud-free Landsat images were chosen both for the purposes of examining shoreline modifications and the urban changes.

Among the tremendous amounts of remote-sensing data, Landsat data were selected because of their efficiency and no cost. In order to detect shoreline changes and urban development, four types of Landsat satellite images – Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Land Data Continuity Mission (LDCM, Landsat 8) – were acquired for different dates (Table 3). The 1992 image does not cover the whole city of Quy Nhon, so the Landsat image acquired on 27 August 1988 was used to cover the remaining area. These images were selected because they presented the extent of Quy Nhon City every 10 years from 1973 to 2013.

Landsat images provide information with sufficient spatial and spectral resolution. The infrared and shortwave-infrared images support the study's ability to calculate the urban index, which is useful for monitoring urban change. The infrared channel can also provide information about the shoreline if a threshold value is used in this channel.

Topographic maps at scale of 1:50,000 and 1:25,000 were used. The entire area of Quy Nhon City is covered by four 1: 50,000 sheets numbered D-49-51-A, D-49-51-B, D-49-51-C, D-49-51-D; and four 1:25,000 sheets numbered D-49-51-A-b, A-49-51-A-d, D-49-51-B-a, D-49-51-B-c. Those maps were published in 2001 and 2002 by Vietnam Publishing House of Natural Resources, Environment and Cartography. The topographical maps were made using MicroStation (*dgn extension), so a conversion into ArcGIS was made. Separated map sheets were merged together to cover the entire area of Quy Nhon.

Table 3. Landsat images used for the study

Sensor/acquired date	Wavelength (µm)	Spatial resolution (m)	Swath (km)	Source
Landsat MSS 23/02/1973	0.50–0.60	60	179	
	0.60–0.70	60		
	0.70–0.80	60		
	0.80–1.10	60		
Landsat TM 27/08/1988 05/07/1992 Landsat ETM+ 04/04/2002 03/11/2005	0.52–0.90	15 (ETM+ only)	185	The US Geological Survey
	0.45–0.52	30		
	0.53–0.61	30		
	0.63–0.69	30		
	0.78–0.90	30		
	1.55–1.75	120		
Landsat LDCM 28/05/2013	0.50–0.68	15	185	The US Geological Survey
	0.43–0.45	30		
	0.45–0.51	30		
	0.53–0.59	30		
	0.64–0.67	30		
	0.85–0.88	30		
	1.57–1.65	30		
	2.11–2.29	30		
	1.36–1.38	30		
	10.60–11.19	100		
	11.50–12.51	100		

The topographic maps are in VN-2000 datum which is a national coordinate system based on Ellipsoid WGS84 (World Geodetic System – see National Geospatial-Intelligence Agency, 1984) with major axis a = 6378137m, and flat parameter =1:298.2 with Universal Transverse Mercator projection. The topographical maps in this study all used the same database coordinates system.

Beside topographic maps, different maps were collected such as the 2005 and 2010 land-use map, the urban planning map up to 2020 (under the Decision No 98/QD –TTg on 1 June 2004 of Prime Minister on adjusting urban planning in Quy Nhon City), and a map of Thi Nai Lagoon. Theses maps were used for references in multiple logistic regressions to test the relationship between urbanisation and different variables. The results from the statistical analysis could be used to build future scenarios.

The statistical yearbooks of Quy Nhon were collected for 2000–2012. Population data is important for understanding how the population has grown in different communes in Quy Nhon City. Population growth is considered one of the strong socio-economic driving forces for urban expansion, and so population figures were captured in the database.

Field trips were conducted for confirming data, conducting accuracy assessments and interviewing local people on climate change as well as land-use changes related to urban expansion.

3.2 Methodology

3.2.1 Remote sensing

The use of remote sensing technology is an important tool in monitoring spatial patterns of urban growth and shoreline change. Satellite remote sensing collects multispectral, multiresolution, multitemporal data providing valuable information for understanding and monitoring the process of urban changes. As data is digital, it can be transferred into GIS, to provide a suitable platform for data analysis, update and retrieval. Urban development can be captured in terms of both geographic location and absolute area. The growth profile obtained helps in formulation of development policies as well as in comparing with urban planning.

Supervised classification was applied to delineate the urban area of Quy Nhon City from 1973 to 2013. Initially, built-up areas were selected, then other land-cover types such as water bodies, vegetation and sand. Then the Maximum Likelihood Classification was applied to derive the expansions of built-up areas in the city over time. Since the images were acquired at different times, several indices were calculated to set the threshold to delineate the difference between water and land, so as to classify the built-up areas and water bodies. These classes were reclassified using on-the-ground triangulation to obtain changes in urban areas and shoreline.

Shorelines change shape and position continuously due to dynamics conditions and other driving forces. Any change in shorelines is mainly associated with waves, tides, winds, periodic storms, sea-level change, and the geomorphological processes such as erosion and accretion and human activities (Van and Binh, 2009). The absorption of infrared radiation by water and its strong reflectance by vegetation and soil make such satellite images an effective tool for mapping the spatial distribution of land and water. Compared to other approaches to detecting shoreline modifications (such as ground surveying, using altimetry technology and aerial photography measurements) the multispectral satellite image has some advantages as it is readily available, low-cost and can monitor large areas of ground. Comparing satellite imagery over long periods of time can determine how much shorelines are changing, including any changes caused by natural coastal processes as well as human activities.

Experiments have shown that water is a strong absorber of near-infrared radiation (NIR), so Landsat MSS Band 7, Landsat TM Band 4, Landsat 8 Band 5 (0.76–0.90μm) are useful for locating and delineating water bodies, distinguishing between dry and moist soils and providing information about coastal wetlands, swamps and flooded areas.

In the first step, the histogram thresholding method was used on the NIR band to distinguish between land and water. The threshold values were selected based on the minimum and maximum values of samples selected for water bodies so that all water pixels are separated from the land pixels. Water pixels are then assigned to ‘1’ and land pixels to ‘0’. This then produces a binary image.

3.2.2 Geographical information systems

Geographical information systems (GIS) are used to explain the relationship between urban expansion, shoreline modifications and other human activities.

The output maps primarily focused on available information for geographic features, population and land-use changes, etc. The database was designed to detect and explain urbanisation and shoreline modification in Quy Nhon City. Many acquired maps used the VN-2000 datum system while the satellite images (Table 3) used the WGS-84 datum system.

The data was integrated with satellite images using the 1984 World Geodetic System (WGS 84) coordinate system for the datum for the whole set of GIS data for Quy Nhon. All of the above acquired maps were converted to WGS84 datum.

To create a database of Quy Nhon, four steps were carried out:

- Designing a geo-database file called ‘QuyNhon’ in ArcGIS with the coordinate system of WGS-84 UTM Zone 49N. The feature dataset consisted of different features like administrative boundaries, residential areas, rivers, elevation and transportation.
- Using *feature manipulation engine* (FME) software to translate the necessary layers of data from topography map scale 1: 50,000 in MicroStation to ArcGIS and insert the feature classes corresponding to the geo-database which was created above.
- Classifying and filtering to erase those elements located outside of the study area or not necessary.
- Updating outdated information from topographical maps (in 2002) by detecting new elements from Landsat 8 in 2013.

After establishing the database of Quy Nhon, city development and coastal area development were integrated with the current urban plan using the spatial analysis function in GIS.

3.2.3 Spatial analysis

A multiple logistic regression (MLR) model was used as a statistical method for spatial analysis. This method was also used to predict a binary outcome of a dependent variable based on one or more predictor variables (features). A multiple logistic regression model consists of a dependent variable in binary format and some independent variables.

- Understanding the historical urbanisation and urban development of Quy Nhon, the study is concerned with the relationship between urbanisation and other independent variables (topography, slope, transport networks, hydrological networks, land uses). Therefore, a multiple logistic regression model was applied, which considered urbanisation as a dependent variable, and different independent variables were tested in the MLR model.
- The independent explanatory variables are:
    - Topography (m)
    - Slope (degree)
    - Distance to main roads (m)
    - Distance to all roads (m)
    - Distance to rivers (m)
    - Distance to coastline (m)
    - Land use: paddy fields, aquaculture, unused areas, land used for annual crops, productive forests, protected forests, special-use forests, grazing land and industrial areas.
- The dependent variables: 0 is equal to no urbanisation and 1 is urbanisation present.

Multiple logistic regression is used to model the probability of occurrences of a binary or dichotomous outcome. Binary-valued covariates are usually given arbitrary numerical coding such as zero (0) for one possible outcome and one (1) for other possible outcomes. The response variable in this study is the presence or absence of a land-use change over a considered period and follows a binomial distribution. The explanatory variables in this study are continuous (e.g. elevation, slope, distance to main roads) which is considered quantitative, or categorical (e.g. land use) which is considered qualitative. Therefore, land-use variables are in qualitative format, and the rest are in quantitative format. Land-use categories (Figure 5) were coded from 1 to 9.

MLR techniques estimate regression coefficients for each independent variable based on a set of observed events. These coefficients can be used as parameters to calculate transition probability maps. If X_k is a collection of independent variables and Y is a binomial outcome variable with probability of success $p = Pr(Y=1|X)$ with $Y = 0$ meaning the absence of change, $Y = 1$ meaning the presence of change, a linear logistic model has the following form:

$$\text{logit}(p) = \text{In}(p/(1 - p)) = a + b_1X_1 + \ldots + b_kX_k$$

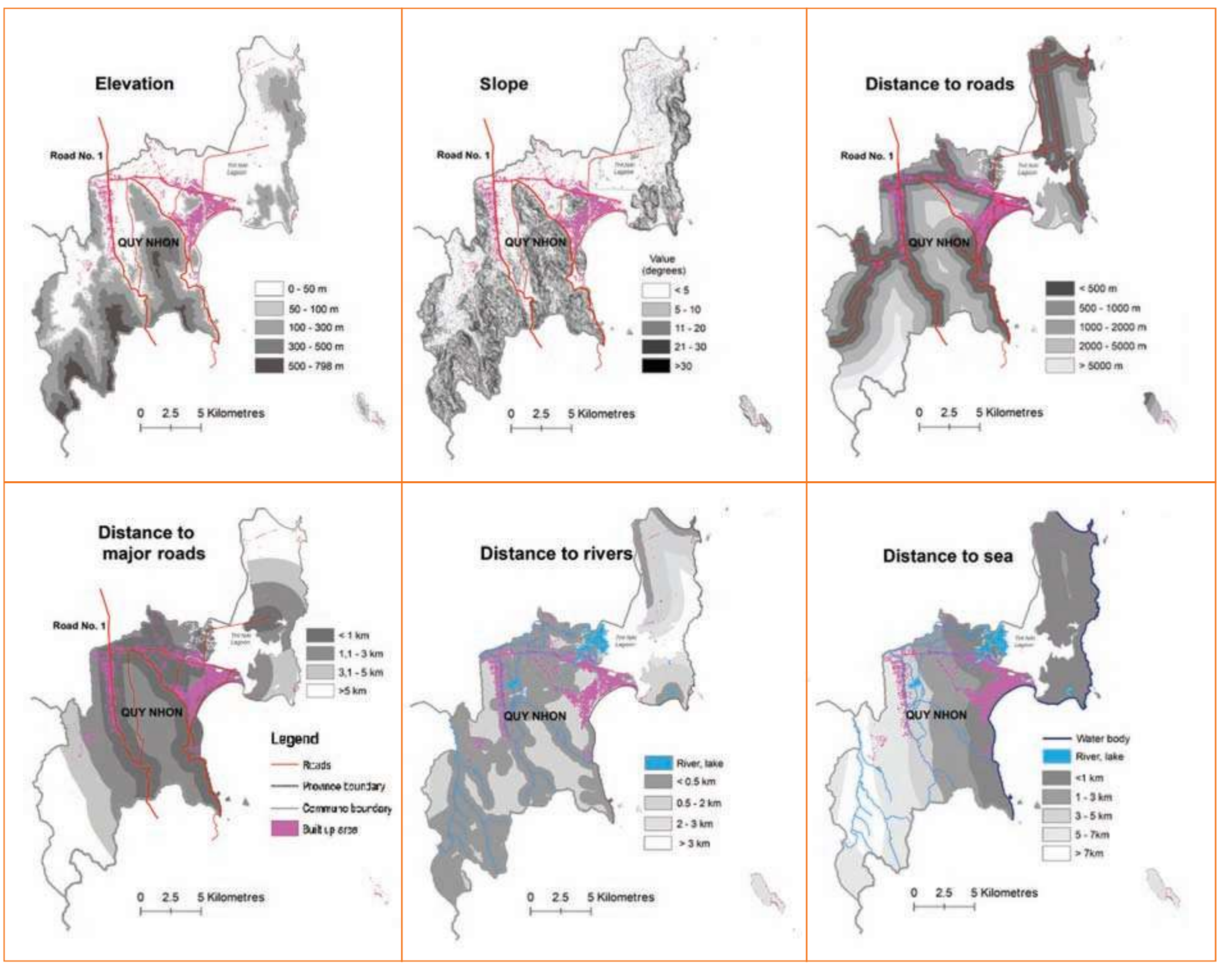
where a is the intercept, $b_1, \ldots, b_k$ are parameters

In the equation, logit (p) is the natural logarithm of the odds ratio which is the likelihood an event will happen (p) divided by the likelihood an event will not happen (1 – p) (Hosmer and Lemeshow, 2000). Urbanisation probabilities (p) values can thus be assessed using the following equation:

$$p = \frac{e\,(a + b_1X_1 + b_2X_2 + \ldots + b_kX_k)}{1 + e\,(a + b_1X_1 + b_2X_2 + \ldots + b_kX_k)}$$

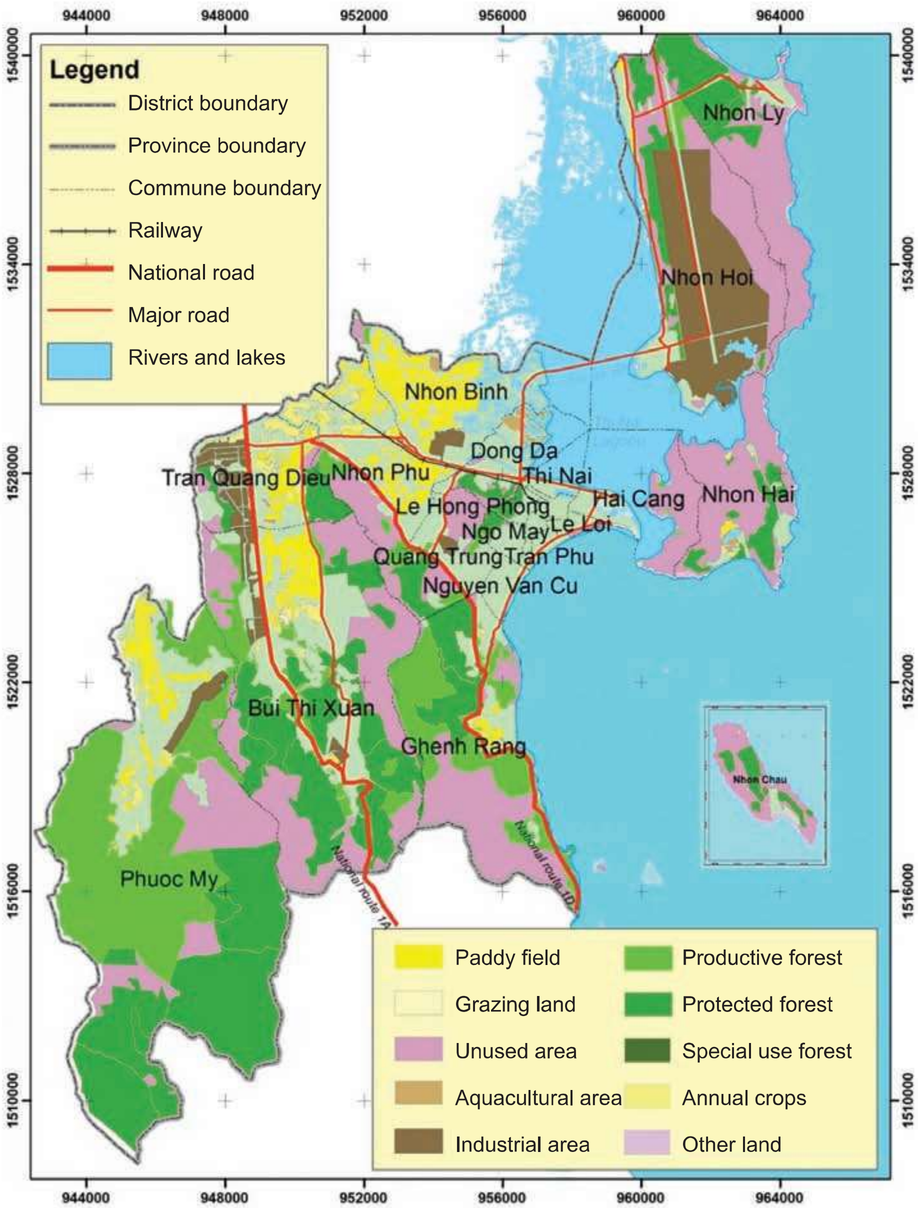
The assessed parameters (b_i) describe how much change will occur in X_i. For example, if $e^{b_i} = 2$ then the odds will double with each unit increase in X_i. If $e^{b_i} = 0.5$ then the odds will halve with each unit increase in X_i. Negative estimates for bi indicate that higher values of dependent variable X_i reduce the probability of a land-use transition.

Figure 4. Various independent variables



The MLR analysis was run on 10,000 stratified sample points of urbanised and non-urbanised locations, which were taken randomly over the study area. This sampling procedure combines the strong geographic coverage of the systematic scheme with the low potential for bias of the random scheme. For each sample point the following data were collected: (1) the value of the dependent variable (1 if it was considered that urbanisation had occurred during the observed time, 0 if it had not) and (2) a set of independent explanatory variables such as distance to shoreline, rivers and roads, elevation (topography), slope and land use (Figure 4).

Figure 5. Land-use map 2010



Using the tool 'Create Random Point' in ArcGIS to find the values at the sample points in eight layers of variables, the attribute data was exported into Excel to do further statistical analysis using XLSTAT software to carry out logistical regressions. The results are presented in different tables in section four.

3.2.4 Focus group discussions

To obtain local perspectives on different issues – from urban planning and infrastructure development to environment management in the context of climate change – focus group discussions were carried out with local experts and local trainees in Quy Nhon.

The group discussions included 26 local experts from different departments such as the Department of Agricultural and Rural Development (DARD), the Department of Natural Resources and Environment (DONRE), the Department of Construction (DOC), the City People's Committee (CPC) in Quy Nhon, Climate Change Coordination Office (CCCO) Binh Dinh and University of Quy Nhon.

Local experts in related fields were grouped by their specialised interest as well as their understanding of study area. Discussions in each group focused on four main issues:

- The current situation
- Solutions that have been implemented
- What GIS and remote sensing can support
- Recommendations from the group

Brainstorming and mind mapping methods were used. The discussion topics were divided into four groups as below:

- Group 1. Construction and urban management in Quy Nhon
- Group 2. Climate change impacts in Quy Nhon
- Group 3: Urbanisation and industrialisation
- Group 4: Management of mangroves, coastal zones and dyke systems

In group discussions, participants were asked to propose a project that meets Quy Nhon's development needs, from their own point of view.

3.2.5 Limitations of data and methodologies

The remote sensing data used in this study is Landsat imagery, which has a medium spatial resolution (20*20m) in recent images and coarse resolution (30*30m) in older ones. Whilst this data has advantages, including being free of charge, it covers a period of 40 years, and it allows use of different spectral bands to detect shorelines change or the tendency of spatial urban development.

However, with this medium resolution, it is necessary to go into the field to triangulate the data and check how previous changes have been exposed in the satellite image. Higher resolution remote sensing data such as Quickbird, Worldview or IKONOS, with 1m or less resolution, or LIDAR data with 0.6 vertical accuracy, might have provided more optimal results. However, the cost and expertise requirement for processing data prevented their use here. This study began with the application of remote-image data in detecting shoreline modification and urbanisation; however, the accuracy of shoreline change detection cannot be higher than the finest resolution, i.e. 15m of data that was used. Further research with higher resolution data is recommended.

The GIS and remote-sensing techniques, which were used in this working paper, were compatible with the collected data. MLR was used to predict future urbanisation. However, this method used statistical analysis of previous data to predict future patterns. Therefore, to some extent, it can be useful for predicting future growth in the short term, but as the trends might not always be consistent with the long-term future, so the results might be exaggerated by the past trends.

4 Spatial analysis

4.1 Shoreline modifications

4.1.1 Collecting information on shorelines and dyke systems

By comparing satellite imagery over long periods of time, it is possible to determine how much shorelines are changing including changes caused by natural coastal processes as well as by human activities. Using a series of remote-sensing data, coastal erosion can be observed in certain places. To verify the indoor processing results, fieldwork surveys were conducted and integrated with existing data of urban planning and irrigation to understand the driving forces behind the changes.

The information on river dykes in the estuaries and human construction on the shoreline are very important in this study. A list of acquired data on dyke systems was obtained from the Irrigation sub-Office in Binh Dinh (Table 4 below).

Table 4. Acquired data on dyke and river systems

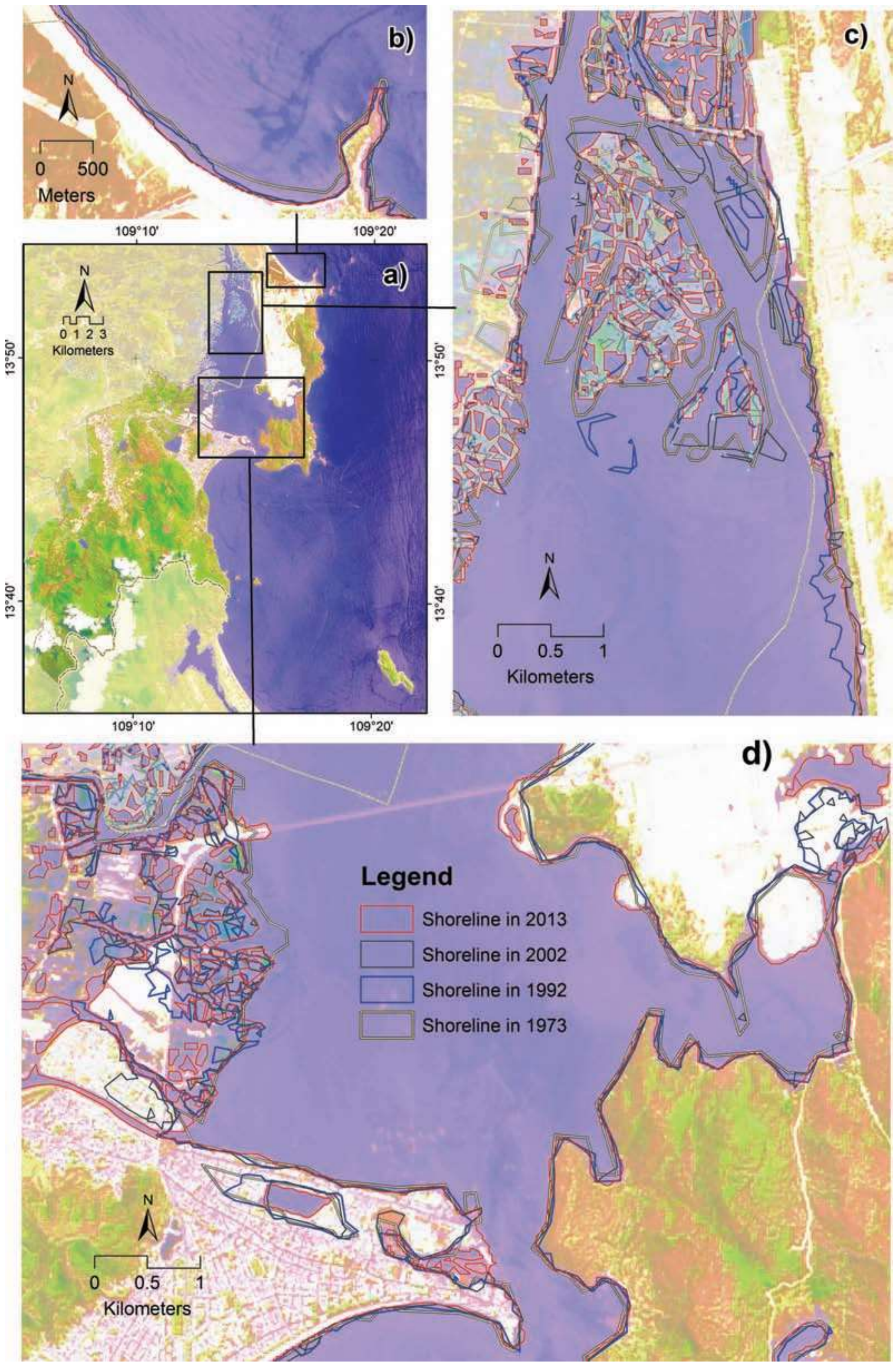
Type of data	Year	Format
Flood map of downstream Ha Thanh River	2010	Autodesk
Dyke system map	2010	Autodesk
Drainage system map of Quy Nhon	2010	Autodesk
Map of sub-catchment of downstream Ha Thanh River	2010	MapInfo
Dyke system planning and flood map of Quy Nhon	2010	MapInfo
Irrigation planning map of Binh Dinh	2010	MapInfo
Dyke planning and drainage systems	2010	Picture map

All the data were in different formats such as Autodesk and Mapinfo. To make comparisons and do further analysis, data were converted into ArcGis and inserted into the geo-database.

4.1.2 Detecting shoreline modifications

Among different approaches to detecting shoreline modification such as ground surveying, altimetry technology or aerial photography measurements, multispectral satellite imagery has some advantages. It is not time consuming to use, is low-cost and can cover large areas of ground. With the digital imageries in infrared spectral bands, the boundary between land and water is well defined.

Figure 6. Landsat 8 image of Quy Nhon and its shoreline change from 1973 to 2013



(a) Overview of the city. (b) Shoreline change in Nhon Ly commune. (c) Shoreline change in inlet area part of Nhon Hoi. (d) Shoreline change in Thi Nai lagoon, Quy Nhon center city.

4.1.3 Image analysing

To evaluate the accuracy of this method, the extracted shoreline from this method was compared with the on-the-ground triangulation results from four field trips in May–October 2013. The shoreline data collected from the fieldwork is assumed to be the known truth, and used to quantify the accuracy of the proposed approach in this study.

Results from remote-sensing analysis of shoreline modifications are in Figures 6 and 7 and reveal that most shoreline sections in the Lang Mai Bay surrounding Quy Nhon's city centre and in the inlet of Nhon Hoi Commune were sedimented whereas the shoreline in Nhon Ly commune was eroded.

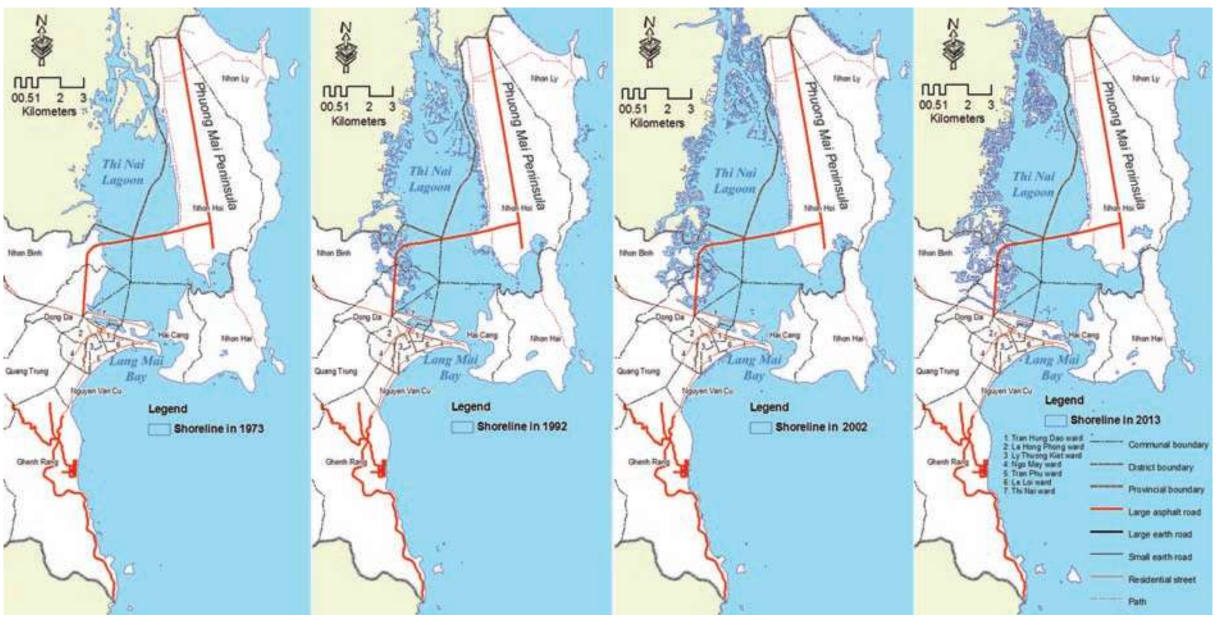
The shoreline sections surrounding the Lang Mai Bay have been modified due to development. As noted in the climate change resilience action plan report (Climate Change Working Group of Quy Nhon city, 2010), Quy Nhon is heavily impacted by natural hazards such as typhoons combined with heavier rains and sea-level rise. According to studies (Bang et al., 2006), the coast of Quy Nhon is characterised by accumulation and abrasion processes with rocky cliffs jutting into the sea. Abrasion often happens in areas where there are strong winds, loose sand and soft rock. The villages of Ly Chanh and Ly Hung (north of Nhon Ly Commune) have beaches which are blown nearly perpendicularly by the north wind in the winter and south wind in the summer (Bang et al., 2006). Therefore, the abrasion process is dominant there. However, most coastal shorelines have been stabilised with concrete walls, so only those with no dyke, such as the village of Ly Hung, have eroded. In contrast, in the coastal area of Thi Nai Lagoon, the accumulation process is likely to predominate due to sedimentation from rivers and mangrove development. However, the agrarian transition in this area, combined with aquaculture development, has changed the shoreline quite remarkably. It should be noted that in Quy Nhon, human activities are the main cause of shoreline modification, especially coastal sedimentation rather than natural causes.

The remote-sensing analysis shows the extent of urban development in Quy Nhon (Figure 11), showing that urbanisation has occurred mostly in the city centre surrounding Lang Mai Bay, which could have contributed to shoreline modification here due to the increased use of concrete for urban development. As can be seen in Figure 11, urban areas are increasing within the limits of coastal Quy Nhon City and, along the national and provincial road network, in inland towns within the Ha Thanh and Kon river delta. The most urbanised wards within the coastal area are Nhon Binh, Nhon Phu, Quang Trung and Dong Da in the north of the city. Another developed area belongs to the wards of Bui Thi Xuan and Tran Quang Dieu lying along the national road number A1. Over the Nhon Hoi Bridge, from 2002 to 2013, the area of Nhon Hoi has also experienced dramatic urban development.

According to urban development plans for Quy Nhon by 2020 (The Prime Minister of Vietnam, 2004), the city is now proposing to include Phuoc Thuan, Phuoc Son, Phuoc Thang and Phuoc Hoa communes within the city's administrative boundaries. This would increase the city population to 500,000. However, the urban expansion of Quy Nhon revealed from remote-sensing analysis in the last 40 years shows that the city has not expanded much. Within the city centre, infilling is taking place as farmland and vacant plots are being used for to construct individual homes and for larger-scale state and private sector projects. Along the main roads, ease of access and the relatively lower cost of land is encouraging a similar pattern of development, with several industrial zones developing here such as Phu Tai and Long My. From 2002 to 2013, city expansion was observed over the coast of Thi Nai Lagoon to the Phuong Mai Peninsula with the development of the Nhon Hoi economic zone. Therefore, the coastal zone along the Thi Nai Lagoon has been sedimented, mostly due to the need to develop this new industrial area. References to those areas are illustrated in the administrative map of Quy Nhon (Figure 1).

Looking forward, the city of Quy Nhon could be seen as the coastal hub of an inland road network, as the national 1A Highway crosses the city. A new section of road, the national 1D Highway connects Quy Nhon City with Song Cau District in Phu Yen Province to the south along the coast. National Highway 19 links Binh Dinh with the central highlands, northeast Cambodia, southern Laos and Thailand. Over the longer term, this road is likely to be extended to increase regional trade. In addition to these upgrades and network expansions, a 107km coastal road is currently under construction between Nhon Hoi and Tam Quan communes along the Phuong Mai Peninsula east of the Thi Nai Lagoon. The main purpose of the road is to encourage development of the tourism industry.

Figure 7. Maps of Quy Nhon city and its shoreline positions from 1973 to 2013



Top (left to right): shoreline in 1973, 1992, 2002 and 2013
Bottom left: changes to Lang Mai Bay
Bottom right: changes to upper Phuong Mai Peninsula

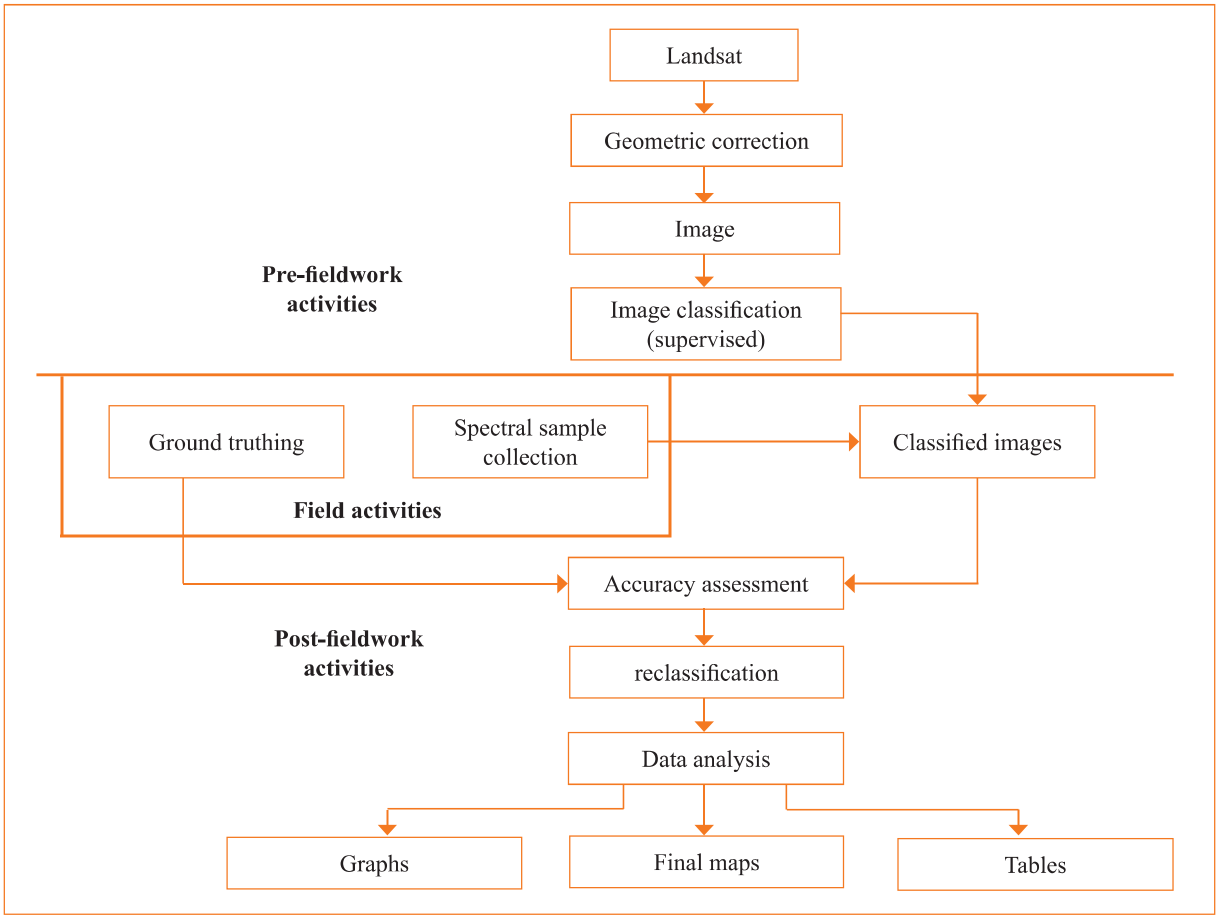
4.2 Spatial urbanisation

4.2.1 Urban area extraction

The remote-sensing images were processed for the first two sub-objectives: land-use classification and detecting urban expansion. The digital topography map was processed as per necessity for remotely sensed images registration.

Urban land cover was detected based on temporal remotely sensed images and a digital topographic map of Quy Nhon (Figure 8).

Figure 8. Generating urban development plans from satellite images



The 10m spatial resolution of SPOT 2009 data is a valuable source of information for urban built-up area extraction in Quy Nhon. With such fine spatial resolution, it is possible to delineate the boundary between an urban area and adjacent rural land using satellite images. After enhancing the SPOT image, the urban built-up areas were easily discernible. Therefore, possible visible urban built-up areas were identified based on visual interpretation by recognising the spatial characteristics such as shape, texture, pattern, size, shadow, location and association. The same process was carried out on the Landsat 2013 multispectral 30-metre resolution image.

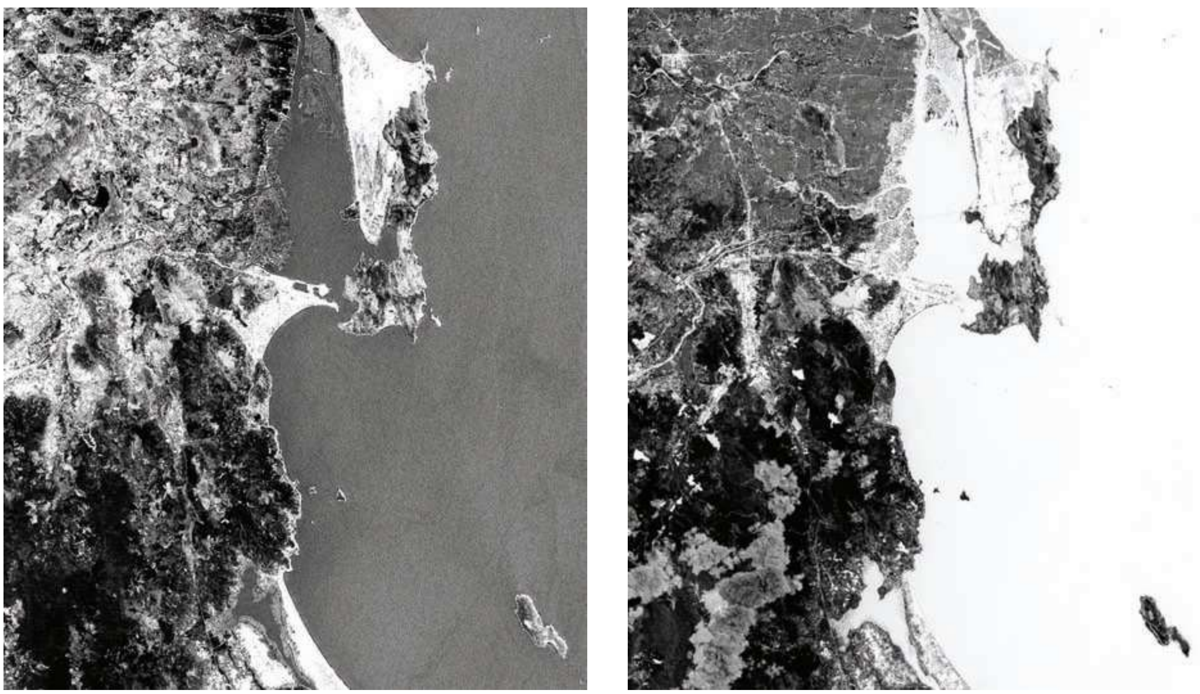
Calculating Urban Index (UI): one of the tasks of this research was to identify built-up urban areas such as those with houses and other buildings, roads and concrete yards in Quy Nhon over time. Therefore, Landsat satellite image series were taken advantage of to obtain built-up area maps by calculating the urban index images.

Based on the typical response to built-up urban areas in spectrum regions of shortwave infrared (SWIR) (2.08–2.35µm) and NIR (0.76 to 0.90µm), Kawamura *et al.* (1997) suggested that the urban index (UI) could be applied in the Landsat satellite images. The UI was calculated as:

$$UI = \left[\frac{Band_{SWIR} - Band_{NIR}}{Band_{SWIR} + Band_{NIR}} + 1.0 \right] x100$$

This expression is based on the typical response to urban built-up areas in spectrum regions of SWIR (2.08 to 2.35 microns) and NIR (0.76 to 0.90 microns). The bigger values of UI indicate built-up urban areas. This equation produced grey-scale images that appear brighter in dense urban areas but darker in agricultural areas or bodies of water (Figure 9). One exception is the brighter colour seen in the 2013 UI image showing bodies of water, which could be explained by the different bandwidths used in Landsat 8 and previous Landsat generations. However, it is still possible to distinguish built-up urban areas using the threshold to detect them.

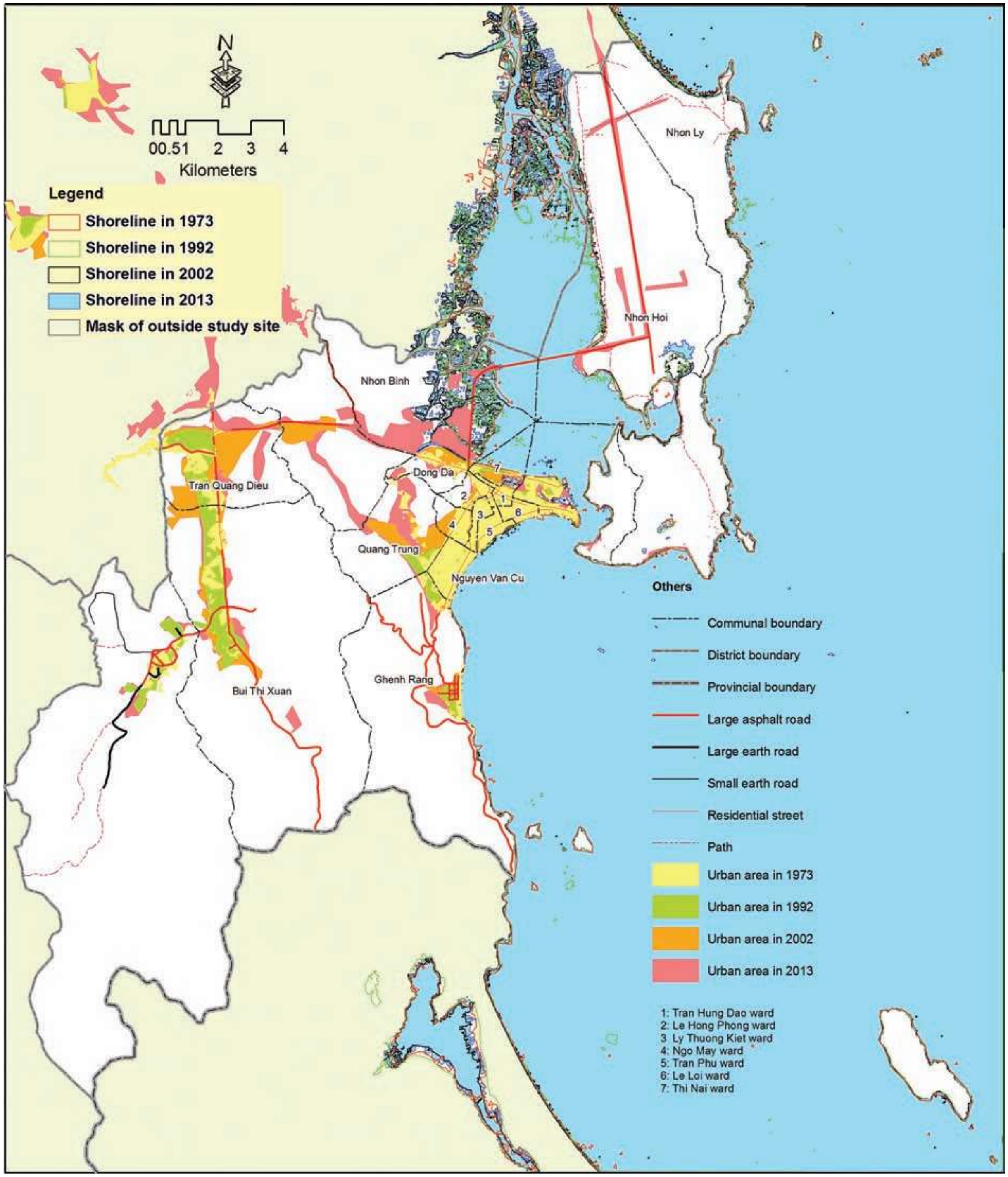
Figure 9. Urban index image: 2000 (left) and 2013 (right)



Threshold evaluation and masking: the urban images range from 0 to 255 in the greyscale. Though the brighter colour shows the high-density, built-up areas, it is still necessary to separate out the regions of the images corresponding to the urban areas. The thresholding technique provides a convenient way to perform this segmentation on the basis of different levels of greyscale. It was applied for detecting the built-up urban area in the UI images. The knowledge-based visual interpretation was carried out while evaluating the thresholds. The resulted values further translated into 0 and 255 on the greyscale. The code 255 was assigned to built-up areas whereas 0 was assigned to other areas that could be e.g. water or agriculture land. Furthermore, the images were masked based on region of interest to remove unwanted areas.

After delineating the urban areas at different times, the urban extension and shoreline maps were overlaid to obtain a full picture (Figure 10) of urban extension in Quy Nhon over 40 years from 1973 to 2003 with intervals of 10 years, except for the period between 1973 and 1993, when no image from the early 1980s was available at the USGS archive. Depending on available remote-sensing data and based on periods of rapid urbanisation and industrialisation in Quy Nhon City according to the government's master construction plan (The Prime Minister of Vietnam, 2004), further multiple logistic regressions were analysed for two periods: 1992–2005 and 2005–2013.

Figure 10. Urban extension of Quy Nhon 1973–2013



4.2.2 Urbanisation from 1992 to 2005

The results from the spatial analyses with Logistic Regression Models for urbanisation in Quy Nhon in 1992–2005 are presented in Table 5. Here, urbanisation is considered as a dependent variable and all the variables listed in Table 5 are the dependent variables. The Chi^2 is used to test the significance of independent variables in the models. If (Pr> Chi^2)< 0.05 then the variable is a significant variable in the model. If (Pr> Chi^2) > 0.05, the variable is not significant and can be ignored.

Table 5. Urbanisation results 1992–2005

Independent variables	Estimated coefficient	Standard error	Wald Chi^2	Pr> Chi^2	Odds ratio
Intercept	1.488	0.086	301.767	< 0.0001	1.000
Distance to shoreline	0.0001	0.000	18.262	< 0.0001	1.003
Distance to rivers	–0.001	0.000	159.368	< 0.0001	1.000
Distance to all roads	–0.001	0.000	114.592	< 0.0001	0.983
Topography	0.006	0.001	23.412	< 0.0001	0.999
Slope	–0.004	0.007	0.309	0.578	0.996
Unused area	0.742	0.134	30.534	< 0.0001	0.610
Industrial area	–0.179	0.161	1.226	0.268	3.264
Aquaculture	2.802	0.826	11.503	0.001	7.148
Paddy fields	3.576	0.821	18.965	< 0.0001	4.264
Protected forest	2.405	0.487	24.357	< 0.0001	1.840
Productive forest	1.325	0.365	13.175	0.000	1.382

According to the Table 5, there are a few variables which do not significantly play a role in the models such as slope with (Pr> $Chi^{2)}$ = 0.578 and industrial zones with (Pr> Chi^2) = 0.268. Therefore, these variables were left out of further calculations.

Based on the positive and negative values, the relation between the dependent variable (urbanisation) with other independent variables can be seen. For example, the distance to the river has value of –0.001, meaning that urbanisation depends inversely on this variable. This means that the shorter the distance to the river, the more urban development there is likely to be. Urbanisation can be calculated by 1/e(estimated coefficient*unit), where the unit of distance is metres, so 100m = 100 units. For every 100 metres closer to the river an area is, the possibility of observed urbanisation increases by 1.1 times (1/e(–0.001*100)).

Meanwhile, the distance to roads has a negative estimated coefficient. This implies that urbanisation is more likely to occur closer to roads, and the likelihood decreases as the distance grows. The distance to the shoreline and topography have a positive estimated coefficient, which means that the trend of urbanisation in this period seems to be towards inland areas, and new urban development seems to happen predominantly in higher places.

For the qualitative variables such as land use, the positive and negative estimated coefficients are demonstrated in the models of each category in comparison with the reference category. In this model, all the categories such as unused areas, aquacultural land, paddy fields and protected and productive forests have positive estimated coefficients, therefore all the categories have possibly a high chance of urban development compared to 'other land use' (i.e. land for military services, markets, education, transportation or irrigation, residential, cultural heritage or religion areas etc.). 'Other land use' was considered as a reference category, in which paddy fields demonstrate the highest possibility for urbanisation, followed by aquacultural land and productive forests.

4.2.3 Urbanisation from 2005 to 2013

Using the same approach, all the independent variables such as topography and slope; distances to shorelines, rivers, main roads and other roads; paddy fields and unused, industrial, annual crop and aquacultural areas are significant variables in the model for the urbanisation process in the period of 2005–2013.

The results of the MLR for urbanisation in 2005–2013 are shown in Table 6. The variables on topography, distance to roads and distance to main roads have negative coefficients, meaning that urban development is more likely to occur in lower-lying areas and those areas near roads. For example, the variable on distance to the main road has an estimated coefficient of –0.004, meaning that places closer to the main road have a higher possibility of urbanising than other places. Every 100m closer to the main road means that the likelihood of an area becoming urbanised increases by 1.5 times (100m = 100 units, a= $1/e^{(-0.004*100)}$=1.5).

Table 6. Urbanisation results 2005–2013

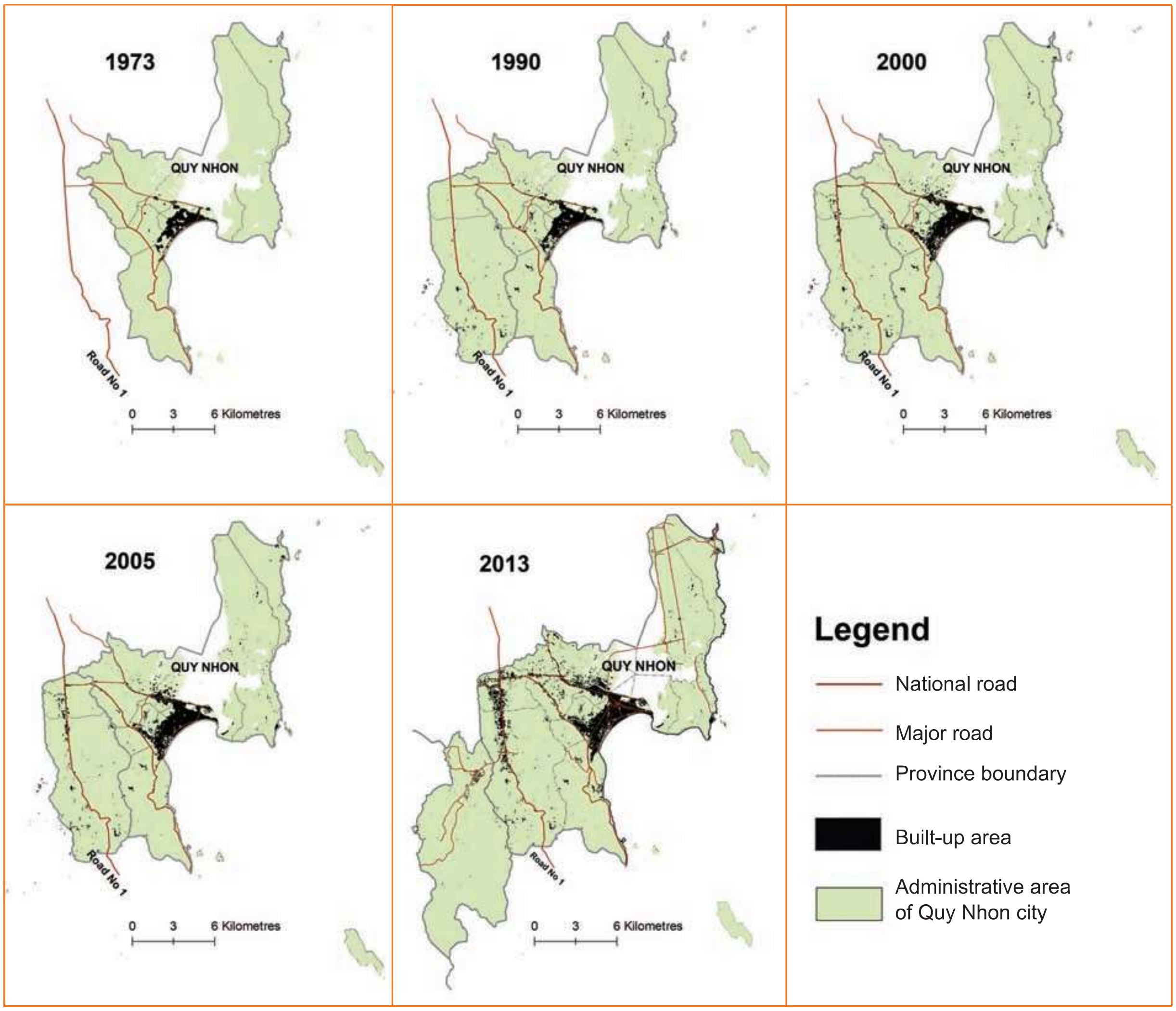
Independent variables	Estimated coefficient	Standard error	Wald Chi²	Pr> Chi²	Odds ratio
Intercept	–1.689	0.204	68.609	< 0.0001	
Topography	–0.031	0.005	47.629	< 0.0001	0.969
Slope	0.020	0.010	3.706	0.05	1.020
Distance to shoreline	0.0003	0.000	48.698	< 0.0001	1.000
Distance to rivers	0.0004	0.000	31.592	< 0.0001	1.000
Distance to main roads	0.0003	0.000	7.604	0.006	1.000
Distance to other roads	–0.004	0.000	129.668	< 0.0001	0.996
Unused area	0.000	0.000			2.1
Industrial area	0.773	0.205	14.233	0.000	2.166
Annual crops	–1.379	0.519	7.058	0.008	0.252
Aquaculture	–1.656	0.848	3.809	0.05	0.191
Paddy fields	–1.938	0.394	24.249	< 0.0001	0.144

However, unlike the previous time period analysed, the higher the topography, the less possibility there is of urban development. Every 100m in height gained decreases the likelihood of urbanisation by 1.36 times (100m = 100 units, then a= $1/e^{(-0.031*100)}$=1.36).

The other variables such as slope and distance to shoreline or rivers have positive estimated coefficients. Therefore, if a place has a higher value of these variables it will have a higher chance of becoming urbanised.

In this period, the 'other land uses' as described above were considered as the reference categories. According to Table 6, it can be seen that urbanisation occurred in the annual crop and aquacultural areas less than in the unused areas, so cultivated areas are being maintained. The most prominent area in the urban development process in Quy Nhon in 2005–2013 is the industrial area.

Figure 11. Built-up area growth from remote-sensing images 1973–2013



In general, as can be seen in Figure 11, the built-up urban area has expanded over the years. It confirms observations of three related processes underway in the city. Within the city, 'infilling' is taking place as unused areas are being converted into built-up urban areas. Second, areas along the main roads are seeing a similar pattern of development. Third, within villages themselves, houses on settlement plots are being redeveloped and home gardens are being converted to urban uses. These observations are also confirmed from the two periods of the MLR analysis (1992–2005 and 2005–2013). Urbanisation has expanded inland and closer to the roads and main roads, and tends to replace unused and the adjacent paddy fields and aquacultural areas. From 2005, it can be seen clearly that urbanisation is related closely to the development of new main roads. This finding can be used to further predict future scenarios of urbanisation in Quy Nhon.

4.3 Land-use change

Table 7. Land-use area (ha)

	2005	2010		
	Quy Nhon	Quy Nhon	Phuoc My	Quy Nhon (excluding Phuoc My)
	(1)	(2)	(3)	(4) = (2) - (3)
Agricultural land	8520.21	13585.08	5246.64	8338.44
Non-farming land	5784.02	8388.81	631.07	7757.74
Unused land	7418.90	6578.96	952.01	5626.95
Total area	21723.13	28552.85	6829.72	21723.13

Source: Department of Natural Resources and Environment

Table 7 shows the areas of different land-use types in Quy Nhon City in 2005 and 2010. There is a difference in total areas because when this land inventory was made on 1 January 2005, Phuoc My Commune (with a total area of 6827.72 ha) did not yet belong to Quy Nhon City. To provide a clearer view of urbanisation, Quy Nhon in 2005 is compared with Quy Nhon in 2010, excluding Phuoc My. It can be clearly seen that the agricultural land and unused areas have decreased in size while areas of non-farming land have expanded. Detailed information on non-farming areas can be seen in Table 8 below.

Table 8. Non-farming land (ha)

	2005	2010		
Year	Quy Nhon	Quy Nhon	Phuoc My	Quy Nhon (excluding Phuoc My)
	(1)	(2)	(3)	(4) = (2) - (3)
Residential area	840.55	1006.58	43.21	963.37
Special use (public use)	1955.62	4219.03	226.61	3992.42
Religious area	30.34	34.43	3.78	30.65
Cemetery	224.67	211.83	27.14	184.69
Water body	2716.46	2890.97	325.33	2565.64
Other non-farming land	16.38	25.97	5.00	20.97
Total non-farming land	5784.02	8388.81	631.07	7757.74

Source: Department of Natural Resources and Environment

Table 8 shows that there has been a rapid expansion of residential and special use (public use) areas. This is can be considered as an indicator of urban expansion. From the statistical figures in the period 2005–2010, the urban expansion rate of 432 ha per year can be calculated.

Table 9. Agricultural land (ha)

	2005	2010		
	Quy Nhon	Quy Nhon	Phuoc My	Quy Nhon (excluding Phuoc My)
	(1)	(2)	(3)	(4) = (2) - (3)
Annual crops	1717.61	2034.84	500.79	1534.05
Permanent crops	818.90	906.67	181.97	724.70
Aquaculture	691.4	371.48	2.17	369.31
Forest	5292.3	10270.09	4561.71	5708.38
Total agricultural land	8520.21	13583.08	5246.64	8336.44

Source: Department of Natural Resources and Environment

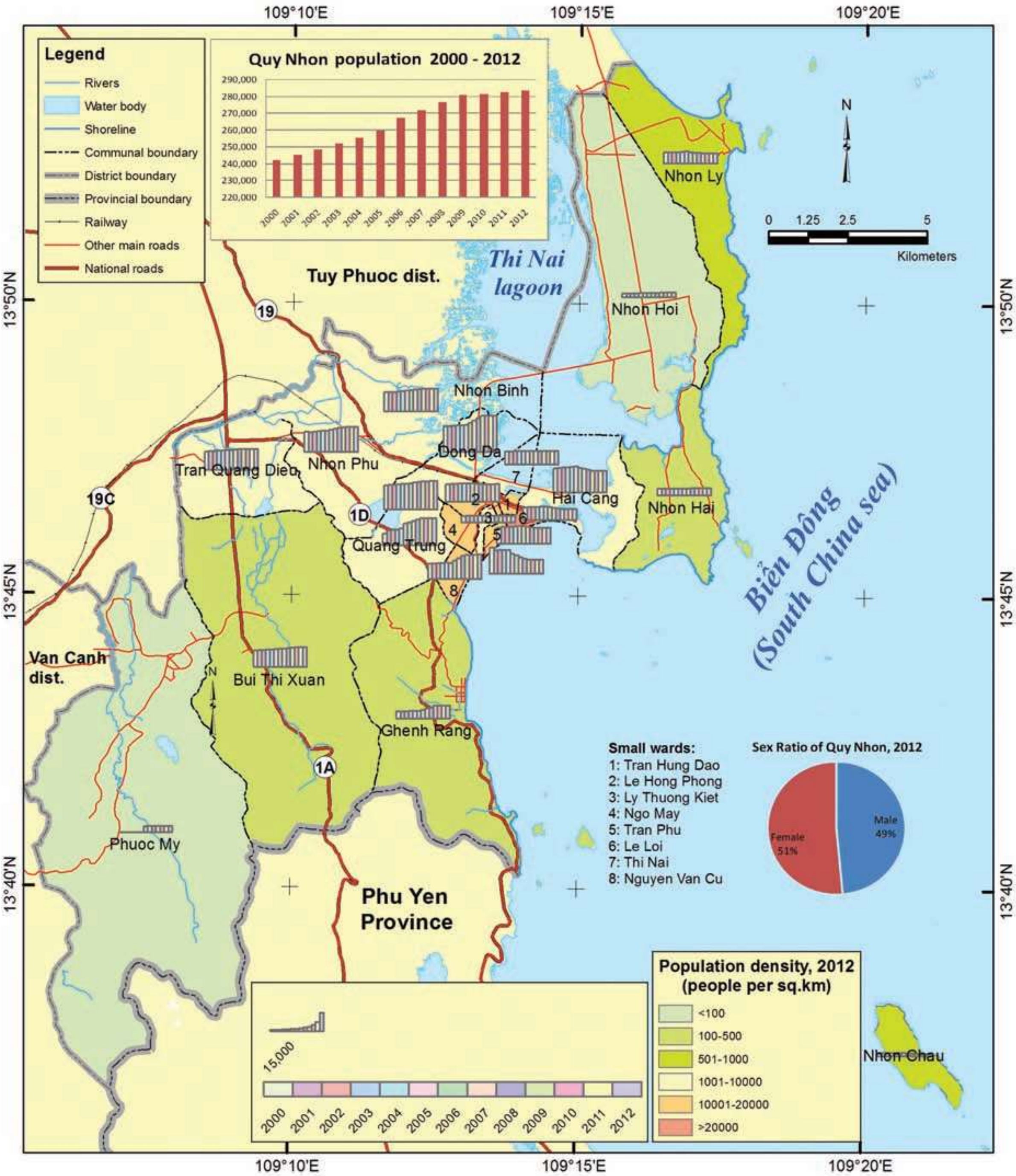
As well as the expansion of residential and public use areas shown in Table 8, Table 9 shows a reduction in agricultural land, and land used for aquaculture in particular.

Overlaying the two layers of land-use patterns in 2005 and 2010 shows the land areas that have been developed and built up: 26 per cent of the new urban expansion was in unused areas in Ghenh Rang and Nhon Hoi; 24 per cent was in protected forest in Nhon Hoi; 14 per cent was in paddy fields in Nhon Binh, Nhon Phu, Tran Quang Dieu and Bui Thi Xuan; 12 per cent was in the aquacultural area of Nhon Phu; 13 per cent in lands used for annual crops along National Road 19 in Nhon Binh, Nhon Phu and Tran Quang Dieu; 7 per cent in productive forest in Ghenh Rang and Bui Thi Xuan and 4 per cent in grazing land in Tran Quang Dieu.

4.4 Population growth

As well as spatial urbanisation, population growth can be observed in Quy Nhon (Figure 12). Over the last decade, the population has grown rapidly from 241,830 inhabitants in 2000 to 283,403 inhabitants in 2012 (Quy Nhon Sub-office of Statistics, 2013). However, different communes have different trends of population growth. Figure 8 shows the population growth at communal level, in which the populations of Ghenh Rang, Dong Da, Quang Trung, Nguyen Van Cu, Nhon Hoi and Nhon Phu communes/wards have rapidly increased. The populations of Ghenh Rang, Nguyen Van Cu, and Dong Da have doubled over the last 12 years. Other populations have slowly increased and in some cases decreased over the last 12 years, such as Nhon Chau, Tran Phu, Tran Hung Dao communes/wards (Figure 12).

Figure 12. Population growth 2000–2012



Source: Quy Nhon sub-Office of Statistics (2013)

4.5 Future urban development

4.5.1 Infrastructure improvements

Beside the new residential areas and industrial zone, new infrastructure such as bridges, roads, river walls and sea walls have been constructed or are being planned:

- Nhon Hoi Bridge was completed in December 2006 to create a link between Quy Nhon City and the Phuong Mai Peninsula.
- A new section of road, called National Highway 1D, connects Quy Nhon City with Song Cau District in Phu Yen Province to the south along the coast, including a new road from Phu Tai to Long Van.
- National Highway 19 connects Binh Dinh to the central highlands, northeast Cambodia, southern Laos and Thailand. It has expanded to the Nhon Hoi Bridge, linking it to the Nhon Hoi Port, which is still under construction. When the seaport is complete, the current Quy Nhon International Port will become a general services coastal transfer port, and Thi Nai Port will become a local port. Additionally, a 107km coastal road is currently under construction between Nhon Hoi and Tam Quan communes along the peninsula east of the Thi Nai Lagoon.
- The river embankments along the downstream portion of Ha Thanh River have been constructed.
- Construction of a concrete sea wall was completed in Ly Chanh village in 2012. A part is also planned to be built in in Ly Luong (Nhon Ly Commune) in 2014.

4.5.2 Future scenarios for urban development

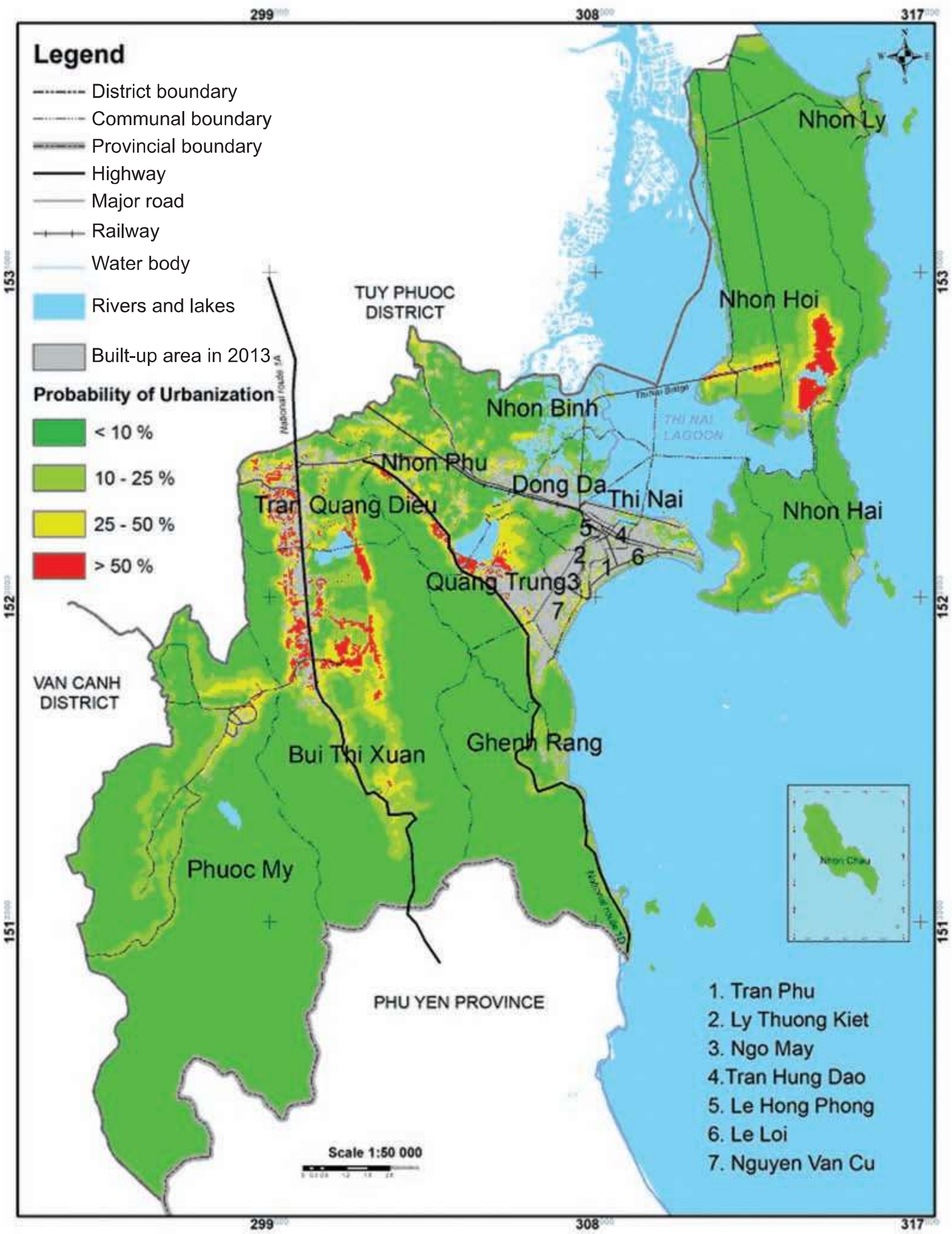
Based on plans for future infrastructure development in Quy Nhon, the urbanisation process can be predicted by calculating the probability from MLR analysis. Base on the MLR results, we can calculate the probability of whether a pixel might change to urban using the following equation:

$$P = \frac{\text{Exp}\,(L(x))}{1 + \text{Exp}\,(L(x))}$$

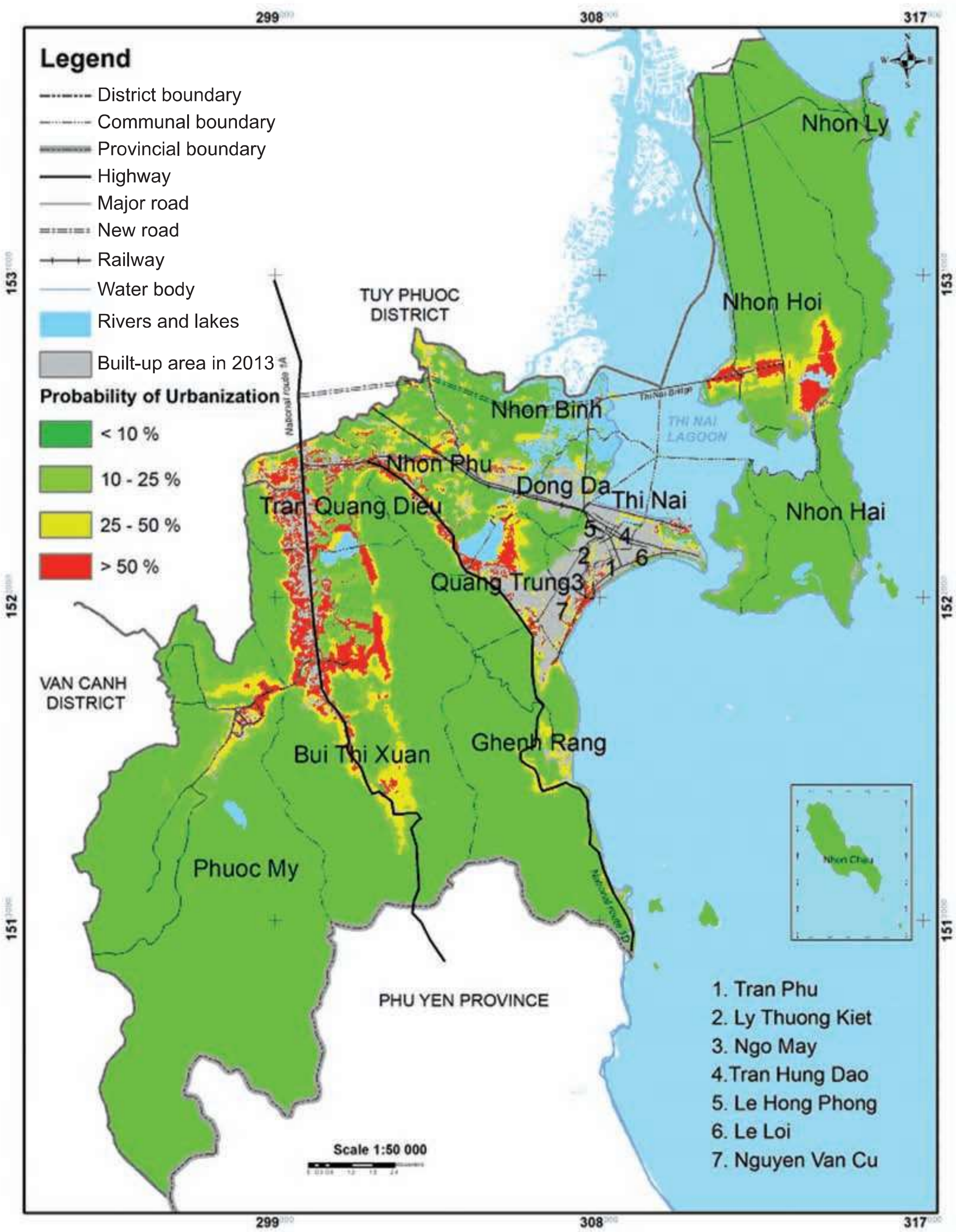
In which $L(x) = (a + b_1[X_1] + b_2[X_2] + \ldots + b_n[X_n])$

From the new road development, two urban scenarios can be created, based on current and future roads, based on the MLR analysis for the recent period from 2005 to 2013. The results from two future scenarios can be seen in Figure 13b.

Figure 13. Two future scenarios for urban development



a. Present road situation



b. Construction of new roads

Figure 13 has shown the probability of urbanisation in the future. From our analysis, if the urban area continuously grows following the trends from 2005 to 2013, the high chance of urban development can be seen in red color in the Figure 13a. If planned new infrastructure is factored in, the future urban development patterns can be seen in Figure 13b.

5 Field observations and focus group discussions

5.1 Climate change impacts in Quy Nhon

The impacts of climate change and sea-level rise are imperceptible over a short time-period. However, during the focus group discussions with Group 2 (experts with a local background and interest in climate change impacts in Quy Nhon) extreme climate events such as the 2009 flooding were discussed and some other issues related to the advantages and disadvantages of climate change (Box 1). The flood in 2009 was considered the biggest flood in the last 50 years.

Box 1. Climate change impacts

Climate change-induced erratic and abnormal weather conditions (such as the heavy rains in 2009) affect agricultural production and people's lives. In 2009, in Nhon Binh, Nhon Phu and Le Hong Phong wards and the surrounding areas of Bau Sen were flooded. Saline intrusion occurred in Nhon Binh and coastal erosion can be seen in Nhon Ly and Tran Phu wards. The climate tendency is unpredictable. However, one advantage of climate change is the appearance of rain during the dry season (Group 2).

Group 2 also mentioned current solutions being implemented in Quy Nhon such as upgrading the city drainage system (Box 2). However, each solution has both advantages and disadvantages.

Box 2. Solutions implemented in Quy Nhon

A sea dyke was constructed to prevent coastal erosion in places such as Ly Chanh (Nhon Ly). However, it affected the beauty of the coastal landscape.

A sea dyke with open gates was built in Nhon Binh to prevent saline intrusion. However, it can sometimes limit access to the waterway during floods.

There were some projects to upgrade the city's drainage system to increase its capacity during floods. However, building and improving drains can also destabilise buildings (Group 2).

The discussions broadly covered climate change impacts and possible solutions. Rising temperatures were not mentioned by any of the focus groups and thus appear not to be of immediate concern. Flooding was the biggest concern observed during the discussions. Reducing construction on floodplains to improve drainage was proposed as a solution.

However, according to plans for future urbanisation in Quy Nhon outlined in the previous section, construction will clearly take place on the floodplains. Therefore, it is very urgent and important to consider climate change issues and integrating climate resilience in new urban planning, particularly flood-protection measures.

5.2 Management of coastal zones and dyke system

During the focus group discussions the management of coastal zones and dyke systems was raised by Group 4, who were experts working in irrigation in the agricultural sector.

In section 4.1.3, it was shown that the most significant change in coastal zones was the degradation of mangrove forest in the Thi Nai Lagoon. The data in section 4.1.1 clearly shows that the river dyke has been reconstructed in some places and that a new dyke was recently built along the Ha Thanh River. Section 2.3 also shows that new urban developments and infrastructure are being built in the flood drainage corridor. This issue was also discussed in the focus group discussions (Boxes 3 and 4).

Box 3. Managing coastal zones and dyke systems

During periods of rapid urbanisation, insufficient attention was paid to maintaining the flood drainage corridor, which has caused more severe flooding events. Specific examples include infrastructure such improvements to National Road 1, a new road from the city to Thi Nai Bridge, or to reclamation of mangroves for residential areas.

Mangroves play a very important role in Quy Nhon, especially in preventing the impacts of climate change such as sea-level rise and acting as buffers against storms. However, the area of mangrove forest has decreased due to the impact of urbanisation and aquaculture, and there are few new planting areas (Group 4).

Besides the river dyke and mangrove forest, this study has also discussed the detection of coastal erosion (section 4.1.2). The satellite imagery results were supplemented by fieldwork observations and interviews with local inhabitants about coastal erosion in the villages of Ly Hung and Ly Chanh in Nhon Ly Commune (Figure 14).

Box 4. Sea dykes in Ly Chanh and Ly Hung

The village of Ly Hung has a long beach with no dyke along the coast. The village residential area has expanded very close to the coast. In 2009, a heavy storm hit the village and destroyed six houses in Ly Hung. According to villagers, a new dyke will be built in 2014 to protect the village. However, during the fieldwork in Ly Hung some abandoned shrimp ponds were observed along the coast. These were totally covered by sand after being abandoned for five to six years. Will a new sea dyke help to protect the village in the long term? There is a need to study the patterns of sand movement before constructing such a dyke.

In Ly Chanh, a village near Ly Hung, a stable dyke was built along the coast in 2011. At present, local inhabitants seem confident that the new dyke should protect their houses from storms (fieldwork observation).

Figure 14. Coastal landscape in Nhon Ly: Ly Chanh (left, with dyke) and Ly Hung (right, without dyke)

Photos: NhonLy Friends

A similar case can be found in Xuan Dieu Street. The road was built along the coast, where there used to be sand dunes. The street was completed in 2008. At present, it can be seen as a sea dyke along the coast. However, during the daytime, the wind blows strongly inland from the sea, blowing sand over the street. During the night, the wind blows from the inland toward sea but with less intensity, so that the sand does not blow back into the sea and covers the street instead.

To prevent the problem of sand movement, a high embankment was constructed and sand removed from the beach (Figure 15). The problem has temporarily stopped. However, the natural cycle of sand movement will occur again in the future. There is a need to further study sand movement before any construction is done along the coast to ensure that similar problems do not happen in future.

Building a dyke along the coast can work for short time-period, but it might not be the best solution for reducing coastal erosion for longer periods in the context of climate change and sea-level rise. For longer-term solutions, in-depth studies on coastal geomorphology such as sand movement, coastal deposition and erosion might produce a better plan to resettle residential areas further inland.

Figure 15. Xuan Dieu Street: satellite image and embankment construction

Sources: (Left) Google Earth (Right) Nguyen Huu Xuan

Similarly with river dykes, it is hard to calculate how high a dyke should be, especially in the uncertain context of climate change and sea-level rise in the future. Local residents who live along the bank must be aware of and be prepared for the risk of floods. From a scientific point of view, hydrological models and hydraulics studies must be carefully carried out in different climate scenarios before constructing any dykes. As an example, the photo in Figure 17 was taken after an overflowing dyke caused a severe flooding event in November 2013.

Figure 16. East dyke, Nhon Binh, 21 November 2013

Photo: Nguyen Huu Xuan

The role of mangrove forests along the coast, especially in the lagoon, has been raised in many studies (Tinh and Tuan, 2013). Especially in the context of climate change and sea-level rise, the mangrove forest has played an important role to play in preventing coastal erosion as well as protect inland areas. However, the observation from the satellite images has shown the degradation of mangrove forest in Thi Nai Lagoon over the last 40 years. At present, some aquaculture areas in Nhon Binh have already been urbanised. Local authorities should be aware of such causes of ecological imbalance and should take them into account in their urban and ecological planning.

5.3 Urban construction and management

The urbanisation in Quy Nhon can be observed spatially from satellite images and also quantitatively from the statistical yearbooks on population growth. From the urban development in Quy Nhon over the last 10 years, a group of local experts from different provincial departments have discussed construction and urban management in Quy Nhon City. The group discussion focused on favourable and unfavourable conditions for urban development in Quy Nhon (Box 5).

Box 5. Urban construction and management

Quy Nhon is the political and socio-economic centre of Binh Dinh Province. The city has the role in promoting the development of the regional economy. Quy Nhon is located in a favourable geographical position with an intersection of many major transport routes such as highways, railways, waterways and airways. However, there are some unfavourable factors such as its hilly terrain, rivers and lakes, which limit the spatial development of the city.

In its current state, urban management and city governance have not yet reached the level of rapid expansion of urban areas. Quy Nhon is a coastal city, which is effected heavily by climate change and sea-level rise. However, these impacts have not yet been taken into account in city planning. The expansion of certain industrial areas or new residential areas in unfavourable and flood-prone location may worsen flooding in the future (Group 1).

Figure 17. Construction of the new Long Van–Long My Road

a. Field observation, 30 September 2013

b. Flooding, 16 November 2013

Photos: (Left) Nguyen Thi Thuy Hang (Right) Nguyen Huu Xuan

The new Long Van–Long My Road was built on the floodplain of a tributary of Ha Thanh River. During interviews, local inhabitants near the road described how the village close to the road was severely flooded in 2009. Observations in October 2013 showed a new road, the Long Van–Long My Road, was under construction. A hundred tons of material from the nearby mountains was brought to the flood plain to build a higher foundation for the new road. During construction, the drainage system did not function properly. Consequently, it caused a severe flood November 2013 (Figure 17b).

5.4 Urbanisation and industrialisation

The advantages and disadvantages of urbanisation and industrialisation in Quy Nhon was raised by the Group 3, which consisted of experts in land management (Box 6).

Box 6. Urbanisation and industrialisation

Quy Nhon City has extended and developed rapidly in recent decades. The city became a Grade III urban centre in 1986 and Grade I in 2010. Its economic structure has also changed: the industrial and services sectors have increased, while the agricultural sector has decreased.

In particular, new urban areas, industrial areas and industrial clusters such as Nhon Hoi, Bac Ha Thanh, An Phu Thinh have promoted economic development. New residential areas have been built including the East Bus Station, East Dien Bien Phu, Vo Thi Sau, Nhon Binh and Xom Tieu. New roads have been constructed, such as National Road 1D, Xuan Dieu Street, the extension of the Nguyen Tat Thanh road and the Quy Nhon–Nhon Hoi Road.

The drainage system in the city has been upgraded. Local inhabitants have access to clean water and wastewater is treated before being discharged into the sea.

The proportion of urban inhabitants has also increased. Consequently, new public utilities such as bus services, telecommunications, supermarkets, and open markets have been installed. Infrastructure for services such as hotels, restaurants, hospitals and schools has been improved. Inhabitants in surrounding areas have been influenced by the urban lifestyle.

The disadvantages of urbanisation and industrialisation in Quy Nhon can be seen in areas like the Xom Tieu residential area and Nhon Binh and Quang Trung industrial clusters, which were built in unfavourable places. In addition, urbanisation causes an increase in social problems and illegal activities in land trading and development (Group 3).

Along with urbanisation, urban planning plays the most important role in the city's future sustainable development. In the discussions with the different groups, some solutions were also raised (Box 7).

Box 7. Solutions for urban and ecological planning

It is necessary to improve the current residential area of Xom Tieu. Relocating the Quang Trung and Nhon Binh industrial clusters to new places is also needed to reduce the risk of flooding. Therefore detailed urban planning at commune/ward level is essential (Group 3).

Mangrove reforestation around the Thi Nai Lagoon and protecting forests in the Nhon Hoi economic zone should be done. A concrete master plan of Quy Nhon City should be made, integrating climate change resilience and adaptation (Group 2).

6 Conclusions and recommendations

This study has underlined the spatial nature of the urban planning process, which needs to be supported by multi-disciplinary studies taking into account issues from social aspects to the natural conditions of the urban territory, and should also consider city development in the global context. In particular, urban planning processes become more complex when considering a developing city in the context of rapid urbanisation and industrialisation combined with the added uncertainty of climate change impacts, as in Vietnam.

This study has been innovative in its use of a mix of methodologies to demonstrate their value to urban planning processes. Remote sensing and GIS have clearly demonstrated the expansion of the city of Quy Nhon as well as shoreline modifications over recent decades. By means of statistical analysis, a number of independent variables that are correlated with the spatial pattern of urbanisation were identified such as current land use, slope, elevation and distance to roads, main roads, shorelines or rivers. The distance from roads appears to highly correlate with the degree of urbanisation. This could be explained by the fact that new residential and industrial areas are often built alongside roads and the city has expanded inland along the main roads.

Based on the current urban planning situation in Quy Nhon, the results of MLR analysis were used to predict the future scenario for Quy Nhon. This shows that the areas in which further urban development will take place are located in areas that are exposed to the impacts of climate change, particularly flooding. This was confirmed during focus group discussion, where experts asserted that certain new industrial clusters and residential areas had been located in flood-prone areas, which might accelerate flooding risks in the future. Sometimes, the flooding risk becomes worse when a new road is built without taking waterways into consideration. Therefore, flooding problems must be an important consideration in any longer-term development, especially in the context of climate change and sea-level rise in the future.

In-depth studies on hydrological and hydraulic models integrated with climate change scenarios must be carried out carefully before any new urban infrastructure is constructed. Urban planning must be done with serious consideration of climate change impacts. In this context, community participation should be promoted, especially for mangrove forest co-management. No urban construction should encroach on or replace the mangrove forest area which plays a vital role in the city's defence against the impacts of climate change. Shoreline modification due to human activities needs to seriously consider any potential impacts in the future.

Dealing with shoreline modification is significant part of any coastal city development. The satellite data have been shown to be a powerful tool for detecting shoreline changes in Quy Nhon due to urban expansion. The urbanisation in Quy Nhon has been strongly driven by the boom in industrial investment, with its new industrial areas and economic zones. According to the city plan, in the near future, more tourism infrastructure will be built near the northeast coast in Nhon Ly. However, this study has shown that this area has an eroded and unstable shoreline. This finding could be used to inform city planners when considering the sustainable development of Quy Nhon City.

The focus group discussions were done at the same time as training on GIS and remote sensing with local government officers from different departments in Quy Nhon. During the training workshop, participants from different background were able to learn from each other, as well as the techniques used in this study. In future, local officers will be able to use the method for further relevant study and become main actors in building their city's resilience to climate change.

In certain contexts, urban systems, the agents (people and organisations) and institutions that link systems and agents, and patterns of exposure to climate change in Quy Nhon City have been involved in the study. However, there is still a lack of connection between these components. Urban systems – including ecosystems and infrastructure – have been developed without considering to the patterns of exposure of climate change and sea-level rise. Even this study was limited to local researchers and local government officials. While these agents have recognised the fragility of the city's systems, they lack the power to positively influence those institutions ruled by central and local decision makers. To build a climate change resilience plan for Quy Nhon City, a concrete framework must involve all those components, including local people, local authorities and central government.

References

Bang, D., Hieu, N.T., 1998. History of Quy Nhon city (Lịch sử thành phố Quy Nhơn). Thuan Hoa Publisher (Nhà xuất bản Thuận Hóa).

Bang, D., Hieu, T.D., Hong, N.X., 2006. Monography of Binh Dinh: Nature, Population and Administration (Địa chí Bình Định, tập Thiên nhiên, Dân cư và Hành chính). Ho Chi Minh City General Publishing House (Nhà xuất bản Tổng hợp TP. Hồ Chí Minh), Ho Chi Minh city, p. 454.

Climate Change Working Group of Quy Nhon city, 2010. Climate change resilience action plan. Asian Cities Climate Change Resilience Network.

DiGregorio, M., 2013. Learning from Typhoon Minrinae: Urbanization and Climate Change in Quy Nhon City, Vietnam.

Herold, M., Hemphill, J., Liu, X., Clarke, K.C., 2006. Urban patterns and processes: A remote sensing perspective, 1st EARSeL Workshop of the SIG Urban Remote Sensing, 2–3 March 2006 Humboldt-Universität zu Berlin.

Hosmer, D.W., Lemeshow, S., 2000. Applied Logistic Regression, 2nd ed. Wiley-Interscience Publication.

IMHEN, 2011. Scenario of Climate Change and Sea-level rise in Binh Dinh. Vietnam Institute of Hydrology, Meteorology and Environment, Hanoi, Vietnam.

Kawamura, M., Jayamamana, S., Tsujiko, Y., 1997. Comparison of Urbanization and Environmental Condition in Asian Cities using Satellite Remote Sensing Data', Asian Conference on Remote Sensing

Li, J., Xie, S.-P., Cook, E.R., Morales, M.S., Christie, D.A., Johnson, N.C., Chen, F., D'Arrigo, R., Fowler, A.M., Gou, X., Fang, K., 2013. El Nino modulations over the past seven centuries. Nature Clim. Change 3, 822–826.

Quy Nhon Sub-office of Statistics, 2013. Statistical yearbook of Quy Nhon city, Quy Nhon.

Romero-Lankao, P., 2008. Urban areas and climate change: review of current issues and trends. Issues paper prepared for Cities and Climate Change: Global Report on Human Settlements 2011, 101pp.

Romero-Lankao, P., Dodman, D., 2011. Cities in transition: transforming urban centers from hotbeds of GHG emissions and vulnerability to seedbeds of sustainability and resilience. Current Opinion in Environmental Sustainability 3, 113–120.

Seto, K.C., Christensen, P., 2013. Remote sensing science to inform urban climate change mitigation strategies. Urban Climate 3, 1–6.

The Prime Minister of Vietnam, 2004. Decision 98/2004/QD-TTg dated 01 June 2004 on Approval of adjusting the master plan for construction in Quy Nhon city to 2020.

Tinh, B.D., Tuan, T.H., 2013. Cost benefit analysis of mangrove restoration in Thi Nai Lagoon, Quy Nhon Asian Cities Climate Resilience Working Paper Series, IIED, London.

Van, T.T., Binh, T.T., 2009. Application of remote sensing for shoreline change detection in Cuu Long estuary. VNU Journal of Science, Earth Sciences 25, 217–222.

Van, T.T., Thai, T.H., 2011. Climate change impacts and adaption measures. VNU Journal of Science, Earth Sciences 27, 119–126.

World Bank, 2011. Global Facility for Disaster Reduction and Recovery (GFDRR) country profile for Vietnam. http://sdwebx.worldbank.org/climateportalb/doc/GFDRRCountryProfiles/wb_gfdrr_climate_change_country_profile_for_VNM.pdf Assessed on 30 September 2014, 16.

Coastal urban climate resilience planning in Quy Nhon, Vietnam

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