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HUMAN-ENVIRONMENT INTERACTIONS AND
SUSTAINABLE URBAN DEVELOPMENT: SPATIAL
MODELING AND LANDSCAPE PREDICTION
THE CASE STUDY OF NANG RONG TOWN, THAILAND

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PARIWATE VARNAKOVIDA

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**HUMAN-ENVIRONMENT INTERACTIONS AND SUSTAINABLE URBAN
DEVELOPMENT: SPATIAL MODELING AND LANDSCAPE PREDICTION
THE CASE STUDY OF NANG RONG TOWN, THAILAND**

By

Pariwate Varnakovida

A DISSERTATION

**Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

HUMAN-ENVIRONMENT INTERACTIONS AND SUSTAINABLE URBAN DEVELOPMENT: SPATIAL MODELING AND LANDSCAPE PREDICTION THE CASE STUDY OF NANG RONG TOWN, THAILAND

By

Pariwate Varnakovida

It is now well-recognized that, at local, regional, and global scales, land use changes are significantly altering land cover, perhaps at an accelerating pace. Further, the world's scientific community is increasingly recognizing what, in retrospect, should have been obvious: that human behavior and agency is a critical driver of Land Cover and Land Use Change. In this research, using recently developed computer modeling procedures and a rich case study, I develop spatially-explicit model-based simulations of LULCC scenarios within the rubric of sustainability science for Nang Rong town, Thailand. The research draws heavily on recent work in geography and complexity theory. A series of scenarios were built to explore different development trajectories based upon empirically observed relationships. The development models incorporate a) history and spatial pattern of village settlement; b) road development and changing geographic accessibility; c) population; d) biophysical characteristics and e) social drivers. This research uses multi-temporal and spatially-explicit data, analytic results, and dynamic modeling approaches combined with to describe, explain, and explore LULCC as the consequences of different production theories for rural, small town urbanization in the South East Asian context. Two Agent Based models were built: 1) Settlement model and 2) Land-

use model. The Settlement model suggests that new development will emerge along the existing road network especially along the major highway and in close proximity to the urban center. If the population doubles, the settlement process may inhibit development along some corridors creating low density sprawl. The Land-use model under the urban expansion scenario suggests that new settlements will occur in close proximity to the town center and roads; even though that area is suitable for rice farming or located on a flood plain. The Land-use model under the cash-crop expansion scenario captures that new agriculture will occur on the flood plain and other areas suitable for rice farming. The Land-use model under the King's Theory scenario suggests that agriculture agents occupied less marginal and unsuitable lands for agriculture than the cash-crops scenario. In addition, the King's Theory scenario provided more access to water surface than other scenarios and was the most sustainable development plan.

These products offer a better understanding of the urban growth and LULCC at a regional scale and will potentially guide more systematic and effective resource management and policy decisions. Although this research focuses on a specific site, the methods employed are applicable to other rural regions with similar characteristics.

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When someone asks me, “Tul (my nickname), why would you want to study a Ph.D.?” the origin of this long process started as a dream from my father for his only child. Once, he told me that “I do not have a business or any asset for you; there is only education that I can support you to the end.” I never had this thought of studying a Ph.D. in my mind until the day he passed away and I saw all his students come back for him. I was inspired and realized that I want to be just like him. He had spent his career being just a “reua” which means a simple boat. His goal was always to provide passage for his students and to help them find their way across to shore, as does my mother. She has been my role model and could not have been more supportive and as always offered unconditional love for me. I offer my heartfelt thanks to my parents Preecha and Suwanna Varnakovida who made my life possible. Thanks especially to my grandmother and loving family who have been patiently waiting for this achieving day.

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Images in this dissertation are presented in color.

CHAPTER 1

INTRODUCTION

Since the invention of agriculture, humankind has been substantially modifying the arrangement of natural features, the functioning of natural systems, and the sustainability of the earth system (Gutman et al. 2004; Zimmerer and Bassett 2003; Steffen et al. 2004a). Though there are many cases where human ingenuity and action have completely altered natural systems, there are still many physical factors that limit how humans interact with the environment (Homer-Dixon 1999; Lambin et al. 2001). One of the most informative contemporary examples of research into the relationship between human and natural systems is the science of Land Use and Land Cover Change (LULCC).

The interactions between people and the environment are complex and dynamic (Evans and Moran 2002; Dale et al. 2000; Lambin et al. 2001). One of the most difficult tasks has been to understand the complexity of the relationships linking people with change over synoptic and diverse areas (Entwisle et al. 1998; Geoghegan et al. 1998; Lambin et al. 2001; Robbins 2003). More recently, there has been increasing understanding of the social and natural science linkages and processes that drive landscape characteristics through spatial analyses using remotely sensed imagery, Geographic Information Systems (GIS), systems modeling, and social surveys (Entwisle et al. 1998; Fox et al. 2003; Geoghegan et al. 1998; Hutchinson 1998; Liverman et al. 1998; Rindfuss and Stern 1998; Walsh et al. 2002; Aldrich et al. 2006).

These continuing methodological developments can be applied in a wide variety of geographic contexts, but much of their use and development is focused on current 'hot spots' of land use and land cover change, many of which are in the tropics (Steffen et al. 2004a, 2004c; Myers 1993; Ojima, Galvin, and Turner II 1994). Among the greatest of concerns is the loss of tropical forest and the expansion of built-environments throughout less developed regions, posited to have significant local, regional, and global effects on climate (Steffen et al. 2004b; Vitousek 1994; Ojima, Galvin, and Turner II 1994), water quality (Steffen et al. 2004b), agricultural production (Walker 1999; Asner et al. 2004), among many other important systems and processes.

Though there are many different ecotones in the tropics undergoing transformation, the priority for selecting areas for intensive human use varies among settings because spatially heterogeneous variables make some locations more desirable or susceptible to change than others; certain biophysical and social characteristics encourage or discourage intensive human use (Nelson 2002). In this research, using recently developed computer modeling procedures and a rich case study, I develop spatially-explicit model-based simulations of LULCC scenarios within the rubric of sustainability science for Nang Rong, Thailand. The research draws heavily on recent work in geography, demography, sociology, and complexity theory. A series of scenarios exploring sustainability are built based upon empirically observed relationships in the following areas: a) history and spatial pattern of village settlement; b) road

development and changing geographic accessibility; c) population; d) biophysical characteristics and e) social entities. Results of the simulations are used to examine the spatial distribution and composition of LULCC in the context of sustainability in Thailand. It is expected that this project will provide generalizably relevant findings, methods, and insights applicable to other similar places where resource-poor biophysical environments correspond with socio-economic marginalization.

1.1 Built-environment and sustainable development

The World Commission on Environment and Development defined sustainable development as “development which meets the needs of the present without compromising the ability of the future generations to meet their own needs” (WECD, 1987). It has been argued that any movement towards sustainability requires that natural resource utilization include consideration of both intergenerational and intragenerational equities (Vojnovic, 1995). Intergeneration equity requires consuming resources at rates less than their regeneration rates and maintaining waste discharges at or below the carrying capacity of natural environment. Intrageneration equity requires equitable access to resources among existing populations (Vojnovic, 1995). In the context of less developed regions, intragenerational equity must also satisfy the basic needs of the people in the existing generations. As argued by Cedric Pugh (2001), sustainable development is basically about enhancing and maintaining environmental assets

for the present consumption without reducing significant opportunities for consumption in the future.

The built-environment constitutes a dynamic evolutionary process, and can be viewed as a complex system that regularly changes over time (Bai, 2003). In this context, I apply the definition of “sustainable cities” as those that meet the satisfactory of needs of those within the boundaries while minimizing the transfer of environmental costs to others or into the future generation (Satterthwaite, 1997). I extend the definition to include the minimization of costs throughout the region serviced by the city, in this case, of a marginal agricultural region like Nang Rong District, specifically through the management and preservation of soil and water resources. These biophysical systems are primary inputs for local economic and land use systems (Welsh, 2001). It is believed that land degradation conditions are now common in many locations within the broader study area, providing interesting questions of how to plan and manage the built-environment in Nang Rong in a sustainable manner. Significant spatial factors and biophysical determinants of built-environment morphology including 1) water resources, 2) land availability, and 3) soil quality will be conceptually tied to the sustainability concept in the context of Nang Rong and regional sustainable development.

1.2 Urban transitions and development in Thailand

Thailand, (Figure 1) located in Central Southeast Asia, is bordered by the Andaman Sea and Myanmar on the west, Laos and Cambodia on the east, and the Gulf of Thailand and Malaysia to the south. Thailand has been inhabited by humans since the Pleistocene dating back to at least 27,000 B.P. (Anderson, 2005). The first Thai or Siamese state was founded in 1238 A.D. and was called the Sukhothai kingdom. The current (Rattanakosin) era of Thai history began in 1782 A.D. following the establishment of Bangkok as capital of the Chakri dynasty under King Rama I the Great (Muscat, 1994).

Modern Thailand covers approximately 514,000 sq. km and is administratively divided into 76 provinces, comprising 876 districts, 7,255 sub-districts and 68,501 villages. As of 2005, the total population was 62,418,054 with a population density of 121.6 per square kilometer (National Statistical office, 2006). The central region, which includes the capital city of Bangkok, has the highest population density of any region in Thailand. Bangkok is an interesting example of how a state emerges as an extension of the capital city. The urbanization of Bangkok reflects its development as the administrative and commercial center of Thailand. During 1782-1851, most national construction activities focused on palaces, temples, and defensive structures within Bangkok. During the King Rama V period (1868-1910), modern urban development in Bangkok was promoted by making it the center of a centralized administration. During this period, the king sponsored several significant projects such as creation of

Chulalongkorn University, Siriraj Hospital, a national Medical College, the post office, and the Ministry of Justice. To support the growing administrative role of Bangkok, a modern infrastructure was established. The capital was connected with other provinces via newly constructed roads, bridges, and railways (Evers and Korff, 2000). The city was no longer shaped by palaces and temples, but increasingly by private buildings, shops, and commercial offices. Bangkok, today, has dramatically expanded; however, it does not have one central core, but rather contains several edge cities developing simultaneously.

The national policies of 19th century attempted to decentralize power. Railways and roads were built to connect Bangkok to the other regional centers and provinces. Critical infrastructure development began in the 1960s with the development of new and the extension of existing roads throughout the region to support the increasing population and the transportation of agricultural products (Dixon, 1996). Electrification, an ongoing project spanning the 1970s and 1980s, was followed by a rapid increase in the ownership of electronic goods and other consumer goods (Welsh, 2001). Over the past ten years, governments at all levels have invested substantial public resources towards creating a built environment to host global investment and better compete regionally (Douglass, 2000). As a result, extensive recent land use and land cover changes have occurred throughout the country.

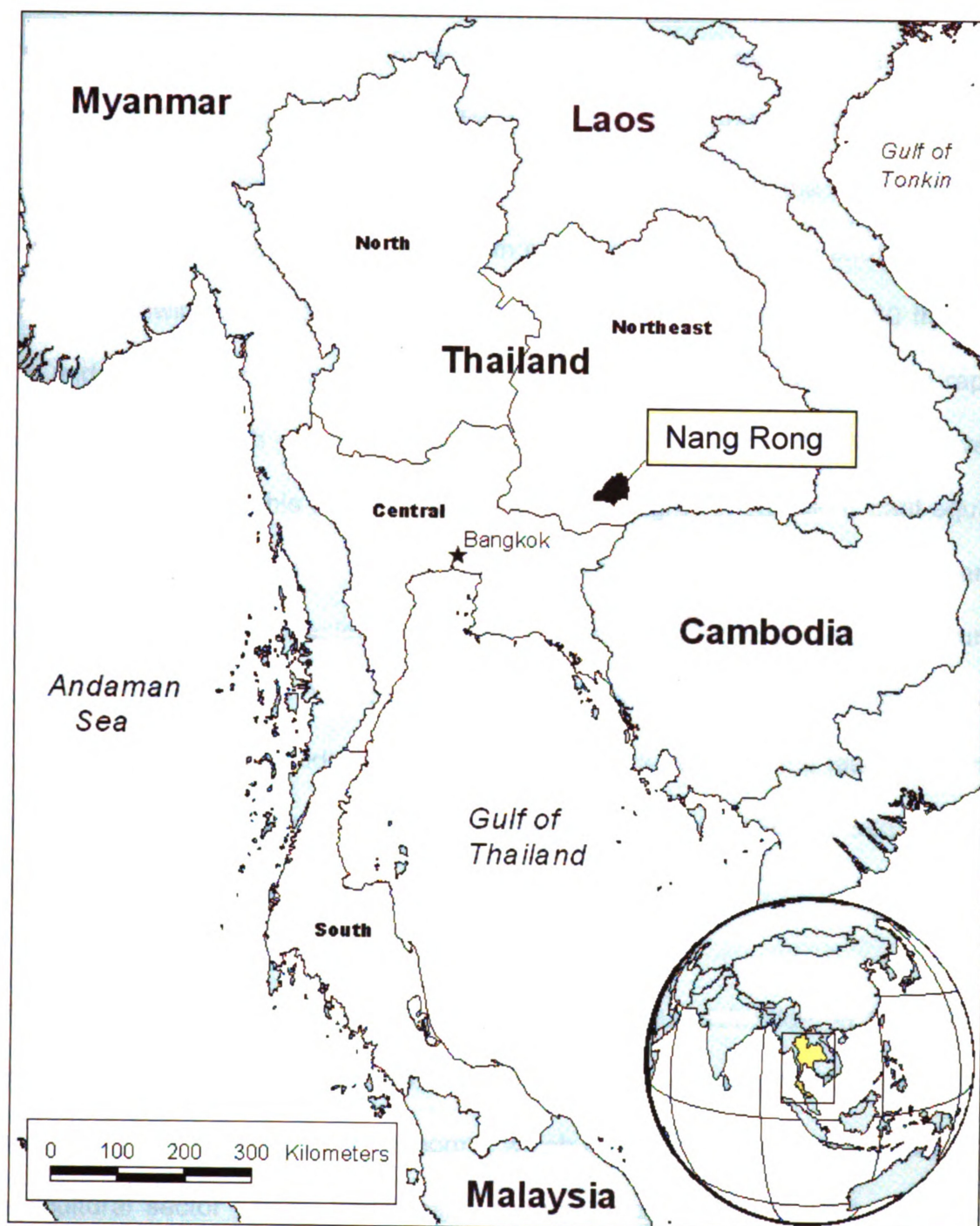


Figure 1.1 Study site: Nang Rong, Thailand (Nang Rong Archive)

1.2.1 Thailand under export-oriented growth model

During the late 20th century, much of Southeast Asia adopted the pro-growth policies of the International Bank for Reconstruction and Development. The Export-Oriented Growth model focused on development in the industrial and commercial sectors using resources from rural economies (Hirsch and Lohmann, 1989). Following regional trends, Thailand during the period from 1960 through the mid-2000s adopted the National Development Plan which focused on rapid GNP growth through capital-intensive industrialization (Dixon, 1996). However, with the adoption of this development plan, uneven growth and significant equity imbalances resulted with highly disproportionate income distributions and extreme differences in basic living standards emerging between urban and rural areas (Kaothien, 1991). Concurrently, land and other natural resources increasingly became maldistributed as early settlers acquired the last remaining available lands, and of course, preferentially selected the best lands with the best soil and water conditions, further exacerbating inequities.

While Thailand was focusing on capital-intensive industrialization, in 1974, King Bhumibol Adulyadej introduced a new national development model, the philosophy of the 'Sufficiency Economy', which focused on investment in the rural agricultural sector where, traditionally, the vast majority of the Thai population was, and still is, employed (NSO, 2007). The Sufficiency Economy is explicitly sustainable based on the holistic concepts of moderation and contentment. The philosophy was introduced with the idea of production not just for profit

maximization but also for advancement towards sustainability. However, the Sufficiency Economy was not given full consideration until the 2000s. Over the last four decades, the competing development strategies between capitalistic free market economic models and the Sufficiency Economy offered very different approaches to economic growth and produced varying social and environmental stresses. These processes played important roles in shaping national, regional, and local policies in Thailand.

1.2.2 Current problems with development in rural areas

In rural areas, the subsistence economy remains an important form of production. Peasants produce their own food and perhaps their own clothing, and other household goods (Evers and Korff, 2000). However, under globalization contexts, the expansion of the modern form of the free market economy has resulted in a more competitive and complex system for commercial agricultural production. The expansion and extensification of upland cash cropping, for example, occurred as a direct result of increased domestic and international demand for upland field crops, improvements in communication, the importance of the private sector and commodity middlemen, the availability of credit, and organized market and collection systems (Rojnkureesatien, 2006). Consumerism and demand from outside of the region further motivated households to deforest the uplands and to extensify cultivation of traditional field crops as well as to intensify paddy rice in the lowlands (Bello et al., 1998).

Over the last 30 years, many towns in rural areas have experienced rapid urbanization and demographic changes often moving in uncorrelated and unsustainable trajectories. With frequent and often reverse migratory patterns, rural towns function in the context of often declining population densities combined with increasing urbanization and transformation of adjacent natural and agricultural lands.

1.3 Land use suitability for rice farming

The dramatic and extensive LULCC experienced throughout Nang Rong district during the past half-century has likely placed the district and Nang Rong town on an unsustainable path. Specifically, urban areas have expanded where actual land is best suitable for agriculture and relatively unsuitable for urban development. In the past several decades, the majority of land use within Nang Rong district was dominated by rice agriculture.

In 1984 roughly 99 percent of all households were agricultural, but this has decreased dramatically in 2000 to roughly 75 percent (Wongsaichue, 2006). The principal trajectory of land use change is from agriculture to urban and/or residential areas. Over the last several years, the rate of urban expansion has increased with major developments along lands adjacent to roads (Rojnkureesatien, 2006). The typically urban issue of impermeable surfaces has emerged.

These activities contributed to faster rates of soil degradation and increased likelihood of flood events. While present LULC patterns are configured to maximize short-term economic gain from conversion of agricultural land to urban land uses or by selling agricultural lands to investors, this research will show that this is an unsustainable trajectory from both economic and ecological standpoints. This unsustainable trajectory is inevitably leading to environmental degradation, inefficient use of the limited arable lands, and inequality among the population.

To establish a sustainable development policy and move towards equity, planning for appropriate and efficient use of land is necessary. Therefore, one goal of this research is the analysis of land use suitability for rice agriculture. Land use suitability mapping and analyses are among the most accepted and widely used applications of GIS for land use planning and management (Malczewski, 2004), but does depend on the definitions of land use and the contexts of its use. Therefore, it is important to distinguish between land use and land cover (Briassoulis, 2003). Land cover refers to the physical land cover over the land's surface, including water, vegetation, bare soil, and man-made structures (e.g. buildings). Land use is the human employment of a land cover type that may alter land surface processes including biogeochemistry, hydrology and biodiversity. It involves both the manner in which the biophysical attributes of the land are manipulated and the purpose for which the land is used, such as agriculture, forestry and building construction (Turner et al., 1995).

1.4 LULCC modeling and simulation

Urbanization is well known as one of the most important drivers of LULCC. Traditionally, urban modeling and simulation have represented urban systems by means of spatially aggregate units of the geographic region of interest such as geographic zones, tracts, and socioeconomic groups (Openshaw, 1983). Specific geosimulation approaches, however, are oriented toward spatially disaggregate objects such as homes, households and vehicles. This characteristic of geosimulation links the spatial relationships in models. An example is the gravity model by Fortheringham and O'Kelly (1989). Spatial relationships are characterized as flows in a Newtonian system, as inversely proportional to some power of distance between origin and destinations. Geosimulation models consider interactions as an outcome of the basic geographic objects' behavior and also directly address time. Different phenomena occur at different time scales and even the simplest urban systems change over time. Long-term cycles of urban expansion and decline may operate over decades while catastrophic shocks may occur in one day. The center of an urban district may shift while households may change their demographic or consumption characteristics. Urban simulations are designed for generating or testing hypotheses related to the dynamic processes that shape cities at different spatial and temporal scales (Benenson and Torrens, 2005).

1.5 Objectives

This research uses multi-temporal and spatially-explicit data, analytic results, and dynamic modeling approaches to describe, explain, and explore sustainability as the consequences of different production theories for rural, small town urbanization. Using a case study set in Nang Rong Town, Nang Rong District, in North East Thailand, LULC patterns emergent from the complex underlying production modes, environment, and demography will be explored and described in an spatial and temporally explicitly, sustainability context. This study area is illustrative of the processes at work behind environmental change at many scales of analyses, and is a local example of processes commonly at work elsewhere at local, regional, and global levels.

This dissertation essentially asks the question: Do actions towards the Sufficient Economy lifestyles by individual farmers improve the sustainability of the local and regional environment? This research explores five specific objectives and goals:

- a) To expand the underlying knowledge of the complex interactions (systems) between people and urban land cover change in Nang Rong Town.
- b) To predict multi-scale, spatio-temporal patterns of settlement and landscape conversion in Nang Rong Town.
- c) Geosimulation agent-based models will be designed and used to (re)create settlement patterns using existing urban structures,

transportation, accessibility structures, biophysical factors, and social histories, while expanding the scope of this type of model application to smaller, more complicated urban settings.

d) To study and describe the urban patterns, problems, and to plan and manage urbanization towards sustainable development in Nang Rong Town with generalization to Thailand.

e) To evaluate the consequences of observed and predicted changes between different sets of schemes: 1) moving toward sustainability with the Sufficiency Economy theory proposed by the King and 2) the Export-Oriented Growth model.

1.6 Hypotheses

The built environment is both cause and consequence of the complex interactions, thresholds, and feedback systems of the urbanization processes in effect.

Hypothesis 1: Endogenous physical characteristics such as road accessibility and previous settlement patterns modify the nature and rate of urban change expressed as expansion, retraction, or morphology in Nang Rong.

In the absence of a centralized urban planning framework, development takes place haphazardly and often sprawls over the best quality agricultural lands and/or lands not suitable for housing. These urban and road expansions are

more likely to create problems associated with land misallocation and exhaustion of good quality soil and areas suitable for agriculture, especially for rice.

Hypothesis 1a: Nang Rong Town's population fluctuates as residents move to Bangkok and other major cities for labor. This creates an unstable trend in population density with an uncorrelated urban form process. This urban form process is likely to be unsustainable and replaces areas suitable for rice agriculture with low-density residential sprawl.

If these scenarios are repeated in every town across the region, shortages in land, good quality soil, and water access may arise causing a decline in local economy which could influence sustainability of Nang Rong town.

Hypothesis 2: Land use/cover changes are driven by multiple stakeholders interacting through endogenous and exogenous processes. Endogenous physical characteristics that support rice agriculture such as water accessibility, soil quality, and elevation modify the nature and rate of LULCC. Exogenous factors such as crop prices in world markets modify the nature and rate of LULCC. Both are expressed as expansion, retraction, or morphological process in Nang Rong as endogenous and exogenous factors.

Hypothesis 2a: Uncontrolled urban growth and/or high global demand for cash-crops create scenarios of land misallocation.

Hypothesis 3: People in Nang Rong, especially small-scale farmers, tend to have unequal access to land and natural resources. To create sustainable development in the Nang Rong context, one must maintain equity.

Hypothesis 3a: Given different sets of schemes, the Sufficiency Economy theory proposed by the King of Thailand focuses on providing equitable access to natural resources including water and fertile soil and could be considered an alternative development strategy.

Local scale sustainability may be achieved by adopting the Sufficiency Economy model and the related sub-concept of New Theory farming. Its main aim is to bring food security and self-sufficiency to poor farmers on small land holdings with scarce water resources. The most important concepts of New Theory farming are mixed land uses and effective allocation of lands to serve the different needs of farm households. The area allocated to each kind of land use can be flexible, according to local resources. In addition, the path towards sustainability may be achieved by providing equitable access to natural resources, while promoting goal seeking behaviors that limit over-consumption and preserve natural resources, particularly by maintaining soil quality and limiting urban expansion.

CHAPTER 2

LITERATURE REVIEW

In this chapter, I discuss the history of Thailand, where the impacts of globalization and the adoption of an urban based development policy have had considerable implications on basic issues of social equity and natural environmental stresses. The national pressures associated with increasing social disparities caused by some three decades of export-oriented growth development eventually led to a military overthrow of the government in 2006. The coup set in motion the adoption of a new policy direction based on King Aduladej's 'Sufficiency Economy' as Thailand attempted to pursue its own version of a more sustainable socio-economic and environmental system. The organization of the remainder of this chapter follows an overview of complex systems/general systems theory and reviews of methodological approaches in land use studies. Each element serves as an introduction to the subsequent chapters.

2.1 Urban transitions and development in Thailand and the rise of the Sufficiency Economy

With the implementation of the Fourth to the Eighth National Development Plans (1977 – 2000), primary interests were placed on economic growth through the promotion of export-oriented industries. Plans were implemented for the establishment of industrial estates in cities, and growing economic disparities

emerged between urban and rural areas. The growing economic pressures on small settlements throughout the country were also exacerbated by the rise of commercial agriculture, which began to replace small-scale, labor intensive farming. The emerging economy not only promoted inequality in resource distribution and unbalanced and unstable growth throughout Thailand, but also placed severe pressures on natural ecological systems, particularly evident with increasing pollution and large scale deforestation (Trebuil, 1996).

With growing social and environmental stresses, and growing political pressures for a new development direction, the government marketed the Ninth National Development Plan (2001 – 2006) as a starting point for implementing some of the King's Sufficiency concepts. However, while some innovative programs from the Sufficiency Plan were introduced, it soon became clear that the government had no interest in implementing the full Sufficiency strategy. Instead, a new tactic in its development plan was to directly inject investment into village development funds, resulting in more spending in the general economy. While production and investment were stimulated by the government spending, there was also growing evidence of increased corruption, authoritarianism, and the use of legal loopholes to support the government and this new national program. The growing political opposition facilitated a military coup in 2006, deposing the prime minister and setting a new national policy reliant much more fundamentally on the King's National Sufficiency Program. The introduction of the Tenth National

Development Plan (2007-2011) implemented the king's concept of Sufficiency Economy and was based on the "middle path" as a way of life.

The Tenth National Development Plan dismantled the Export-Oriented economic approach of the last four decades. The goal for national development over the next 10 to 15 years will be based on the "Green and Happiness Society" according to the Sufficiency Economy Philosophy and People-Centered Development (BOI, 2006). The Plan focuses on four objectives: 1) developing a knowledgeable and moral population, 2) promoting equality and strengthening the society, 3) reforming economic structures for sustainability and fairness, and 4) developing good governance as a norm at all political levels. Before Thailand's Sufficiency Plan is explored in more detail, the chapter will first review some of the socio-economic and environmental stresses that gave rise to this program.

2.2 Globalization, agricultural production, and growing environmental stresses under the export-oriented growth model

Driven by the National Development Plan from the 1970s to the 1990s, Thailand's economy rapidly expanded and the country was poised to join other Asian Tigers as a "Newly Industrialized Country (NIC)." Thailand's export-oriented growth development policy produced GDP increases for each 5 years period of 5.7 percent between 1970 and 1975, 7.8 percent between 1976 and 1980, and 9.9 percent between 1986 and 1990 (National Statistic Office, 1997). Urban centers and services expanded throughout the country. At the same time,

Thailand evolved highly uneven patterns of development, particularly evident between high growth urban and slower growth rural areas. Environmental degradation was also rampant with deforestation rates and pollution of all kinds increasing (So and Lee, 1999). However, the general economic strength of the country created an atmosphere of growth, prosperity, and security. Concerns over sustainability and equity were ignored by most people and political groups.

With respect to socio-economic pressures, the new prosperity was clearly not equally distributed across the population. As Table 2.1 shows, the majority of income was controlled by the top quintile group, with the bottom quintiles predominantly located in the rural areas.

Table 2.1 Income share by quintile groups, 1975/76 -1992 cited in Bello et al. 1998 p. 37.

Quintile	1975	1981	1990	1992
Bottom Quintile	6.1	5.4	4.1	5.6
2 nd Quintile	9.7	9.1	7.4	8.7
3 rd Quintile	13.9	13.4	11.6	13
4 th Quintile	21	20.6	19.7	20
Top Quintile	49.3	51.5	57.3	52.7

With globalization, the expansion of the market economy for agricultural products resulted in a more open and competitive global market (Jitsanguan, 2001). However, with the new global economy the growing demand for agricultural products also placed natural ecological systems under increasing stress. Since the mid-1970s, deforestation and agricultural extensification in upland areas in

Thailand were driven by European Economic Community (EEC) countries' demand for calorie-rich livestock feed (Welsh, 2001) (see Tables 2.2 and 2.3). In addition to increasing world market demand, upland cash cropping was facilitated by other factors, including improved infrastructure and the adoption of new technologies in farming.

Increasing globalization led to the emergence of large-scale commercial farmers who produced mainly for export markets. It also motivated small-scale farmers to change their agricultural patterns to be more competitive by switching to short-term profit commercial upland cassava agriculture (Rojnkureesatien, 2006). Most of the small-scale farmers own less than 6 rai of land (1 rai = 0.0016 sq.km. or 1600 sq.m.) (Pookpakdi, 1992), and while they make up approximately 50 percent of total farm population, they contribute only 25 percent of the total market value of agriculture production (Jitsanguan, 2001). National statistics show that both number of small-scale farmers who hold land less than 6 rai and number of large-scale farmers who own land more than 10 rai fluctuated during 1993 – 2003 (Table 2.4) as some migrated to big cities.

Table 2.2 Forest area in Thailand 1961-2004 (Forestry Department, 2005).

Year	Forest (sq.km.)	Percent
1950	344,000	67.00
1961	273,629	53.33
1973	221,707	43.21
1976	198,417	38.67
1978	175,224	34.15
1982	156,600	30.52
1985	150,866	29.40
1988	143,808	28.03
1989	143,417	27.95
1991	136,698	26.64
1993	133,554	26.03
1995	131,485	25.62
1998	129,722	25.28
2000	170,111	33.15
2004	167,591	32.66

Table 2.3 Expansion of agricultural area (sq.km.) in Thailand 1986-1991 (Forestry Department, 2004).

Year	Forest	Agricultural area	Housing	Rice field	Cash crops
1986	148,424	209,438	4,974	118,758	52,359
1987	146,071	209,924	5,024	115,471	53,532
1988	143,808	210,836	5,163	113,324	53,185
1989	143,417	210,930	5,256	112,304	53,020
1990	139,982	211,399	5,379	111,098	53,464
1991	136,698	212,922	5,527	110,805	53,617

Table 2.4 Report of the 1998 survey of Agriculture National Statistical Office.

Total area holding (rai)	Number of holders			Percentage of holdings		
	1993	1998	2003	1993	1998	2003
under 6	1,114,038	1,066,346	1,372,215	19.7	19.1	23.6
6-9	745,982	779,357	816,588	13.2	14.0	14.0
10-39	3,064,632	3,205,114	2,970,571	54.3	57.5	51.1
40-139	694,292	505,940	625,917	12.3	9.0	10.8
140 and over	28,564	21,438	29,338	0.5	0.4	0.5
Total	5,647,490	5,578,195	5,814,679	100	100	100

Throughout this period, other coincident exogenous factors—including the Asian economic crisis and a severe drought—increasingly disrupted the socio-ecological system, accelerating environmental degradation and increasing rural poverty within Thailand (Welsh, 2001). The degree of inequality among sub-group populations and regions remained high. The gini coefficient (0.524 in 1990, 0.527 in 1994, 0.511 in 1998, and 0.511 in 2002) shows that inequality is high and has not been resolved.

The official poverty lines in Table 2.5 were used to monitor and measure poverty incidences and revealed that the majority of impoverished households are found in rural areas (Table 2.6). The poverty lines were based on costs of buying products for basic needs. The costs differ from region to region. Households with average per capita income below the poverty line were considered as income poor. According to Table 2.5 the increasing gap between urban and rural incomes revealed the severity of rural poverty and rural/urban inequality that emerged under the national export-oriented growth model program

Table 2.5 Thailand's official poverty lines 1988-2002 (NESDB).

Region/Areas	Poverty Lines (baht per capita per month)								
	1988	1990	1992	1994	1996	1998	2000	2001	2002
Central	476	526	599	622	714	876	882	925	930
Rural/ Non-Municipal	462	509	581	601	691	864	856	862	866
Urban/Municipal	592	659	744	784	895	968	1,059	1,082	1,089
North	459	498	563	581	702	791	777	828	830
Rural/ Non-Municipal	448	486	549	566	696	779	758	781	783
Urban/Municipal	585	626	706	752	846	938	996	1,011	1,009
Northeast	443	477	577	611	698	880	864	890	898
Rural/ Non-Municipal	435	469	570	599	687	869	850	856	864
Urban/Municipal	597	641	734	773	883	1,064	1,057	1,059	1,068
South	466	518	582	624	716	843	841	879	890
Rural/ Non-Municipal	441	492	553	593	684	804	797	806	819
Urban/Municipal	620	682	763	829	951	1,108	1,100	1,123	1,129
Bangkok	587	684	752	835	950	1,019	1,101	1,109	1,112
Bangkok Vicinity	506	604	666	658	774	935	972	1,027	1,021
Rural/ Non-Municipal	474	537	596	614	710	894	884	896	886
Urban/Municipal	568	681	749	838	931	1,015	1,107	1,113	1,110
Whole Kingdom	473	522	600	636	737	878	882	916	922
Rural/ Non-Municipal	445	485	566	592	690	840	825	835	841
Urban/Municipal	590	672	746	816	930	1,020	1,086	1,086	1,090

Under the export-oriented growth model, alternative forms of agriculture, particularly contract and industrial farming, were introduced to rural areas

(Wiboonpoongse, et al. 1998). Local elite land owners hired the poor or landless to exploit the forests to acquire more land for cash crop agriculture. Small-scale farmers were pressured to enter wage labor arrangements to supplement falling inflation-adjusted incomes, or to relinquish land, and sometimes both (Bello et al., 1998). In some cases, farmers' borrowed large amounts of money from creditors to pay for the higher input costs for fertilizers and pesticides. Many forfeited their land to creditors or sold it to repay the loans when incomes failed due to the wide fluctuations of the global rice or cassava markets, or due to the natural variation in climate (Rojnkureesatien, 2006).

In addition, the government promoted the export-oriented programs by providing low interest loans intended to facilitate small-scale farmers postponement of the sale of their rice when world markets' price were low (Bello et al., 1998). However, middlemen and large-scale farmers received far greater benefits from the programs as opposed to the small-scale farmers who often did not meet rice quality minimums to qualify. The quality problems resulted from the fact that many small-scale farmers simply did not have the mills or other technologies to keep their rice dry. This contributed to the lack of rice necessary to use as mortgage collateral during periods of severe drought (Parnwell, 1988).

Table 2.6 Poverty incidence in Thailand 1988-2002 (NESDB).

Region/Areas	Poverty Incidence (Head-Count Ratio)								
	1988	1990	1992	1994	1996	1998	2000	2001	2002
Central	25.2	20.5	12.1	8.4	5.9	7	5.4	4.6	4.3
Rural/ Non-Municipal	28.8	22.9	14.7	9.7	6.9	8.1	6.4	4.5	4.8
Urban/Municipal	10.6	8.6	2.1	5.2	1.6	2.3	2	5	3
North	32	23.2	22.6	13.2	11.2	9.1	12.1	10.6	9.8
Rural/ Non-Municipal	34.3	25.5	25.9	15	13.1	10.2	13.9	11	10.9
Urban/Municipal	14.3	11.3	5.2	3.8	3.6	3.3	3.4	9	6
Northeast	48.4	43.1	39.9	28.6	19.4	24	28.1	24.5	17.7
Rural/ Non-Municipal	51.6	45.9	42.4	31.4	21.1	26.2	30.7	26.5	18.9
Urban/Municipal	19.2	19.1	13.8	6.7	3.6	4	6	15	11
South	32.5	27.6	19.7	17.3	11.5	14.6	11	13.5	8.7
Rural/ Non-Municipal	36.9	30.5	22.7	20	12.6	16.9	12.9	15.2	9.4
Urban/Municipal	13.8	13.9	7.5	5.1	6.3	3	4	8	6
Bangkok	3.8	3.3	1.9	0.6	0.3	1	0	1	1
Bangkok Vicinity	8.7	3	1.7	1.6	1	0.5	0.7	1	2
Rural/ Non-Municipal	12.6	2.3	3	2.2	0.2	0.9	0.1	1.1	0.9
Urban/Municipal	7.8	3.8	0.7	0	3.3	1	1	1	2
Whole Kingdom	32.6	27.2	23.2	16.3	11.4	13	14.2	13	9.8
Rural/ Non-Municipal	40.3	33.8	29.7	21.2	14.9	17.3	19.1	16.6	12.6
Urban/Municipal	8	6.9	3.6	2.4	1.6	1	2	6	4

Overall, the growing competition that accompanied globalization placed increasing pressures on local farmers, and particularly the small-scale farmers. In addition, new pressures were also evident as local farmers increasingly became dependent upon uncontrollable external economic conditions (Siamwalla, 1995). Conditions grew even more severe as Thai elites took advantage of the situation

by acquiring lands from cash strapped, subsistence farmers. This led to more and more farmers changing from independent farming to the status of tenant or landless worker. These problems reinforced existing class inequities (Bello et al., 1998). Table 2.6 shows that even though overall poverty incidence index decreased, rural poverty and rural/urban inequality still take place.

As farmers sold parts, or all of their lands, a new cycle of reinforced poverty emerged in Thailand, as their children were often forced to migrate and/or become landless labor typically living under extreme conditions with very low living standards in urban slums (Bello et al., 1998). The export-driven model thus created issues of social and spatial unevenness in access to resources both within and across generations.

With regard to environmental stresses under the export-oriented growth program, several economic activities contributed to severe resource degradation including logging, prawn farming, destructive methods of fishing, and wastewater from inland factories and households. The loss of the mangrove forests was an example of natural resource degradation influenced by the export-oriented growth model (Rojnkureesatien, 2006). Mangrove forests were cut down for prawn farming due to the high return investment and demand from world markets. In 1961, Thailand had mangrove areas of some 3,679 km² (2,299,375 rai). In 1992, more than half of the mangrove was destroyed leaving only 1,753 sq.km. (1,096,168 rai) (Bello et al., 1998). Forestry Department data in 1999

show that mangrove forests were reduced to 1,675 km² (1,047,387 rai), or 0.33 percent of the country by 1996.

In 1997, the period of economic growth came to an abrupt end. Gross Domestic Product had a dropped to 0.0 percent in 1997 and -2.0 percent in 1998 (National Statistic Office, 2004). The Thai currency was devalued, and the government was essentially forced to change its policy of linking the value of its currency to the US dollar (Crawford, 2000). Throughout the agricultural sector, defaults and indebtedness became widespread. All development within the country stalled, and new social, economic, and political pressures emerged.

2.3 The roles of the King and Buddhism in Thailand

Before examining economic development and the concept of the Sufficiency Economy, two aspects of Thailand are worth exploring that have been fundamental in shaping Thailand's national policies. In Thailand, the royal family, the Chakri dynasty, remains central to the country and Thai culture generally. The Chakri dynasty has ruled Thailand since the founding of the Ratthanakosin era in 1782. The current monarch, King Bhumibol, was crowned King of Thailand in 1946. In the Thai culture, the King is revered. He is considered to have "reigned with righteousness for the benefit and happiness of the Thai people" as manifest through his many social and economic development projects (Royal Thai Embassy, 2009). Since the beginning of his reign, he has continually worked to enhance the livelihood of the poor. First, the king initiated Royal projects on a

small scale in the 1950s and 1960s using his personal funds. During 1980s and 1990s, the number of villages benefiting from Royal Initiative projects expanded to about 4,000 or 7 percent of the villages in the kingdom (Muscat, 1994). Special attention was given to relatively remote areas inhabited by the ethnic minorities and people who lacked access to resources. The aim was to create bonds which closely linked people from all sectors together and to encourage unity, equity in accessibility to resources, preservation of environment, and sustainable development. The King's royal speech given to the graduates of Kasetsart University on July 18, 1974 stated that:

“...Development of the nation must be carried out in stages, starting with the laying of the foundation by ensuring the majority of the people have their basic necessities through the use of economical means and equipment in accordance with theoretical principles. Once a reasonably firm foundation has been laid...a higher level of economic growth and development should be promoted...” (RDPB, 2004).

The king developed and promoted the philosophy of the Sufficiency Economy as an alternative to the export-oriented policies, and also as a complement to the Buddhist way of life, which remains the dominant religion in Thailand with 95 percent adherents (Lawler, 1996). Buddhism in Thailand is largely of the Theravada school, based on the religious movement founded in the sixth century B.C. by Siddhartha Gautama Sakyamuni, later known as the Buddha, who urged the world to relinquish the extremes of sensuality and self-mortification and follow

the enlightened Middle Way. The Middle Way was the central and pervasive norm in the set of discourses that provided both the worldview and the philosophy that Buddhism applied to everyday life (Khemasanto, 2005). Around the sixth century A.D., Theravada Buddhism reached present day Thailand and was made the state religion of the Thai kingdom during the period of Sukhothai in the thirteenth century A.D (Muscat, 1994). In Thailand, the king was, in principle, thought of as patron and protector of the religion (sassaana) and the ordained Buddhist monks (sangha). In 1851, King Mongkut (Rama IV) who had been a monk for twenty-seven years rose to power (Muscat, 1994). He institutionalized the sangha and the kingdom. The links between Buddhism and the state became increasingly integrated and hierarchical in nature (Darlington, 2000).

2.3.1 The King's plan towards the Sufficiency Economy

On the royal birthday in December of 1998, the king in a national broadcast reemphasized the concept he had propounded since the 1970s, the Sufficiency Economy. Again, the foundation of King's concept was originally introduced to the graduates of Kasetsart University on Dec 4, 1974:

“...no matter what others say-whether they will accuse Thailand of being old fashioned or obscurantist. So long as we have enough to live on and to live for- and this should be the wish and determination of all of us- without aiming for the apex of prosperity, we shall already be considered as the top in comparison with other countries in the present world...”
(RDPB, 2004).

The Sufficiency Economy initiated by the king is different from the self-sufficiency concept. The self-sufficiency concept refers to survival without support, aid, or interaction from outside (Puntasean, 2007). The Sufficiency Economy advocates taking the “middle path” in life—the path between two extremes, that of great luxury and great hardship—as the optimal route for personal conduct at all levels: individuals, families and communities. It encourages self-reliance, honesty and integrity, while exercising knowledge with prudence (RDPB, 2004). Trade is allowed as long as individuals are able to live a reasonably comfortable life without excess or overindulgence in luxury. The foundations of King Bhumibol's theory included sustainability, moderation, and broad-based development. He promoted the virtues of leaving the chaos of modern urban life and capitalist economics and a return to what he perceived as more worthy and economically lasting agricultural enterprises, which he believed characterized the best of Thai heritage values. The concepts focused on living a moderate life without greed or overexploitation of the environment and natural resources (RDPB, 2004).

The King's message prompted a new focus on development within the agricultural sector where, traditionally, the vast majority of the Thai population was, and still is, employed (Rigg, 1996). The Sufficiency Economy model promotes the idea of limited production for the purpose of saving the environment and conserving scarce resources. It is an initiative with a strong sustainability theme derived from the concept that replacement of natural capital is limited and

that environmental quality should be maintained (Sathirathai and Piboolsravut, 2004).

The Sufficiency Economy concept aims to preserve ecological sustainability including soil and water qualities over time. Production is limited to the level adequate for family consumption. Equitable access of scarce and unrennewable resources is emphasized (RDPB, 2004). The use of natural resources is not encouraged for large-scale commercial activities, but for household consumption. Activities such as rehabilitation of forests, soil and water conservation systems are advocated, including the use of local knowledge and green technologies. The plan also actively promotes waste recycling and reuse (Puntasean, 2007).

The Sufficiency Economy also advanced the idea of production not just for profit maximization but also for sustainable development for the individual, the household, and the larger community (Jitsanguan, 2001). In this model, food is not only an agricultural product or a hunter-gatherer, subsistence, activity. Excess beyond the needs of the household can be viewed as part of social responsibility and given to the broader society, for example, to monks, parents, relatives, and only then for sale. It was believed that these freely given community products were ways to redistribute resources. Under this scenario, people who received products would be expected under social norms to return the gifts when the opportunity arose.

For small-scale farmers, the Sufficiency Economy starts with a system that emphasizes the household farm. Farmers were encouraged to combine into groups or cooperatives (Puntasean, 2007). Goods and services could be exchanged to increase production efficiency and marketing, while the cooperative members believed in the ethical values of honesty, openness, social responsibility and caring for others (Jitsanguan, 2001). This way, the community will have a "self-immunity" to the changes created from endogenous and exogenous factors. People in the less developed areas with scarce resources could acquire the basic goods and services by exchanging available products or labor (Sathirathai and Piboolsravut, 2004). Money, which was emphasized in the Export-Oriented Growth model, is no longer promoted as the only instrument for exchange. The model stresses meeting the basic needs for all Thai people, with a particular focus placed on the disadvantaged.

It should be acknowledged that the King's plan still promotes industrial activity and trade, but the program's goals are to introduce a new set of values and code of conduct in dealing with globalization. For instance, it promotes investment in business only using funds not exceeding the company's assets. This philosophy encourages spending restraint and controlled expansion of activities and purposefully tries to limit the use of scarce resources (Isarangkun and Pootrakool, 2004). This should ensure that natural services and the quality of natural resources can be maintained over time. If fully adopted the plan promotes natural resource quality and proper landscape composition creating ecological

stability (Puntasean, 2007). However, the Plan recognizes that a balance needs to be found between Thailand's requirements to remain competitive in manufacturing, services, and other non-agricultural economic activities.

The principles of the Sufficiency Economy include moderation, reasonableness, and self-immunity (Puntasean, 2007). Firms are encouraged to establish strong economic foundations by finding their niche, improving the quality of their products, and ensuring competitive costs in production. To this extent, material and energy efficiency are emphasized in the program. Firms are encouraged not to grow too fast by over-borrowing or over-exploiting resources (Isarangkun and Pootrakool, 2004).

In addition, a new emphasis is placed on private corporations realizing their responsibilities to society and strengthening their connections within their communities. This is in recognition that the combination of private firms and the broader Thai society can be extremely effective in mobilizing resources and playing an important role in helping the underprivileged help themselves over the long-run (Isarangkun and Pootrakool, 2004). Many Thai firms have already followed through with this new national promotion and have initiated corporate social responsibility programs and collaborations within their communities. For instance, the Thai Vegetable Oil Public Company Limited is currently operating in accordance with a new policy focusing on social responsibility achievements. The company donates money and products to schools for luncheon programs. It

also established a student trainee program. In addition, the company invested in a waste water treatment system project to help improve environmental quality (Thai Vegetation Oil PCL, 2007, online). Another example is provided by the Siam Cement Group, which established a sustainable development committee and a corporate policy that focuses on a three pronged approach to greater community-corporate cohesion—promoting environmental preservation, community health and safety, and social responsibility (SCG, 2008, online).

The Sufficiency Economy is also being strengthened through government plans and legislation. The current constitution of Thailand is the supreme law of the Kingdom and an interim constitution was promulgated on the October 2006, which stated that the government must encourage the Sufficiency Economy in order to ensure the economic, social, and sustainable development of the country (TEI, 2008). As noted earlier, the 9th Thailand Economic and Social Development plan (2002-2006) did integrate some of the Sufficiency Economy programs that emphasized sustainable development, quality of life issues, and environmental quality under globalization. The national plan focused on economics at the local level, but also encouraged community level activities by, for instance, encouraging community savings for a village fund (EN, 2008, online). The community was encouraged to expand their activities by reaching out to co-operative firms, banks, and other outside sources. The expansion across different levels of organizations or activities can be compared to developing a value-chain in production. The expanded activities include fund

raising, creating direct sales channels, and establishing community rice mills or cooperative stores.

The 10th Thailand Economic and Social Development plan 2007-2011 published by the Office of Prime Minister calls for a “Green and Happiness Society” (BOI, 2006). The plan focuses on building strong communities to serve as building-blocks for the nation and to develop a dependable community level economy to co-exist harmoniously with nature and the surrounding environment. One significant goal was the preservation of forest areas for at least 33 percent of the country. Irrigated agriculture fields were also mandated to at least 31,000,000 rai or 49,600 km². The Plan also explicitly promoted environmental quality and a healthy ecosystem as a necessity to support healthy living conditions (NESDB). The strategy to maintain natural resource quality from the 10th plan was illustrated with the following figure.

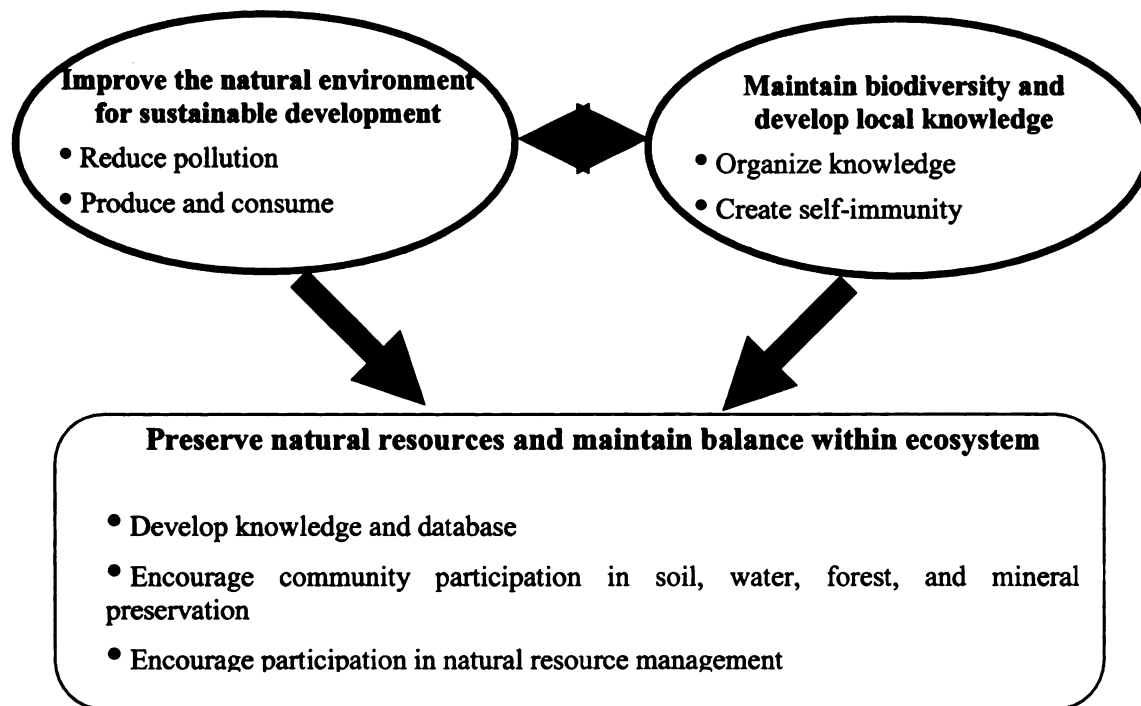


Figure 2.1 The environmental preservation context under the 10th Thailand Economic and Social Development plan 2007-2011.

In the urban context, residents are encouraged to adopt the King's Plan by giving away some of the excess goods to the community and to promote the redistribution of resources to rural areas (Puntasean, 2007). The Buddhist model expects those well-off to return some goods or resources to those who lack opportunities or lack basic materials required for life. Residents are also encouraged to efficiently use resources. For instance, soils suitable for agriculture should not be exploited for urban expansion. Waste reduction is also promoted through recycling and reducing consumption (RDPB, 2004). In addition, creditors and small businesses are encouraged to support cooperatives and small-scale farmers by purchasing their products. The Plan lays the foundation for the establishment of a new culture, where people in different

places and in different generations can adapt the philosophy promoting social/corporate support systems into everyday life (Puntasean, 2007).

2.3.2 Land and soil resources: effective allocation of land to serve the different needs of farm households using New Theory farming

An example of the Sufficiency Economy was the “integrated farming practice according to the New Theory” which promoted step-by-step development, starting from satisfying basic needs at the household level (ONRCT, 2003). There were six Royal Development Study Centers established throughout Thailand in different regions each characterized by different unsustainable development problems. The Royal Development Study Centers were established to conduct studies and experiments on self-sufficiency and to promote appropriate development paths for each region. According to the RDPB (2004):

“The purpose of the Royal Development Study Centers is to develop farmers’ land by means of land development, water resources development, forest rehabilitation and application techniques in agriculture and animal husbandry. The center will serve as a central office to conduct development activities to improve the well-being of the people in the surrounding areas. Once the farmers upgraded their living standard, they might consider setting up a rice mill and rice bank in each village to get an opportunity to train themselves, to finally become self-supporting...”

The King's plan for "New Theory Farming" for small-scale farmers was initiated in the 1980s. It focused on the application of integrated farming systems for poor farmers on small land holdings with scarce water resources, as in the Nang Rong region. Its main goal is to provide food security and to promote the principles of the Sufficiency Economy to the local poor population (RDPB, 2004). Perhaps the most important goal of New Theory Farming was to ensure the effective allocation of land to serve the diverse needs of small farm households, including paddy fields for rice, farm ponds for water and fish, cash crops and trees for income, and a defined residential area (Jitsanguan, 2001). In general practice, the area allocated to each kind of land use should be flexible, according to local resources, but a general land allocation scheme is promoted under the Plan. Essentially, rice is usually grown on 30 percent of the land, another 30 percent of the land is excavated for a pond to be used during droughts or the annual dry season, another 30 percent could be used for cash crops, vegetables, and fruits, while the remaining 10 percent could be used for the household residential area (Jitsanguan, 2001).

The New Theory Farming land allocation model has been suggested to be effective for household resource allocation and public uses. Of course, the most important objective is to produce sufficient goods for household consumption. Under the New Theory Farming model, farmers will be less dependent on the whims of the market and less likely to accrue debt.

Various agricultural development plans were studied at the closest research center to Nang Rong called the Puparn Royal Development Center. Local forests were replanted in an attempt to preserve the watershed. Soil and water conservation systems were studied, and topsoil erosion prevention explored by growing vetiver grass (RDPB, 2004). Soil development enhancements including using organic fertilizer and green manure, making of compost, and constructing ponds were promoted. The sustainability goals in the Northeast focused on small-scale farmers and encouraged the application of the test methods on their own lands to obtain enough rice yields for household consumption and be able to access water resources during the dry periods (RDPB, 2004).

Complexity arises from human's life decisions and the interactions of the components within the social-environmental system. As the economic driver within the urban system, either the Export-Oriented plan or the Sufficiency Economy plan is likely to influence other components, interactions and individuals' decision making process. The urban system under either plan is likely to exhibit unique emergent properties and unique phenomena. Understanding the system' complex behaviors and possible outcomes from different strategies would be helpful for decision-making and may promote sustainability.

2.4 Conceptual and theoretical background

2.4.1 Natural systems: complex systems/general systems theory

The idea that natural systems are comprised of many smaller systems functioning due to the interactions of many even smaller parts has been a common vision since the middle part of the last century (Berryman 1981; Simon 1962). However, there has been a growing sense over this same period that a system is often something more than just an additive sum of all of its smaller processes and parts; systems frequently exhibit emergent properties which apparently come into existence through the interactions of each part of the system (Robbins 2004; Casman et al. 2001; Castree and Braun 2001; Flake 1998; Braun and Wainwright 2001). Crawford et al. (2005) stated that “System is commonly taken to mean a group of interacting, interrelated, or interdependent elements forming a holistic functional whole.” Messina (2001) suggested that complexity appears due to the interaction of different components within the system and develops emergent multi-scale phenomena. Emmeche (1997) identified emergence as a function of synergism not characterized from the additive effects of system components, but from interactions among components. Auyang (1998) suggested that emergent phenomena are not products of aggregation, averaging, or other superposition of microlevel components. They are higher-level structures that are qualitatively different from their lower-level components. Parker et al. (2003) argued that the concept of emergence is directly related to the nested hierarchy phenomena that characterize complex systems, and that emergent phenomena are aggregate macroscale outcomes

arising from microinteraction. These phenomena cannot be predicted by examining the elements of the system in isolation.

One way to conceptualize systems with emergent properties is through the complex systems framework. Complex systems are generally discussed as dynamic systems that exhibit recognizable patterns of organization across spatial and temporal scales (Parker et al., 2003). Essentially, like general systems theory, complexity argues that complex systems are heterogeneous and consist of many simpler parts. Often, the underlying behavior of any of the parts is easily understood, while the behavior of the system as a whole defies explanation (Bak, 1998). This view sees the complex nature of systems as emerging from nonlinearities of number of interactions governed by simple rules. While it seems unreasonable to say that we cannot directly conceptualize (or model) complex phenomena out of smaller level parts, this very characteristic gives rise to the need for specialization:

“If no new phenomena emerged in large systems out of the dynamics of systems working at a lower level, then we would need no scientists but particle physicists, since there would be no other areas to cover.” (Bak, 1998)

Therefore, the emergent properties of complex systems actually enable scientists to focus on specific subsystems of interest to them. Despite its relatively new status, complexity theory can provide novel and illuminating insights into the non-

linear relationships, feed-back mechanisms, multi-scale effects, and critical thresholds that typically characterize human and environment interactions such as in urban studies. Structurally, complex systems are characterized by interactions among agent and their environment including interdependencies, heterogeneity, and nested hierarchies (Manson, 2001). Complexity arises from both human decision making and the explicitly spatial aspects of the landscape environment (Parker et al., 2003). Adaptation is one complex system characteristic. Learning behavior and evolution of strategies may be inherent within the decision-making structure at the individual agent level. Aggregate population evolutionary characteristics may be influenced by birth, death, and migration of agents at the system level (Berger, 2001). Finally rules and institutions may evolve over time in response to changing social and environmental conditions (Lansing and Kremer, 1993).

From Messina (2001) referenced from Cilliers (1998) and Clarke et al. (1997),

“required characteristics of complex systems consist of:

- A large number of elements which when sufficiently large are not effectively describable by conventional means (e.g., a set of differential equations);
- Large numbers of elements are necessary but not sufficient in that the elements must interact dynamically;
- Interaction must exist among many elements;
- Interactions must be non-linear and operate in feedback loops;

- Interaction range must be fairly small (the effective neighborhood);
- Complex systems are usually open systems: the process of framing is used to characterize the scope of a system, and in some respects, is determined by the observer;
- Complex systems are in dis-equilibrium;
- Complex systems have a history which is partly responsible for the present;
- Each element of the system is unaffected by and does not affect the system as a whole.”

2.5 Methodological approaches in land use studies

2.5.1 Remote sensing and Geographic Information System (GIS)

Remote Sensing and analyses using Geographic Information System (GIS) techniques are powerful and increasingly affective tools for researching on global environment change monitoring (Geoghegan et al., 1998). They provide a great opportunity to characterize and map land use land cover distribution and change patterns at multiple scales and different periods of time with great detail not possible using census data or field surveys alone (Townshend et al., 1991). Remotely sensed data can be used to monitor changes in space and time. Dynamic models of regional development and future land use patterns and changes can be developed and validated using remotely sensed data combined with field or survey data, (Moran et al, 1994). The growing interest in making scientific progress through the use of remotely sensed data in social science

research community has been stimulated by this unique advantage of remote sensing, the so called “Pixelize the Social” approach (Schweik and Green, 1999).

Remote sensing and GIS empower Land Use Land Cover Change research to allow researchers to measure landscape attributes otherwise invisible. GIS has the capability to combine, integrate, manage, analyze, and store remote sensing data within a spatial framework (Liu et al, 1993). In addition, the combination of remote sensing and GIS provides considerable advantages for mapping and computing when dealing with temporal data (Lambin, 1994). However, the underlying processes and driving forces of LULCC still need to be understood. In ecology, early works focused on understanding the relationships between pattern and process at landscape scales (Baker, 1989). But many of these studies tended to focus on spatial aspects of patterns rather than the processes and driving forces that involved in the patterns (Grainger, 1995). The pattern to process approach allows us to consider how spatial patterns of LULCC influenced by socio-economic and ecological processes, and how the processes are influenced by the changing patterns.

2.5.2 Land Use Land Cover Change studies and models

Three broad methodological categories in LULCC studies have been identified (Rindfuss et al., 2004): using remote sensing technologies to observe and monitor land use change and to quantify land use change over time; describing causal processes of land use change pattern by identifying factors that drive land

use change; combining categories 1 and 2, using computer models to study land use change (Briassoulis, 2000; Verburg et al., 2004d; Overmars, 2006).

The underlying processes and spatial dynamics of land use systems can be studied, and using simulation models, formulate future land use scenarios. In addition, LULCC can be explored from two basic starting points: “from pattern to process” and “from process to pattern” (Overmars, 2006). Pattern-based methods can be most easily compared to GIS based approaches that analyze land use patterns and identify processes as responses to patterns. LULCC models can then be built to link pattern to process by quantifying the contributing driving forces and representing the sensitivity of LULC to economic, ecological or locational factors. The process-based approach focuses on actors’ decision-making and the interactions between agents, with LULCC pattern maps created from those actors’ decisions. These two approaches can be contrasted by the distinction between inductive and deductive methodologies. The driving mechanisms in land use change are induced in the pattern-based approach, while the process-based approach predicts land use change from causal assumptions and tests those predictions (Overmars, 2006).

Geoghegan et al. (1998) suggested that “socializing the pixel” and “pixelizing the social” can integrate process-based and pattern-based methods. “Socializing the pixel” involves applying remote sensing imagery in an application in addressing concerns of the social science and seeking social meaning. This method aims to

push the pattern-based approaches beyond the biophysical. “Pixelizing the social” is a bottom-up approach in which each pixel is modeled to have the social empirically estimated. Remote sensing and spatially explicit data are thus integrated and used to test social theories through models (Geoghegan et al., 1998; Overmars, 2006). These two methods: “socializing the pixel” and “pixelizing the social” aim at bringing the extremes of the inductive “from pattern to process” and the deductive “from process to pattern” closer together in order to come to an integrated approach (Overmars, 2006).

2.5.2.1 Urban modeling and simulation and complex systems

In general, modelers begin with a theoretical framework and formalize it in computer code in order to examine the ramifications of a framework and potentially generate new hypotheses (Parker et al., 2002). Testing candidate explanations by creating models and simulations is one method to understand complex systems. Emergent properties and patterns of urban complex systems such as the spatial organization inherent in patterns of human settlement can be represented by developing rules for the agents and allowing them to interact with the simulation environment. If the emergent phenomenon is similar to the observed incident, subsequently the candidate explanation for the experiment may be uncovered (Parker et al., 2003).

In addition, modeling and simulation allow modelers to assess the ramifications and boundary conditions of theories and hypotheses, as they provide an

opportunity to systematically test alternative explanations. The theory gains support when outcomes from theoretically based constructions mimic reality. The modelers do not attempt to reproduce actual land-use systems; instead, they focus on specific aspects and on modeling fundamental dynamics. The objective is that the explorations using models and simulations will lead to empirically relevant insights. Researchers may construct a model with the specific goal of examining the possible (but unknown) emergent property of a particular set of individual agent interactions. Thus, in general, modeling approaches allow modelers to 1) demonstrate a set of rules that correspond to the outcome of theory, 2) explore other possible causes that could lead to the same outcome by formally exploring the robustness of the proposed causal explanations, and 3) discover outcomes not originally anticipated (Parker et al, 2003).

The city is "an integrated whole made up of a number of physical, biological, and human subsystems...[and] none of the subsystems can be fully understood if they are considered in isolation from the others" (White, 1998). Within the Nang Rong context, each of the physical, biological, and human-social characteristics manifests at some scale within a "regional construct." The history of the region at any specific time-step influences the local development. An urban area in time-step T is likely to be urban in $T+1$ and correspondingly the neighbor in T , if not urban, may change into an intermediate state in $T+1$ (Messina, 2001). Urban areas develop or expand in traditional manners directly related to neighborhood conditions (Downs, 1981). In Nang Rong town, increasing the accessibility and

the likelihood of any space changing from agriculture to urban by neighboring drivers of change play important roles. Urbanicity in the Nang Rong context is an open system where exogenous factors have a local effect. For example, prices of crops in the international market may drive urban expansion resulting in the conversion of agriculture to housing. It is the interactions between humans and the environment with these factors that create the emergent properties of urban morphology in Nang Rong.

2.5.2.2 Automata

The idea of automata supports the idea of “behaving objects” in the geosimulation framework. An automaton is a processing mechanism with multiple characteristics including internal characteristics, rules, and external inputs that influence changes within the system over time. Surrounding information can be processed by automata. Their characteristics are altered according to rules that govern their reaction to those inputs. Automata provide an efficient formal mechanism for representing their fundamental properties: attributes behaviors, relationships, environments, and time. Automata-based modeling tools offer many benefits for simulation of urban phenomena in space including the decentralized structure of automata systems, their ability to directly handle individual spatial and nonspatial elements, and simplicity of formulation (Parker et al, 2003).

Geographic automata can be distinguished into two types of automata based on spatial generalizations: Cellular Automata (CA) and Agent-Based Systems (ABS). One of the most promising applications of complex system concepts is a class of spatially explicit models collectively referred to as Cellular Automata whose objective is to computationally model complex interactions between people and LULCC by utilizing population and environmental data (Walsh et al. 2003; Walsh et al 2004). First, CA models were demonstrated by Ulam and Von Neumann in the 1940s to provide a formal framework for investigating the behavior of complex, extended systems (Von Neumann 1966). CA models have been used for evaluating the role of density constraints in land development (Batty et al., 1999), explaining the evolution of urban forms (Clarke et al., 1997; Wu, 1998), and simulating land-use transitions (White and Engelen, 1997). CA models are dynamic, discrete space and time systems, which consist of objects occupying space called cells. Each cell can be in one of a finite number of k possible states, which can change through time and space according to local rules. These rules control the influence of neighborhood with and the state of a cell determined by the previous states of a surrounding neighborhood of cells (Wolfram 1984; Messina, 2001). CA models simulate processes where local or decentralized rules that embody local processes generate global or centralized order as “emergent” (Batty, 2005).

CA models embody 4 distinct characteristics. First there are cells, objects which occupy space and possess properties such as adjacency or proximity to one

another. Second, each cell can have only one state at any one time from a set of available states. Third, the state of cell depends on the states and configurations of other surrounding neighborhood (adjacent) cells. The term "configuration" refers to an assignment of states to cells in the grid. Finally, there are transition rules that drive changes of state in each cell as some function of what exists or is happening in the cell's neighborhood. Transition rules or growth rules must be uniform and every change in state must be local. There are conditions that specify the start and end points of the simulation in space and time, which are respectively called initial and boundary conditions (Batty, 2005).

CA models integrate initial conditions, growth or transition rules, and neighborhood effects on LULC patterns and often illustrate the importance of feedback mechanisms, the influences of globalization, local natural resource distributions, and critical population-environment interactions in defining the composition and spatial organization of LULC. What is interesting is that CA models can output very realistic results without utilizing an explicit global algorithm, meaning CA models can, with proper parameterization, model nonlinearity and emergent processes (Flake 1998). Benenson and Torrens (2005) stated that urban systems belong to the category "nonlinear systems" in which autonomy of automata is an important property. Therefore, urban systems can be studied with a number of aggregate units using CA models to simulate urban change processes. The ability to model these processes is important considering that under the right conditions, the properties of complex systems

can express themselves in terms of land use land cover change when specific land use land cover thresholds are exceeded, leading to ecosystem degradation or even abrupt change (Flake 1998; Turner et al., 2001).

In Nang Rong Town, urban change is caused by multiple stakeholders interacting through endogenous and exogenous processes. Urban change combined with the ongoing natural dynamics of the ecological system can produce nonlinear change. Critical points in the spatial structure of land use patterns and feedbacks can produce a system with a high potential for dramatic phase changes (Turner, Gardner, and O'Neill, 2001). For example, Walsh et al. (2004) found that, in Nang Rong District, as LULCC patterns become more fragmented, young adults begin to engage in off-farm employment, which suggests that the landscape has exceeded a real or perceived threshold of land availability or contiguity for use or ownership. This increase in off-farm employment may also offer the opportunity for subsequent households to accumulate additional assets through remittances, thereby affecting household decisions about the use or ownership of the land.

Because of the immense complexity and potential for hard-to-isolate drivers many traditional spatial analysis and modeling techniques are inadequate or unable to adequately describe phenomena such as the landscape (or LULCC) impacts of increased off-farm employment. However, CA models were designed to characterize the development of spatial patterns given certain constraints, non-linearities, feedbacks, and thresholds. As the subject under study exhibits

increased numbers and wider variance in model inputs, most modeling techniques strain to consider the “complications.” Using morphological constraints, the CA computational framework focuses on the neighborhood effects within a strict range of parameterization. Because of this characteristic, many more recent studies of LULCC and urban modeling have used CA methods to model and predict changes (e.g. Battty et al., 1999; Webster and Wu, 1997).

2.5.2.3 Agent-Based Models (ABMs)

Where cellular models are focused on landscapes and transitions, agent-based models focus on human actions. Fundamentally, agents are automata which are able to act and capable of processing and exchanging information with other automata. Agency can be explained as a formal entity or an elementary unit of Geographic Automata Systems in which behavioral responses occur autonomously based on a given set of state transition, neighborhood, and location rules (Benenson and Torrens, 2005). An autonomous agent was explained by Franklin and Graesser (1996) that “ (1) it is a system situated within and a part of an environment; (2) that senses that environment and acts on it, over time; (3) in pursuit of its owns agenda, and (4) so as to effect what it senses in the future.” Autonomous agents have control over their actions and internal state in order to achieve goals and needs strategies that allow it to react to changes in environment (Parker et al., 2003).

An ABM is a group of autonomous agents. Properties and behavioral rules can be assigned to individual agents and used as basic building block. As the characteristics of agents within the system change over time due to interactions among agents or adaptation to dynamic environment. ABMs can be used to examine these basic characteristics and activities of the system (Walsh et al., 2004). As agents learn through experiences and feedbacks developed within finer scale building blocks, the emergent and self-organizing properties in macro-level behaviors may emerge from the actions of individual agents (Walsh et al., 2004). The underlying system may evolve over time due to the influence of agent behaviors (Bak, 1998).

ABMs belong to discrete event simulations category of models. ABMs start with set of identified initial conditions. The program allows agents to carry out their actions until a specified stopping criterion is satisfied (Brown, 2006). In the context of understanding LULCC, ABM is a dynamical system which can incorporate positive and negative feedbacks. The actions of agents can be scheduled to take place synchronously or asynchronously. The behavior of an agent and the information exchange process among agents influences the subsequent behavior of other agents within the system. These feedbacks can be used to represent the endogeneity of various driving forces of LULCC (Walsh, 2007). ABMs are a powerful tool and offer the flexibility to examine pattern and process relations of landscape change (Brown, 2006).

2.5.2.4 Other models

Different approaches for modeling changes to the landscape are reviewed including their advantages and disadvantages by Parker et al (2003) and Irwin and Geoghegan (2001). Modeling approaches for human-environment studies including: mathematical equation-based, system dynamics, statistical, expert system, evolutionary, cellular, and hybrid models. Equation-based models used for population growth and diffusion, though the simplest to implement, are aspatial and static (Sklar and Costanza, 1991). System models allow for more dynamism but are still essentially aspatial (Bruneton et al., 2002). Statistical techniques such as regression and time series analysis are used within agent-based models, but have limited utility on their own (Mertens and Lambin, 1997). Logistic regression is an inductive approach which can be used to study the explanatory factors of the land use changes given limitations in the dependent variable (discrete not continuous) (Nelson et al., 1999; Mertens and Lambin, 2000). Expert models are built more for diagnostics, such as the legal and medical professions, where the system states and decision rules are clear. But they will only respond as programmed, and hence may lack dynamism (Lee et al., 1992). Evolutionary models such as neural networks are spatially explicit and extremely powerful for handling complexity, but are not suited for inference and hence will not be amenable for generalizations (Balling et al., 1999). Cellular models are by definition spatially explicit and are integrated into Land Use Land Cover Change (LULCC) models for generalization purpose (White and Engelen, 1997), but on their own have no explanatory power. Hybrid models are the state

of the art, combining techniques from the other approaches. Some are programmed using specialized computer languages, e.g. Java-Swarm, or available as modeling packages, e.g. CLUE, Cormas, etc. (Bousquet and Le Page, 2004). The review of modeling approaches for human-environment studies are derived in Table 2.7.

Table 2.7 Modeling approaches for human-environment studies.

Model	Uses/Features	Advantages	Disadvantages
1. Equation-based models	Relies on equations for static or equilibrium solutions; Uses simultaneous equations, differential equations, linear programming, etc. in population growth and diffusion modeling (Sklar and Costanza, 1991)	Easy to implement	Aspatial; Limited level of complexity; Numerical or analytical solution to the system of equations must be obtained
2. System models	Represents stocks and flows of information, material, or energy as linked blocks of differential equations iterating over discrete time increments to allow for feedback; Used in human and ecological interactions	Not difficult to conceptualize; Applications available (STELLA); Representing feedback and dynamic processes	Dependent on explicit enumeration of causes and functional representation; Difficulty with spatial relationships (Baker, 1989); Limited explanatory power where heterogeneity and interactions are important
3. Statistical techniques	Spatial regression techniques; spatial econometrics and spatial statistical methods (Mertens and Lambin, 1997)	Impact of heterogeneity, neighborhood effects and spatial spillovers can be assembled. Useful for spatial dynamic processes and interactions that are stationary and uniform over space and time	May downplay decision making and social phenomena unless linked to a theoretical framework; May distill information into parameter estimates; Feedbacks across scale are difficult to modeled.

Table 2.7 cont'd.

4. Expert models	Combines expert judgment with probability techniques, or symbolic artificial-intelligence and rule-based knowledge systems (Lee <i>et. al.</i> 1992); Expresses qualitative knowledge in a quantitative fashion	May enable locating probable land use change	Can be difficult to include all aspects of the problem domain consistencies
5. Evolutionary models	Symbolic approaches developed within a biological evolutionary paradigm, e.g. artificial neural networks and evolutionary programming (Balling <i>et. al.</i> , 1999)	Maybe spatially explicit, models are trained to be able to solve a particular problem	Not suited for inference
6. Cellular models	Includes cellular automata, directed graphs, networks, and Markov models; Focused on landscaped and transitions; Underlies many LUCC models for modeling geographical and ecological processes, e.g. rangeland dynamics, species composition, forest succession, and global LUCC and climate change	Well suited for spatial expression; Flexible for representing spatial and temporal dynamics (based on stationary transition probabilities); Time updated may be synchronous or asynchronous.	Does not model human decision making unless incorporated with a behavioral component
7. Expert models	Combines expert judgment with probability techniques, or symbolic artificial-intelligence and rule-based knowledge systems (Lee <i>et. al.</i> 1992); Expresses qualitative knowledge in a quantitative fashion	May enable locating probable land use change	Can be difficult to include all aspects of the problem domain consistencies
8. Evolutionary models	Symbolic approaches developed within a biological evolutionary paradigm, e.g. artificial neural networks and evolutionary programming (Balling <i>et. al.</i> , 1999)	Maybe spatially explicit, models are trained to be able to solve a particular problem	Not suited for inference

Table 2.7 cont'd.

9. Cellular models	Includes cellular automata, directed graphs, networks, and Markov models; Focused on landscaped and transitions; Underlies many LUCC models for modeling geographical and ecological processes, e.g. rangeland dynamics, species composition, forest succession, and global LUCC and climate change	Well suited for spatial expression; Flexible for representing spatial and temporal dynamics (based on stationary transition probabilities); Time updated may be synchronous or asynchronous.	Does not model human decision making unless incorporated with a behavioral component
10. Hybrid models	Combines any of the other techniques, often programmed with specialized software (Java Swam) or implemented within dedicated packages (DELTA, CLUE, etc.); Successfully implemented for deforestation, endangered-species models, etc.	Wide application, represent individual decision making and temporal and spatial dynamics	An emergent , evolving technique, typically does not represent heterogeneous actors, institutional effects on decision making, or multiple production activities
11. Agent-based models	Focused on human agency, usually through probabilistic or econometric models	Direct inferences on human agency	No spatial expression

CHAPTER 3

The Study Area: Nang Rong, Northeast Thailand

3.1 Introduction

The majority of the Thai population live in places where resource-poor biophysical environments combine with socio-economic marginalization. Nang Rong town is a typical place. Located within the Nang Rong sub-district (Tumbon), Nang Rong district (Aumpur), and established within the Buriram province located in northeast Thailand, this region, also known as the Isaan, is characterized by a very poor natural resource base, generally infertile soils, and inconsistent precipitation levels (Welsh, 2001).

More than 20 million people reside in the Isaan region. With approximately one-third of the country's land area or 105 million rai (170,000 km²), the region is characterized by a combination of lowland flood plains and upland areas of moderate slope (Khon Kaen University-Ford Cropping Systems Project, 1982). Farming is the primary occupation; the per capita income is the lowest in the country (National Statistic Office). Isaan's climate is a wet-dry monsoon in which nearly 80 percent of the total annual rainfall occurs between April and November. The timing and amount of precipitation is highly variable, creating substantial risks to agriculture and creating water supply shortages during the dry season (Kaida and Surarerks 1984; Rigg, 1991).

Burirum is a rural province about 410 km from Bangkok and was an important district of the Khmer empire during the Angkor period (879 – 1432 AD). The province is littered with Khmer ruins. Many of these are little more than piles of stones scattered about the fields of what was once known as Phanom Rung (Figure 3.1), but there are a few very well preserved Khmer temples (NRDO, 2006). *Prasat Hin Phanom Rung* (Phanom Rung Stone Castle) is a Khmer temple complex built in the 10th to 13th centuries and set on the rim of an extinct volcano near the southern border of the district (Thaitravel.info, 2008). After the decline of the Khmer, a new ethnic group called the Mon-Khmer emerged and occupied the region. While not definitive, it is believed that the Thai started to govern this area during the Sukhothai (1238-1438) or the early Ayutthaya period (1350 – 1767) and that Nang Rong town was then formally established as a regional administrative center (NRDO, 2006). In 1892, during the present Ratthanakosin era, King Rama V organized the country and placed Nang Rong town within the newly established Burirum province. Nang Rong district (Figure 3.2), today, is one of 21 districts comprising Burirum Province. The district itself is further divided into 15 sub-districts (Tumbon) with one municipal center and several hundred villages (NRDO, 2006).



Figure 3.1 Prasat Hin Phanom Rung

According to Nang Rong district demographic statistics, the human population in 2006 was 108,206 with a population density of 118 persons per square kilometer. According to CBIRD (*Community-Based Integrated Rural Development*) in 1994, annual population growth in the larger Nang Rong region was estimated to be 1.2 percent. There were 356 administratively defined rural villages in 2000, plus several market centers and administrative towns. As is typical of the larger region, the majority of the local population works in the agricultural sector mainly farming rice and cassava (NRDO, 2006). Human settlements in Nang Rong take the form of nuclear households clustered in villages with agricultural fields

arrayed radially, but not contiguously, around the village core (Crawford, 2000; Rindfuss 2002). A large-scale longitudinal community-level social survey (1994) by Mahidol University in Bangkok and the University of North Carolina at Chapel Hill reported data for 310 villages, not including the central district town of Nang Rong, the focus of this dissertation. People lived in villages ranging in population from 100 to 2,276, with a mean of 470. The total land cultivated for all 310 villages was reported to be 846 square kilometers or 528,857 rai (1 rai = 0.0016 square kilometers). The average village controlled 2.72 km² of farm land. The minimum area reportedly cultivated by a village is 0.08 km² and maximum 16 km² (CBIRD, 1994). However, Nang Rong town, the central subject of this chapter, is a separate sub-district with distinct governance. The legal boundary of the town, officially established in 1986, includes an area of 54 km² and comprises 20 distinct communities, containing both Nang Rong and Thanon Huk sub-districts. Its neighbors include Nang Rong and Nong Yai Pim sub-districts in the north, Sadao and Nang Rong sub-districts in the south, Thanon Huk and Nong Yai Pim in the east, and Nong Bode and Nang Rong in the west. The first Nang Rong district administrative building was built in Nang Rong town in 1901 (Nang Rong District, 2006). In 1954, there were 7 existing villages in the Nang Rong town area including Don Slang Pan, Tanon Huk, Nong Ree, Cha Buak, Thung Lam, Pak Wan, and Khok Long Poe. Khok Long Poe was the oldest village and was founded in 1900. From 1954 to 1990, 7 more villages were established Nang Rong District, 2006). Today, Nang Rong town is a minor tourism gateway

providing access to the most significant ancient Khmer-sites in northeast Thailand and is also a transportation hub to other provinces.

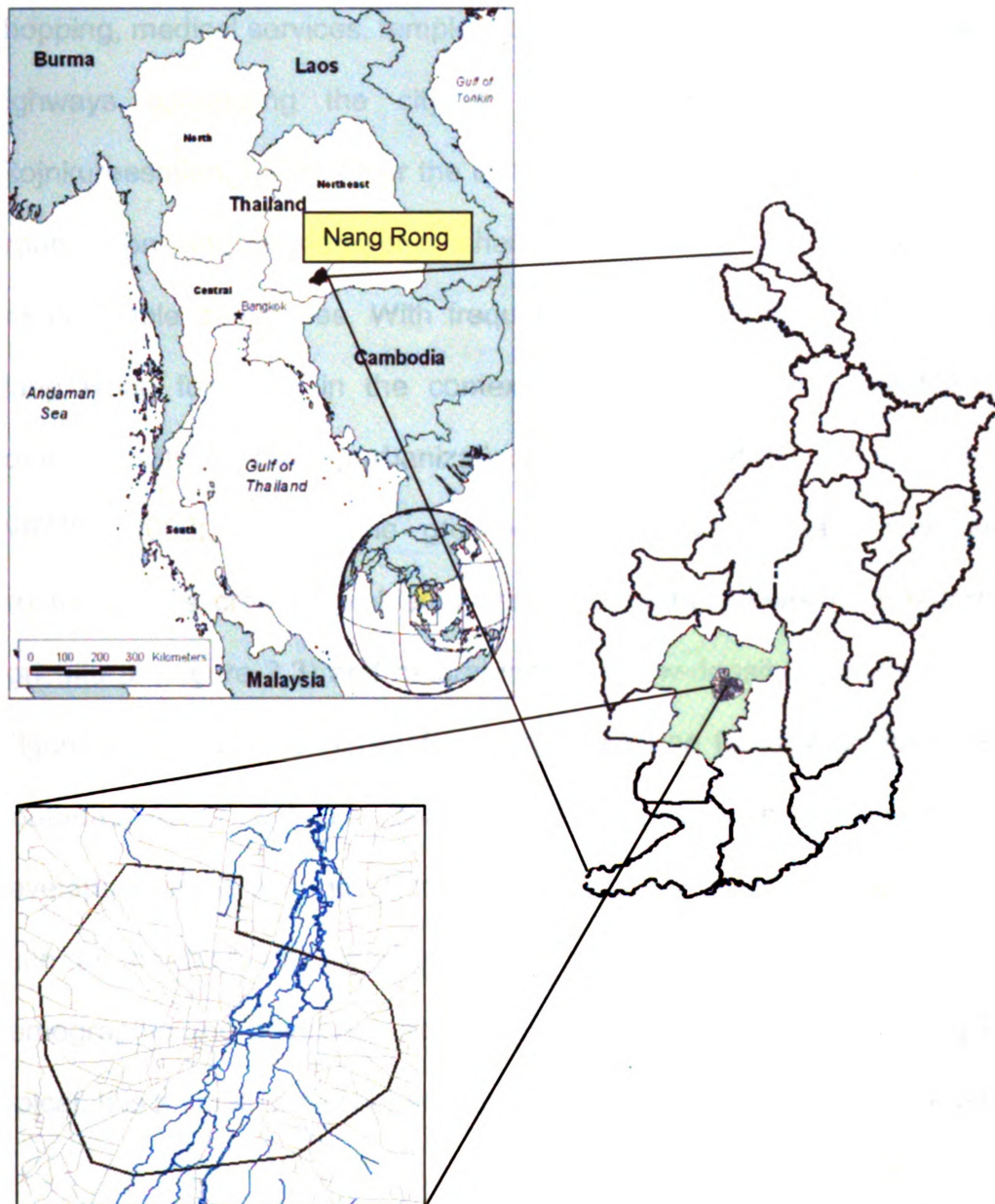


Figure 3.2 Study area: Nang Rong town has an area of 54 km² or 33,750 rai (bottom left picture) and is located within the Nang Rong district (Highlighted - right picture) and within the Buriram province (Right picture) located in Northeast Thailand (upper left picture) (<http://www.cpc.unc.edu/projects/nangrong>). The road network and hydrology are also displayed in the map.

Nang Rong town provides important services throughout the entire Northeastern region. The town is the regional central market, providing the infrastructure for many economic and social activities, such as rice and cassava markets, general shopping, medical services, temples, and schools. Nang Rong is served by major highways connecting the city to Buriram and to other urban centers (Rojnkureesatien, 2006). Over the last 30 years, the town has experienced rapid urbanization and demographic changes often moving in uncorrelated and unsustainable trajectories. With frequent and often reverse migratory patterns, Nang Rong functions in the context of often declining population densities combined with increasing urbanization of adjacent natural and agricultural lands (NRMO, 2003; 2006). The growing prevalence of these new settlement processes has created problems associated with increasing transformation of agricultural (Figure 3.3) and natural lands for low-density residential urban uses (Figure 3.4). In the absence of an urban planning framework optimized for the Southeast Asian context, urban expansion takes place haphazardly and often develops over the best quality agricultural lands or lands not suitable for housing such as on high risk flood-plains. In the context of South East Asia, the demographic and physical infrastructural issues experienced in Nang Rong are typical. It is a small, rapidly changing city directly influenced by global processes.



Figure 3.3 Rice fields where farmers still use buffalo.



Figure 3.4 Urbanization on the periphery of Nang Rong town formerly a rice field.

Nang Rong town has experienced some level of fluctuation in its population and urbanization processes in the recent past due primarily to migration flows (Figure 3.5). The dual issues of urban extensification and intensification occurred while out-migration increased. Total population increased from 31,566 in 1991 to

33,605 in 1993, decreased to 20,806 in 2001, and increased to 21,153 in 2003. Population density fluctuated and increased from 1,002 to 1,019 persons per km² during 2001 to 2003. However, population in 2005 decreased to 20,923, with 10,026 males and 10,897 females. The density decreased from 1,019 to 1,007 persons per km² in 2003 to 2005 almost entirely due to out-migration for wage labor in Bangkok. Conversely, the number of houses increased from 7,732 to 8,538 (NRMO, 2003; NRMO, 2005).

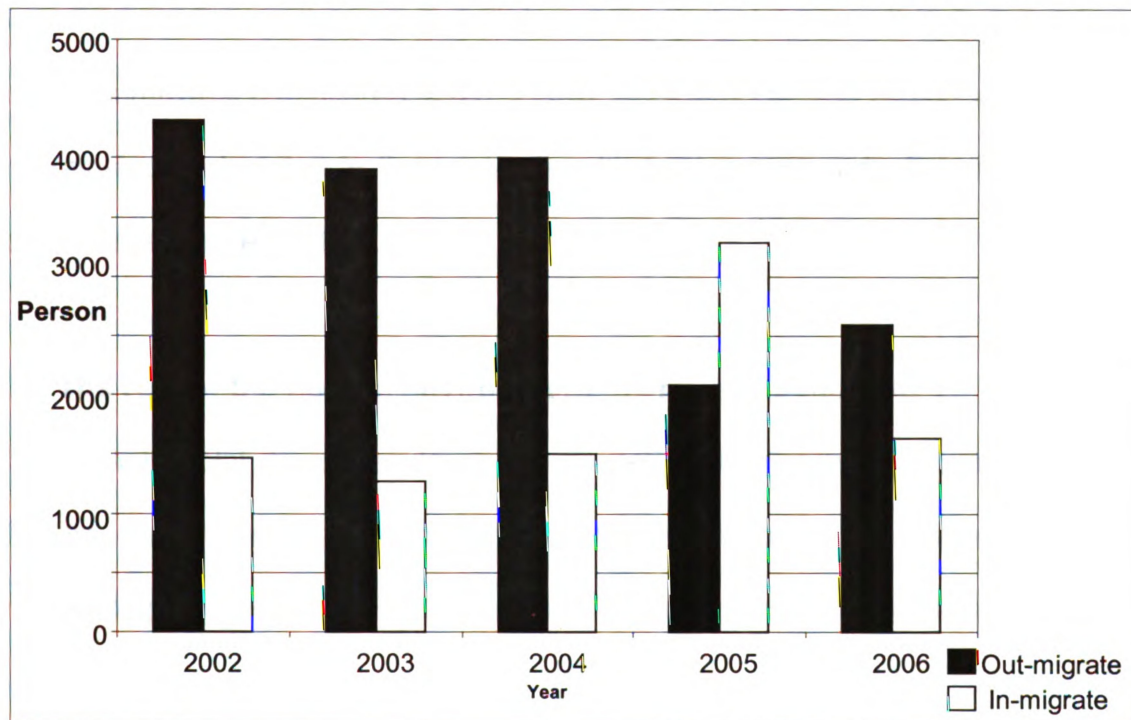


Figure 3.5 Out-migration and in-migration of Nang Rong from 2002-2006 (NRMO, 2003; NRMO, 2006).

3.2 Regional geomorphology and ecology

Nang Rong town lies on the Khorat Plateau, an intermontane basin consisting of Quaternary deposits with horizontal layers of gravel and sand (Heckman, 1979).

Northeast Thailand geology is characterized by Cretaceous sandstone overlain with Tertiary and Quaternary alluvial deposits that have eroded to form a succession of natural terraces (Rojnkureesatien, 2006). The natural vegetation is tropical seasonal (monsoon) forests, primarily dry dipterocarps. Areas of grassland, thorny shrubs, and bamboo thickets are commonly found (Smitinand *et al.* 1980, Parnwell 1986). The majority of Isaan's forest has by now either been removed or degraded (Parnwell, 1988; Rundel and Boonpragop, 1995). Remnant forests are found along riparian corridors and surrounding the two ancient volcanoes in the southern portion of Nang Rong district, as well as in the uplands of the southwest (Rojnkureesatien, 2006). Agriculturally, the region is dominated by rain-fed paddy rice in the lowlands with field crops, and often cassava and sugar cane planted in the uplands.

3.3 The role of the natural environment in shaping built form

Significant social drivers aside, there are certain basic endogenous biophysical factors that have played important roles in shaping the built-environment morphology in the Nang Rong context. These factors include water resources, land availability, and soil quality. First, human settlement and general development of the area significantly depend on easy access to water and reliable supplies of water. Second, there are constraints on land availability; most previously forested lands have been settled, deforested and converted to crop production; regional population growth and movement have reduced the amount of land available to support new settlement and agricultural production; and with

the passing of generations, farms have become subdivided into small pieces through kinship ties resulting in declining income potential and family capital. Third, soil quality determines to a great degree what types of land uses are viable in any area.

3.3.1 Water resources

There are many natural water resources in Northeast Thailand including the three major rivers, the Mekong, the Chi, and the Mun and innumerable smaller rivers and streams (huay). Nang Rong has four rivers (the word for river in the northeast is *lam*): Lam Plai Mat, Lam Nang Rong, Lam Pa Thia, and Lam Sai Yong. Some of these are technically intermittent. Despite the regular drought and/or floods, irrigation canals in Nang Rong are few. Agriculture in this area is almost entirely dependent upon rainfall, and not risk-mitigating ground or surface water irrigation (Rojnkureesatien, 2006). In many areas, saline groundwater percolation, combined with poor water retention characteristics, has created widespread declining soil quality (Phongphit and Hewison, 2001).

Despite these challenges, the primary reason villagers have, over time, settled close to the natural water resources was not for agricultural water; rather, it was for general consumption by the villagers, their cattle, and other animals, and for the provision of food such as fish, shellfish, and certain plants. If they could not settle along the edge of a river, the settlers would look for a place nearby, within one day's walk. Several permanent dams on streams and wells (Figure 3.6) for

irrigation and water reservoirs were built. In the past, villagers did not use permanent dams and weirs during the rice-growing season, but would build temporary structures to control the flow of water through their fields. Villagers usually dug wells for drinking water and community consumption. Rainwater began to be regularly used for drinking only with the introduction of metal roofing about fifty years ago and is now stored in clay jars (Phongphit and Hewison, 2001).

One of the most critical water resource problems is directly the result of unmanaged wastes. Human, animal, and industrial wastes are increasingly discharged directly into local streams and ponds, far exceeding the carrying capacity of the natural environment. Collectively, the phenomena are likely to reduce regional ecological stability and damage system resilience violating basic tenets of sustainable development (Welsh, 2001; Rojnkureesatien, 2006).

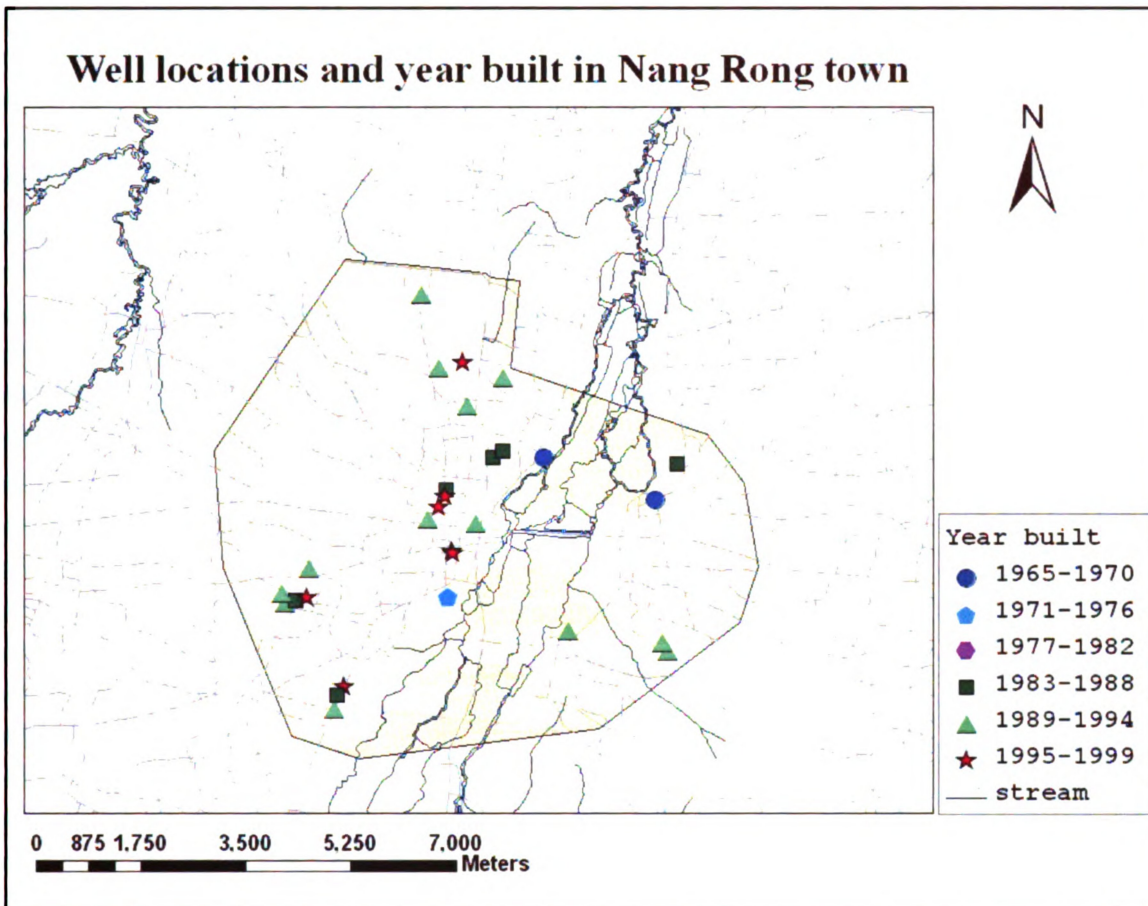


Figure 3.6 Well locations and year built in Nang Rong town (ONEP, 2001).

3.3.2 Soil resources

Most of Nang Rong is a combination of floodplains, and low and middle terraces. Soils tend to be closely associated with specific landforms (e.g. terraces), and hence a relationship between topography and agricultural suitability factors exists within the region (Dixon 1976; Parnwell 1986; Fukui 1993). The most spatially extensive soil order is the ultisol class, though areas of entisols, inceptisols, alfisols, spodosols, oxisols, and vertisols may be found (Soil Survey, 1975 as cited by Welsh, 2001) (Figure 3.7). Some areas are lateritic with weathered and

leached soils generally deficient in nutrients and moisture. A layer of pebble and laterite extending to a depth of about 50-centimeters can be found locally and is generally not suitable for crops (Rojnkureesatien, 2006). These laterized soils are very difficult, i.e. expensive, to modify into productive, good quality soils. Soil quality and water-holding capacity and drainage properties largely determine the areas suitable for paddy rice cultivation, the most important local crop (Evans, 1998).

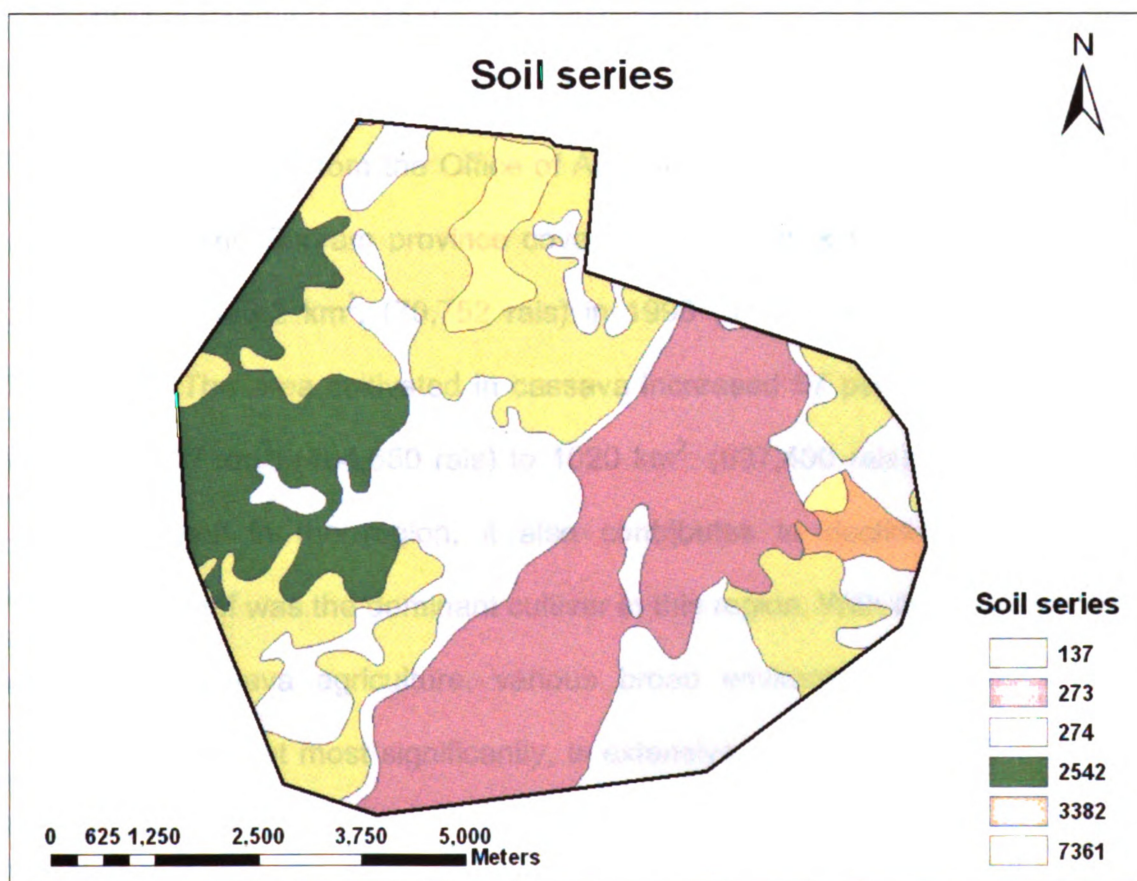


Figure 3.7 Soil of Nang Rong town

137 is Korat soils: fine loamy, siliceous, isohyperthermic oxic paleustults
(Gray Podzolic Soils)

273 is Ratchaburi soils: fine, mixed, nonacid, isohyperthermic aerithropaquepts (Hydromorphic Alluvial Soils)

274 is Roi Et soils: fine loamy, mixed, isohyperthermic Aerice Palequults
(Low Humic Gley soils)

2542 is Roi Et/Korat association soils

3382 is Roi Et/loamy variant soils

7361 is Pond/intermittent pond and wet spot

According to a report from the Office of Agricultural Economics (2005), in 1999, sugar cane in the Buriram province covered 266.65 sq. km. (166,654 rais), an increase from 113.2 km². (70,752 rais) in 1998 (a 111 percent increase in a single year). The area cultivated in cassava increased 57 percent in that same year, from 647 km². (404,650 rais) to 1020 km². (637,400 rais). While cassava does grow well in the region, it also contributes to declining soil quality. Previously, kenaf was the dominant cultivar in this region. With the emergence of commercial cassava agriculture, various broad environmental impacts have become evident, but most significantly, is extensive soil exhaustion (Entwistle et al., 2008).

In addition to the obvious impacts of deforestation, soil related impacts include localized erosion, increased runoff, increased flood events, increased soil

salinity, and sedimentation problems (Grandstaff, 1988). The deforestation also influenced the already challenged regional hydrological cycle. Despite the rural character of the region, the typically urban issue of impermeable surfaces has emerged. Some evidence of this is already occurring as infiltration rates and above ground moisture retention in upland sites have decreased and consequently reduced ground water recharge (Welsh, 2001). This process reduces stream flow consistency while increasing the likelihood of flood events.

It is also likely that local surface temperatures will increase due to the temperature and evaporation effects of the deforestation and laterization processes. Some evidence of fluctuating amounts and spatial and temporal patterns of rainfall have been recorded in the Northeast of Thailand, though this cannot be solely attributed to local changes (Welsh, 2001; Rojnkruesatien, 2006). The increasing severity of heavy rainfall events and their associated flooding have directly impacted Nang Rong, as many recently developed areas are built on flood plains. Also, many of the newly built roads crossing Nang Rong are not useable during the rainy season. These problems limit travel efficiency for people inside and outside the areas (Rojnkureesatien, 2006).

3.3.3 Local land availability

For many centuries, the regional land cover was largely a mixed natural dry tropical forest and savanna. People moved into the region starting during the Khmer empire searching for available natural resources. In the past 50 years,

road building improved access to water and to available land leading to rapid forest conversion to agriculture. This enhanced access is the primary driver for much of the regional land use and cover change (Welsh, 2001).

In-migration and family enlargement were influenced by commercial agriculture expansion, which, in turn, was driven by international market demand for cassava (Entwistle et al., 2008). Concurrently, villagers were encouraged to expand rice production beyond what was needed in the local economy and also to grow commercial crops for national and global markets. Large areas of dry tropical forest were removed or degraded (Hafner 1990); remaining forest now covers less than 10 percent of the landscape (Nang Rong District, 2006). Upland and lowland agriculture were extended well into marginally suitable lands (Dent 1992). Even small-scale farmers ill equipped to compete adopted commercial export-oriented farming. Chemical inputs, machinery, and hired labor were all used to increase crop yields. Many small-scale farmers were forced to sell part or all of their land due to high input cost. Investors bought these lands and converted them into urban land uses (Phongpaichit and Baker, 2002). Agricultural land became less available for redistribution among small-scale farm households' disrupting traditional inheritance distribution models (Dixon, 1999). Ongoing improvements of the road transportation network appear to be closely associated with the previously discussed activities. These have challenged sustainability of urban development and land use suitability both locally and regionally.

Over the last several years, the rate of urban expansion has increased with major developments along lands adjacent to roads (Rojnkureesatien, 2006). Housing increased in Nang Rong town alone from approximately 5000 to 9000 units between 1994 and 2003 (Nang Rong Municipal Office, 2003). Regionally, the number of villages also increased. Road networks further expanded improving local-to-local and local-to-regional connectivity. In 1984, 99 percent of all households were agricultural; by 1994 this had declined slightly to 90 percent, while agriculture households decreased dramatically to 75 percent by 2000 (Table 3.1). The percentage of agricultural households that settled between 1983 and 1984 declined from 99 percent to 50 percent by 2000 (Wongsaichue, 2006).

Table 3.1 Trend of agricultural households in Nang Rong district during 1984-2000 (Wongsaichue, 2006)

Year	Type of Household	Number of Households			Percentage of Households		
		1984	1994	2000	1984	1994	2000
1984	Agri-household	5,850	4,818	4,213	99.78	65.69	50.06
	Non agri-household	13	372	1,159	0.22	5.07	13.77
1994	Agri-household		1,808	800		24.65	9.51
	Non agri-household		337	276		4.59	3.28
2000	Agri-household			1,282			15.23
	Non agri-household			686			8.15
Total agri-households		5,850	6,626	6,295	99.78	90.33	74.80
Total non agri-households		13	709	2,121	0.22	9.67	25.20
Total households		5,863	7,335	8,416	100.00	100.00	100.00

Note: Agri-household = Households used land for cultivation.

Non agri-household = Households did not use land for cultivation.

The combined effects of the population changes, geographical, and biophysical drivers have led to widespread regional changes in land use and cover (Figure 3.8).

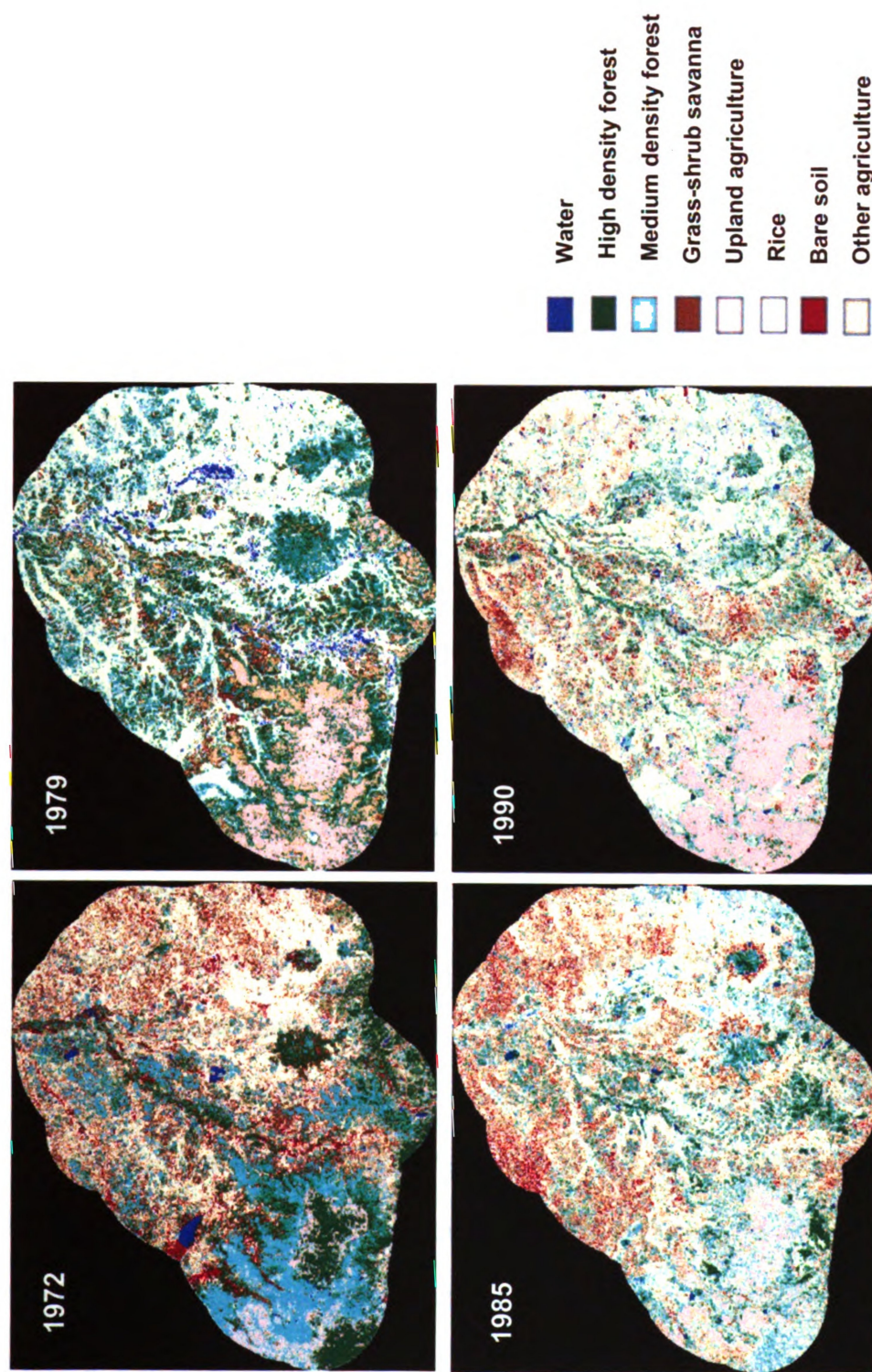


Figure 3.8 LULC of Nang Rong district 1972, 1979, 1985, and 1990 from Landsat TM and ETM+ (<http://www.cpc.unc.edu/projects/nangrong>).

3.4 Exogenous change drivers of the built-environment

The expansion of the free market for agricultural products has resulted in more competitive and also more open global markets for agricultural production (Jitsanguan, 2001). Since the mid 1970s, deforestation (Table 3.2) and agricultural extensification in upland areas in Thailand have been driven largely by European Economic Community (EEC) countries' demand for calorie-rich livestock feed (Phantumvanit & Sathirathai, 1988; Siamwalla 1995). Table 3.3 shows decreasing forest lands and increases in cash crop agriculture. Cassava, corn, and sugar cane are cash crops in Nang Rong and are not part of the local diet (Entwisle, 2005). Upland cash cropping occurred as a result of many factors including: increasing world market demand for cash crops, improved infrastructure, and the adoption of agricultural technologies like pesticide use and seed biotechnology.

These global markets have led to the emergence of large-scale commercial farmers who produce mainly for export markets and a decline of small agricultural households. They have also motivated small-scale farmers to change their agricultural patterns to be more competitive by switching to short-term profitable commercial upland cassava agriculture (Rojnkureesatien 2006). The demand for these crops originates outside the district, and in many instances outside the country. The total area of upland crops in the Northeast region increased until the Southeast Asian economic crisis of the late 1990's.

Table 3.2 Land use in the Northeast region of Thailand 1986-1999 (Rojnkureesatien cited from Office of Agricultural Economics, 2004). Areal units are expressed in sq. km.

YEAR	1986	1990	1994	1999
Total Area	168854	168854	168854	168854
Forest Area	24907	22670	21369	20888
Crop Land	89913	90742	92379	92715
Number of farm	2,081,293	2,131,448	2,260,67	2,598,537
Living area	3330	3410	3617	4158
Paddy	1792	1901	2112	2223
Upland crop	59912	59921	60553	60392
Orchard and tree	20863	21005	20731	18766
Vegetable	1633	2688	3491	5429
Pasture land	259	325	375	341
Fallow	731	666	768	806
Other	3475	3467	3483	3083
Unidentified	1248	769	867	1674

The integration of Nang Rong town and district into the national economy over the past few decades directly influenced the conversion of forested lands to agricultural purposes. These conversions were particularly evident between 1972 and 1997 (Table 3.3). Rice Paddy Land (RP) increased by 169 km² while Forest Cover (FC) decreased by 173 km². Table 3.4a, 3.4b, and 3.4c shows LULC changes between 1972 -1985, 1985 - 1997, and 1972 - 1997. The change from paddy field to other land use types seems to be lower than conversion of land to rice farming in Nang Rong during 1972 – 1997. However, land use has changed in the uplands due to conversion to cash-cropping agriculture after the 1970s. Field crop lands increased from 36 km² to 212 km² between 1972 and 1985. The specific process involved in this alteration was the widespread conversion of natural forest and savanna to agricultural land. This agricultural extensification

occurred due to rapidly increasing population densities, demand for new settlement, and high global demand for cash-crops creating LULCC in Nang Rong district.

Table 3.3 LULC cross-section areas (km²) by classification date in Nang Rong district (Welsh, 2001).

LULC Class	1972	1985	1997
Rice Paddy Land (RP)	704.35	771.71	873.84
Field Crop Land (FC)	36.30	211.97	171.38
Forest (uninhabited)(FOR)	473.21	302.03	306.57
Grass-Scrub-Savanna (GSS)	288.66	216.77	150.70

Table 3.4a LULC post-classification change in area (km²), 1972 to 1985 in Nang Rong district (Welsh, 2001).

From – To	1985 RP	1985 FC	1985 FOR	1985 GSS
1972 RP	541.77	72.67	26.73	62.60
1972 FC	2.87	19.68	9.37	4.27
1972 FOR	94.66	103.23	193.88	81.03
1972 GSS	131.68	16.28	71.81	68.57
Others	0	0	0	0

Table 3.4b LULC post-classification change in area (km²), 1985 to 1997 in Nang Rong district (Welsh, 2001).

From – To	1997 RP	1997 FC	1997 FOR	1997 GSS
1985 RP	611.60	6.78	103.72	49.61
1985 FC	79.41	96.75	19.62	16.19
1985 FOR	74.91	49.17	132.01	45.94
1985 GSS	107.91	18.67	51.23	38.96

Table 3.4c LULC post-classification change in area (sq.km.), 1972 to 1997 in Nang Rong district (Welsh, 2001).

From – To	1997 RP	1997 FC	1997 FOR	1997 GSS
1972 RP	577.05	2.21	89.36	35.16
1972 FC	3.30	27.31	3.59	1.98
1972 FOR	135.15	133.83	135.15	68.74
1972 GSS	157.24	8.02	78.09	44.99

Statistical data from the Nang Rong district social surveys during 1994 and 2000 show that cassava cultivation slightly increased in both percent of agricultural land use area and field size. Paddy field is still the dominant agricultural land use although the average size of rice parcel has declined. Some other agricultural activities such as orchard and livestock have changed dramatically (Table 3.5).

Table 3.5 Percentage distribution of agricultural land use and average size of parcel by plantation in 1994-2000 (Wongsaichue, 2006).

Type of Land Use	1994		2000	
	% of ALU	Rai/Parcel	% of ALU	Rai/Parcel
Rice	90.57	14.43	90.35	11.38
Cassava	6.48	10.10	7.06	10.77
Corn	0.03	2.38	0.05	6.61
Sugar cane	0.56	36.17	0.57	33.20
Orchard	1.44	4.17	0.46	15.26
Livestock	0.25	8.13	0.25	19.74
Vegetable	0.24	2.01	0.14	6.53
Other	0.43	5.45	1.12	14.00
Total	100.00	—	100.00	—

Note: ALU = Agricultural land use (1 Rai = 0.0016 km²)

Besides the demand from outside the country, another reason for the increasing trend in cassava plantation agriculture was its relatively simple planting method. The new plant can be grown by cutting a previously grown cassava stem, planting it in a tractor-prepared row and then covering it with soil. Cassava is suitable for upland areas with poor soil fertility. However, with continued intensive cultivation, cassava rapidly depletes soil fertility. The problem is exacerbated in North East Thailand, as it increases erosion from upland areas because of the combined effects of soil exposure and periods of intense monsoonal rains. Other coincident exogenous factors, such as the Asian economic crisis and a severe

drought, increasingly disrupted the socio-ecological system, leading to accelerating environmental degradation and increasing rural poverty and inequality within the local population (Welsh, 2001).



Figure 3.9 Cassava, an upland crop in Nang Rong
(<http://www.cpc.unc.edu/projects/nangrong>)

CHAPTER 4

Data and Model Development

4.1 Introduction

The project required the development of a comprehensive spatial database for Nang Rong where elements representing social, biophysical, and geographical domains were integrated to support LULC modeling and spatial simulations. Spatial databases were used to examine the temporal and spatial dynamics of LULCC specially related to conversion of land to urban and agricultural areas. The underlying endogenous biophysical and geographical factors included: a) social and spatial history of village settlement; b) road development and changing geographic accessibility; and c) population growth. The exogenous factors included national policies, local manifestation of policies related to the King's Theory, and international markets, all of which have been and continue to be driving forces of LULCC. These were examined through literature, historical records, and theoretical principles. The exploration of sustainability in the Nang Rong context emphasized the assessment of in-situ conditions as measured by landscape characterizations and spatial modeling particularly associated with urban-rural and agricultural expansion. The relationships among household land management, King's Theory, community infrastructure, accessibility, and national and global market forces were examined across space and time with the goal of identifying and predicting future urbanization and land use land cover conversions using "control" sites for calibration and validation.

Erdas Imagine and ArcGIS were used for image processing, data integration, analysis, display, and output. GIS layers, including transportation networks, hydrology, water bodies, and elevation, were created. Both raster (cells or pixels) and vector (points, lines, polygons) spatial data structures were used as appropriate. The remainder of this chapter illustrates the process of data development.

4.2 Image processing and classification

An aerial imagery time-series has been assembled that extends from 1954 to the 2006. A collection of previously analyzed LANDSAT images dating back to 1972 and other remotely sensed data including aerial photos dating back to the 1950s were integrated (Rindfuss et al., 2003). LULC maps were derived from Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) including 1972, 1973, 1975, 1976, 1979, 1985, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, and 1999. Panchromatic aerial photography at scales ranging from 1:6,000 to 1:50,000 have been acquired for 1954, 1976, and 1994 (Rindfuss et al., 2003).

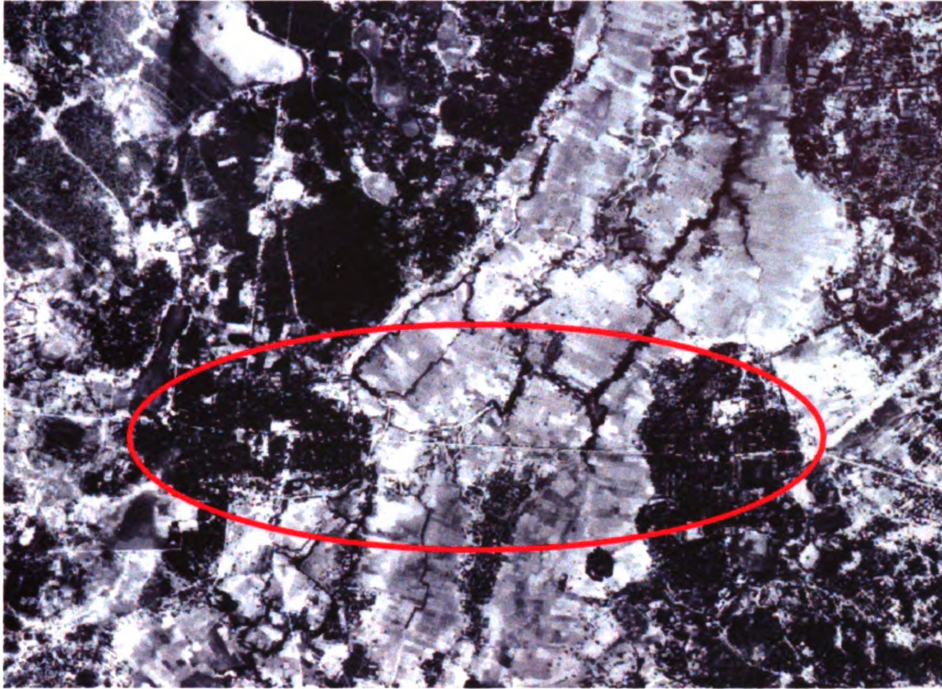


Figure 4.1 Panchromatic aerial photography 1954 with modern Nang Rong town covered by the ellipse

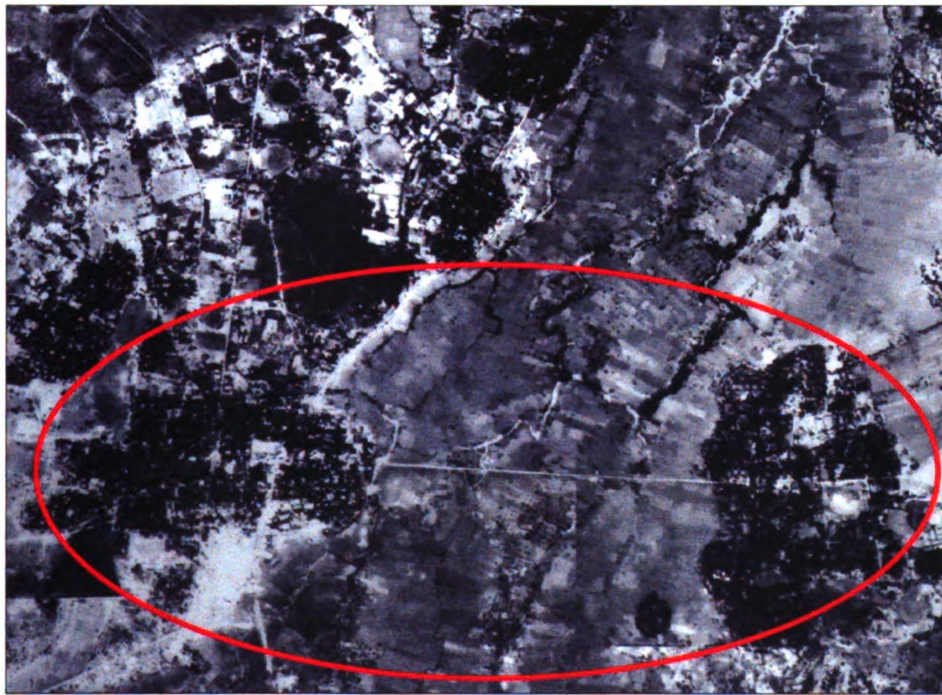


Figure 4.2 Panchromatic aerial photography 1967 with modern Nang Rong town covered by the ellipse

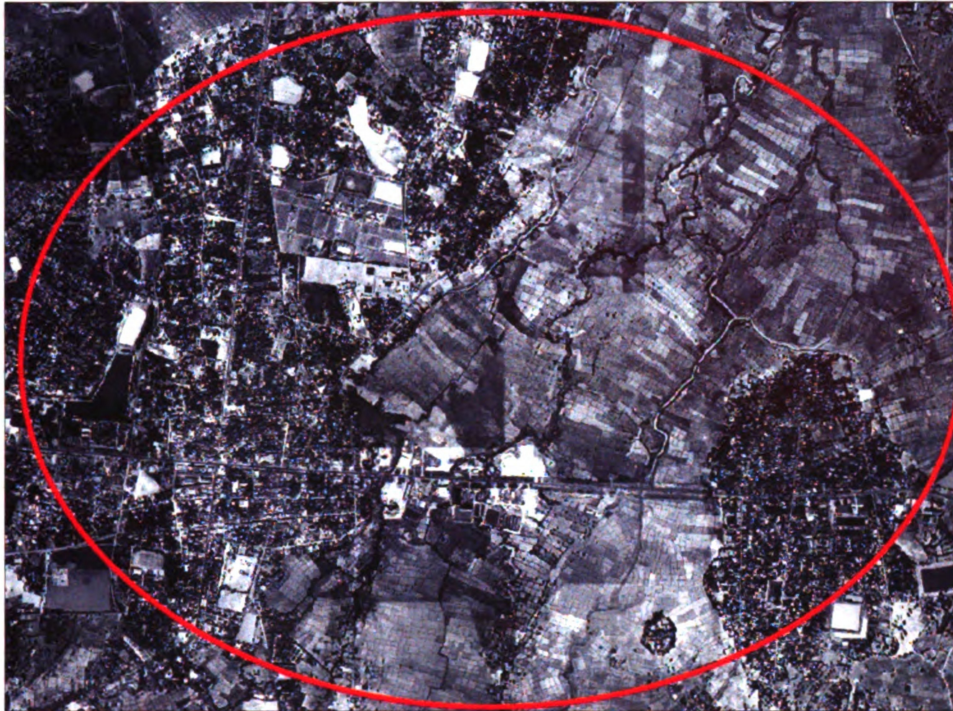


Figure 4.3 Panchromatic aerial photography 1994 with modern Nang Rong town covered by the ellipse

The aerial photos from 1954, 1967, and 1994 (Figure 4.1 – Figure 4.3) were rectified and mosaiced by the University of North Carolina at Chapel Hill (<http://www.cpc.unc.edu/projects/nangrong>). The post-processed aerial photos were used in this research. The buildings and roads visible in the aerial photos were digitized using polyline feature type (Figure 4.4). Next the building polylines were converted to polygons and processed in ArcInfo to create topology. The digitized thematic maps were analyzed to identify urban land cover change. Existing databases of the settlement areas including address number, lot number, year built, building history and data gathered from fieldwork (see section 4.3) were used to identify urban land use. The extent of the urban area in 1990 was digitized as polylines from LANDSAT TM (Figure 4.5a) and urban area in

2003 was digitized from ETM+ (4.5b). These satellite images were received from University of North Carolina at Chapel Hill (<http://www.cpc.unc.edu>). Next, the maps were classified into two categories: urban core and town periphery using visually digitizing technique. Urban core pixels indicate central areas of high population and building density. Pixels classes as urban cores are generally concentrated in two clusters separated by agricultural land and rice paddies in the middle. This area in the middle of two clusters is lowland and is seasonally flooded. Pixels classes as town periphery are those with lower building and low population densities within the town boundary and trees planted around the urban for shade and as sources for fruit and other products (Entwisle, 2008). Traditionally, the urban core will first expand to neighboring areas with geographic similarity to accommodate growing population. As one urban core region expands, the neighboring region must expand its border to accommodate the growing urban core creating shift of periphery and town boundary. The urban core and town boundary regions between 1990 and 2003 were then visually compared. Next, the classified 1990 and 2003 urban core and town boundary regions were processed in Arc/Info to create polygon features and to generate topology and then overlaid to determine net land conversion.

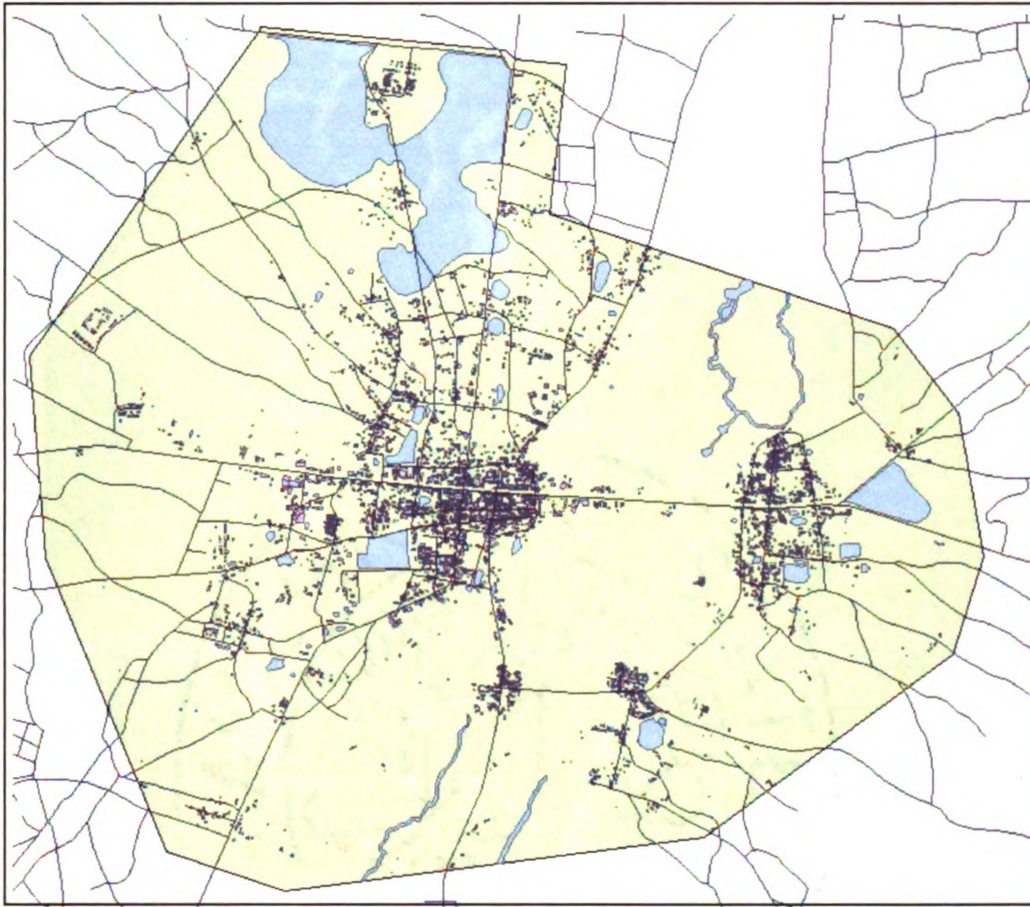


Figure 4.4 Digitized road network and buildings from the 1994 aerial photo.

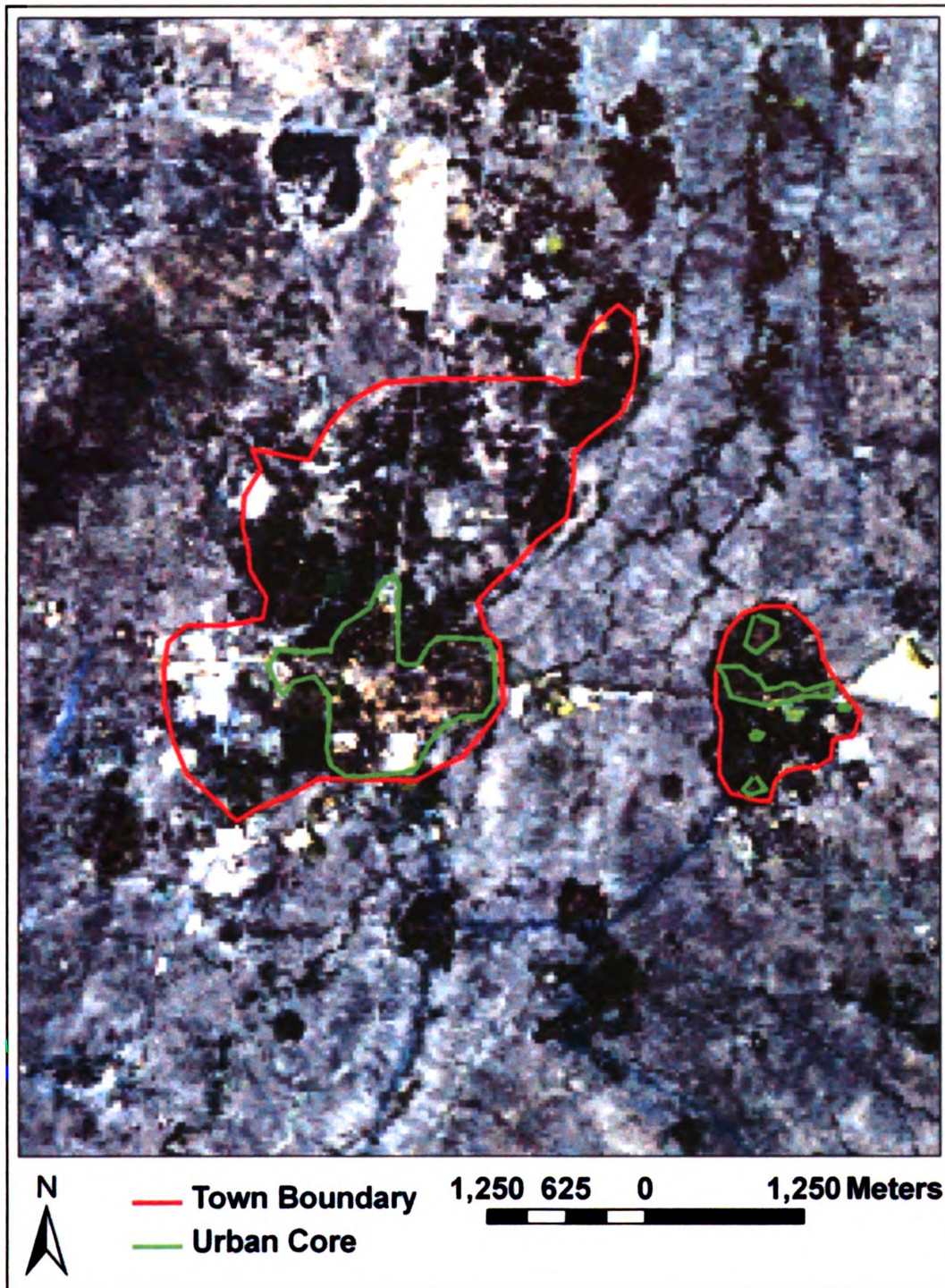


Figure 4.5a: Urban cores and town boundary of Nang Rong town in January 1990 from Landsat TM (<http://www.cpc.unc.edu/projects/nangrong>).

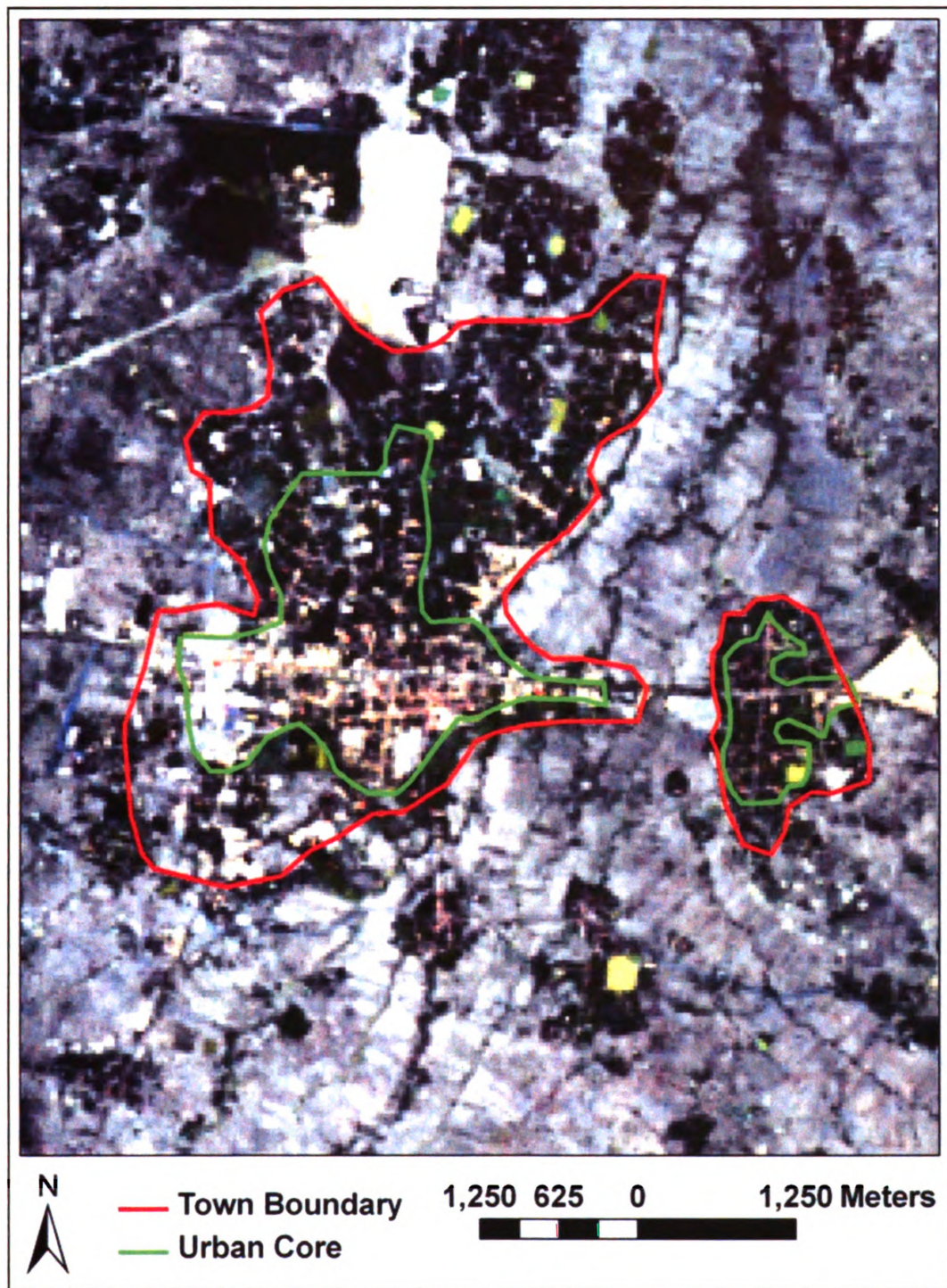


Figure 4.5b: Urban cores and town boundary of Nang Rong town in January 2003 from Landsat ETM+ (<http://www.cpc.unc.edu/projects/nangrong>).

4.3 Fieldwork

During the summers of 2004 and 2006, I visited the Nang Rong municipal office to gather data. A collection of over 150 Thai government cadastral map zones (Figure 4.6) and the corresponding property ownership data for each address in the cadastral maps were collected and used during the spatial data development process. Each zone, defined as building block, contained parcel and building locations. Over 8000 property ownership records were surveyed and recorded on hardcopy by the municipal office. I entered property record for each zone into an Excel Spreadsheet. The property record contained information including: address number, lot number, material, height, year built, grid ID, utility type and building history. An example of the records is shown in table 4.1. Field surveys were conducted for georeferencing and to validate the property records. Randomly selected buildings for each cadastral map zone were visited and GPS locations were collected using Garmin map 76 and Trimble pocket pathfinder with antenna for references. Next, the building locations on cadastral maps were compared to the digitized building dataset. The addresses and information for each property from Excel Spreadsheets were then converted into shapefile format spatial data. In addition, GPS locations and reference points for LULC classes and the official boundary markers of Nang Rong town were collected. Sampled LULC classes included urban, rice field, forest, orchard, cash-crop and water body. The boundary shapefile was then created using these reference points and ArcMap.

Table 4.1 Example of recorded property in Excel spreadsheet

Address	Lot#	material	height	year	Grid ID#	Note
491	001	C	2	2539	02A	
28	002	C/W	2	2531	02A	Rice storage
26	003	C/W	2	2523	02A	
18	006/1	C	1	2531	02A	
18/3	006/1	C	2	2545	02A	
58	009	W	1	2530	02A	Rice storage
32	011	W	2	2525	02A	
6/1	012	C	2	2548	02A	
20	014	C	1	2533	02A	
18/10	016	C	1	2542	02A	3 units
83/19	017	C	1	2532	02A	
83/14	017/1	C	1	2539	02A	
83/15	017/2	C	1	2539	02A	
83/16	017/3	C	1	2540	02A	
83/17	017/4	C	1	2540	02A	3 units
83/18	017/5	C	2	2540	02A	2 units
697	018/1	W	2	2515	02A	Rice mill/ storage + pig farm
699	018/1	W	2	2515	02A	Rice mill/ storage + pig farm

Note: W = Wood, C = Concrete, K = Krabeung (tile), S = Sungkasi (zinc)

4.4 Biophysical spatial data

Daily precipitation and temperature data for Nang Rong are available from 1965. Digital data of the Nang Rong town boundary, roads, rivers, water bodies, elevation, soil types and other spatial-thematic data are collected by the Ministry of Natural Resources and Environment of the Kingdom of Thailand. The contour lines and point elevations on the 1984 1:50,000 scale base-maps were scanned and digitized. The digitized contour lines were interpolated to yield DEMs by the University of North Carolina Population Center (Figure 4.7) (<http://www.cpc.unc.edu/projects/nangrong>). All GIS data were projected to WGS 1984 UTM Zone 48 North using ArcGIS.

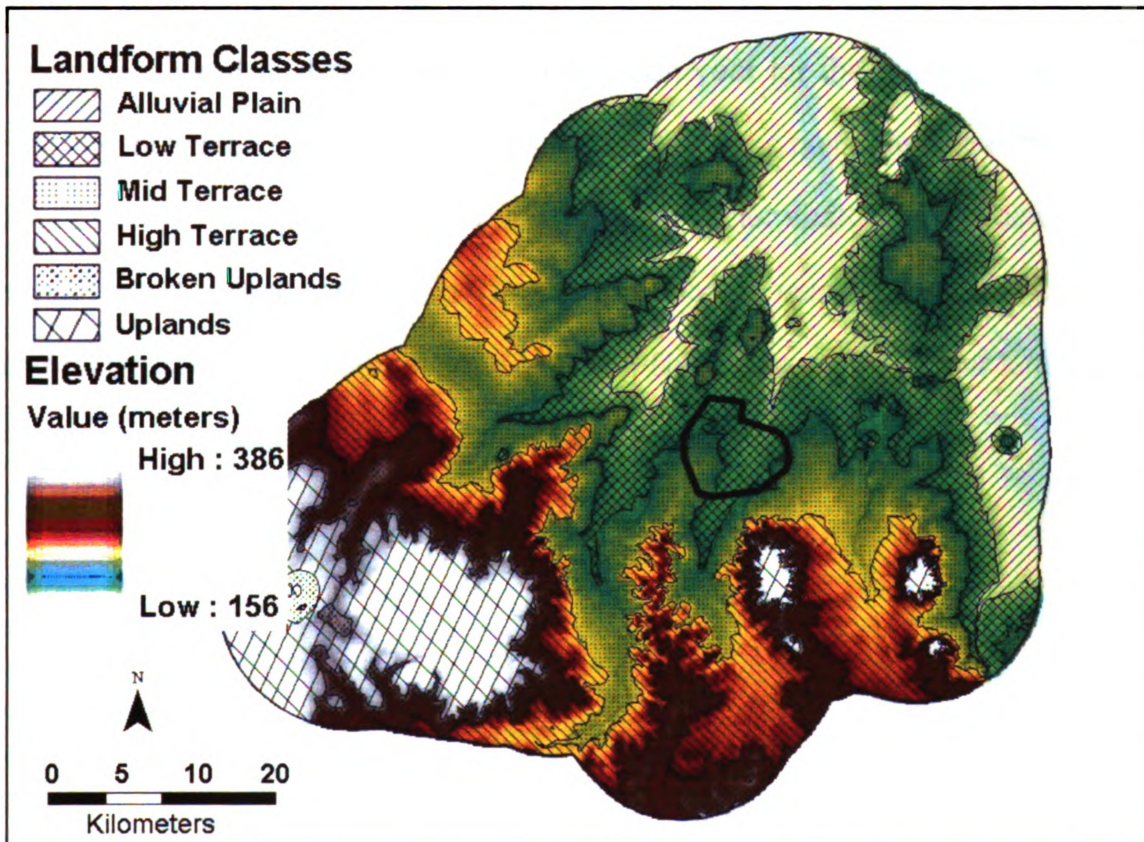


Figure 4.7 Elevation and landform of Nang Rong town (black boundary)

Table 4.2 Data sources

Model Input	Source	Type
Digitized road networks	Aerial Photography 1954, 1967, 1994	Vector
Digitized urban extents	LANDSAT TM and ETM+	Vector
Digitized existing houses	Aerial Photography 1954, 1967, 1994	Vector
Soil characteristics	Shapefile	Vector
Water bodies	Shapefile	Vector
Population	Descriptive data from NR municipal	Quantitative
Elevation	UNC DEM from contours	Raster
Euclidean Distance surfaces	Calculated from road networks	Raster

Road networks and buildings from the respective 1954, 1967, and 1994 aerial photos were digitized (Figure 4.8). The digitized buildings were attributed (Table 4.3). The locations on the digitized maps and on the cadastral maps were compared and matched. The property ownership records and cadastral map zones were used to determine the construction year for the building layer. The matched buildings were then attributed with the year built. Next, the buildings layers with ID one were converted to a 10 meter raster spatial data structure and clipped with the rasterized Nang Rong town boundary using a Boolean operator. The raster datasets were converted to ASCII files using a conversion function in ArcGIS and subsequently used in the Agent-Based simulation models.

Table 4.3 Example of digitized building attribute table

FID	ID	Area	Perimeter	BL address	year
30	1	32.1	23.0	491	2539
31	1	93.2	38.6	28	2531
32	1	110.5	42.4	26	2523
33	1	112.4	43.1	18	2531
34	1	71.7	34.2	18/3	2545
35	1	85.6	38.4	58	2530
36	1	113.6	42.7	32	2525
37	1	150.2	50.9	6/1	2548
38	1	18.7	17.6	20	2533
39	1	149.1	49.3	18/10	2542
40	1	45.2	27.0	83/19	2532

For the road layers, the Euclidean Distances were calculated for 1954, 1967, and 1994 with 10 meters pixel resolution. The function calculates for each cell the Euclidean Distance to the closest existing road. Next, the Euclidean Distance surfaces were clipped with the water body layer using a Boolean operation which resulted in a surface without water bodies. The raster datasets were then converted to ASCII files using a conversion function in ArcGIS.

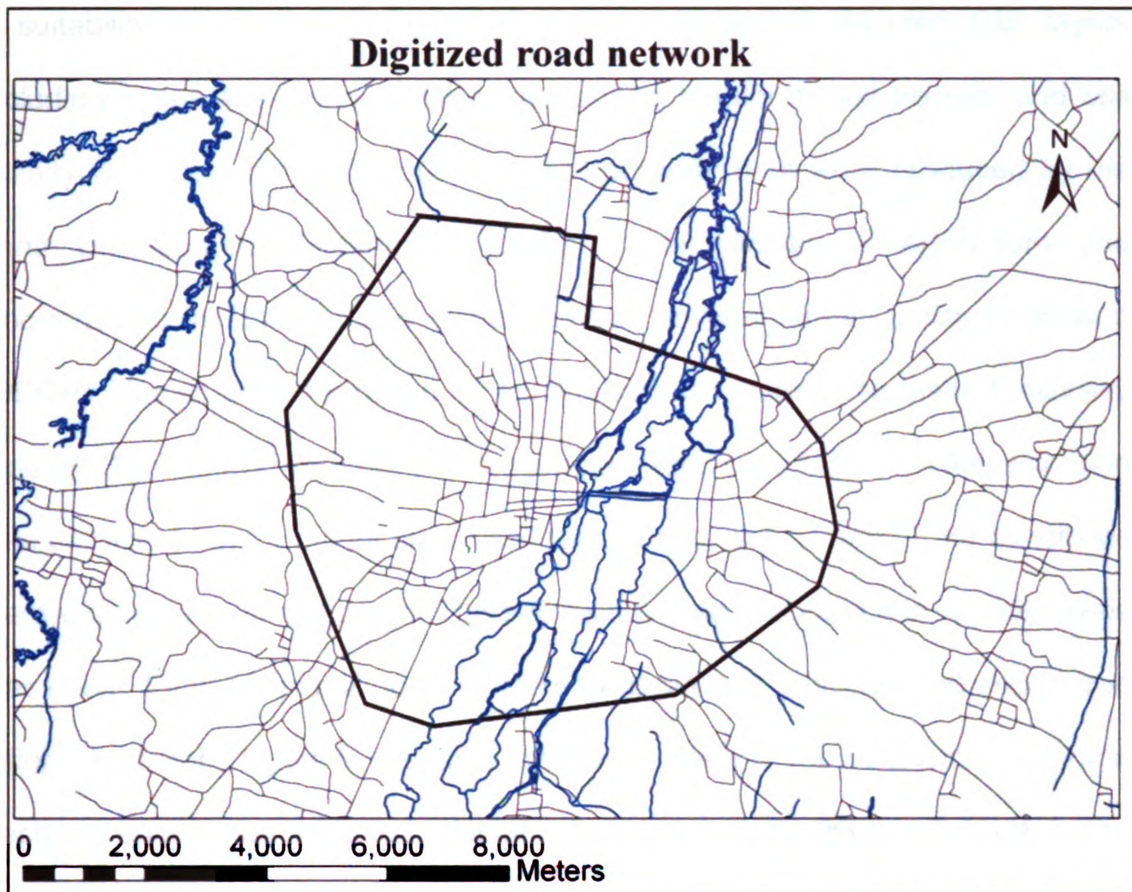


Figure 4.8 Nang Rong town and digitized road network

4.5 Land use suitability for rice farming analysis

Land suitability analyses are methods for determining appropriate locations for a given use (Aldritch 1981; Burrough 1986). The land use suitability for rice farming in Nang Rong can be separated into: 1) soil suitability and 2) water suitability. Here, I combined UET (Ultimate Environmental Thresholds) with map overlays to evaluate soil suitability for rice agriculture. In this case, suitability analyses are related to traditional decision support and Multi Criteria Decision Analysis (MCDA) (Mongkolsawat et al., 1997). MCDA theory was used to create

a suitability index and group areas into zones where selected GIS layers including water availability, nutrient availability, landform, soil texture, and soil salinity were considered (Figure 4.9). Soil property data were produced by the Land Development Department (LDD) of the Ministry of Agriculture and Cooperatives in Thailand and Department of Environmental Quality Promotion (DEQP). The spatial information for each diagnostic factor of Nutrient Availability Index (NAI) was derived from the soil property data from DEQP. Water retention was extracted from a diagnostic of soil texture and particle size. Root conditions were extracted from soil depth. The soil salinity map including four salinity levels was used. Each of the soil quality factors were digitally classified and encoded to different thematic layers in a spatial database. Each of the diagnostic factors of each soil quality was assigned a factor value rating as identified in Table 4.4. The Nutrient Availability Index (NAI) was calculated based on multiplying factor rating values, the method developed by Radcliffe et al. (1982):

$$\text{NAI} = \text{Nitrogen (N)} * \text{Phosphorous (P)} * \text{Potassium (K)} * \text{pH (Equation 1)}$$

Topography includes both landform and slope gradient as they both affect water accessibility during the growing period. The water availability layer was derived from digitizing water bodies from aerial photos combined with water surface data received from University of North Carolina at Chapel Hill and irrigation area data from DEQP. The lack of water in the dry season is a major constraint to agricultural production in Nang Rong. The availability of water was defined by distance from the nearest water body including ponds, reservoirs, and rivers (Yamamoto and Sukchan, 2004). The water from these sources was used not

only for rice planting but also used for supplemental irrigation in the flowering stages of rice. Some stored water was usually used for household plant nurseries and soil preparation in the fields. Therefore, distance to these water resources is crucial. Crop failure occurs more frequently in areas lacking access to surface waters or located too far from water resources (Caldwell et al., 2002). Following Yamamoto and Sukchan (2004), distance buffers of 100, 300, 1000, and greater than 1000 meters from water sources were used. Each of the buffer areas was assigned a rating factor (see Table 4.4). The further the distance from the source, the lower the rating factor. The water availability layer and the soil suitability layer were next integrated using the union tool in ArcGIS. The final result yielded the suitability map for rice farming composed of both soil property suitability and water availability. The final equation (Mongkolsawat et al., 1997) was:

$$\text{Rice suitability} = \text{Water Availability} * \text{Nutrient Availability} * \text{Water Retention} \\ * \text{Root Condition} * \text{Salt Hazards} * \text{Topography (Equation 2)}$$

Five zones representing different levels of land suitability for rice farming were generated (Table 4.5).

Settlement areas in 1967 and 1994 were overlain with results from the suitability for rice agriculture analysis to assess the rate of urban expansion on land suitable for rice farming. Next, the rice suitability map was used as an input for the urban model to simulate different land use schemes. Figure 4.9 shows the process flow model.

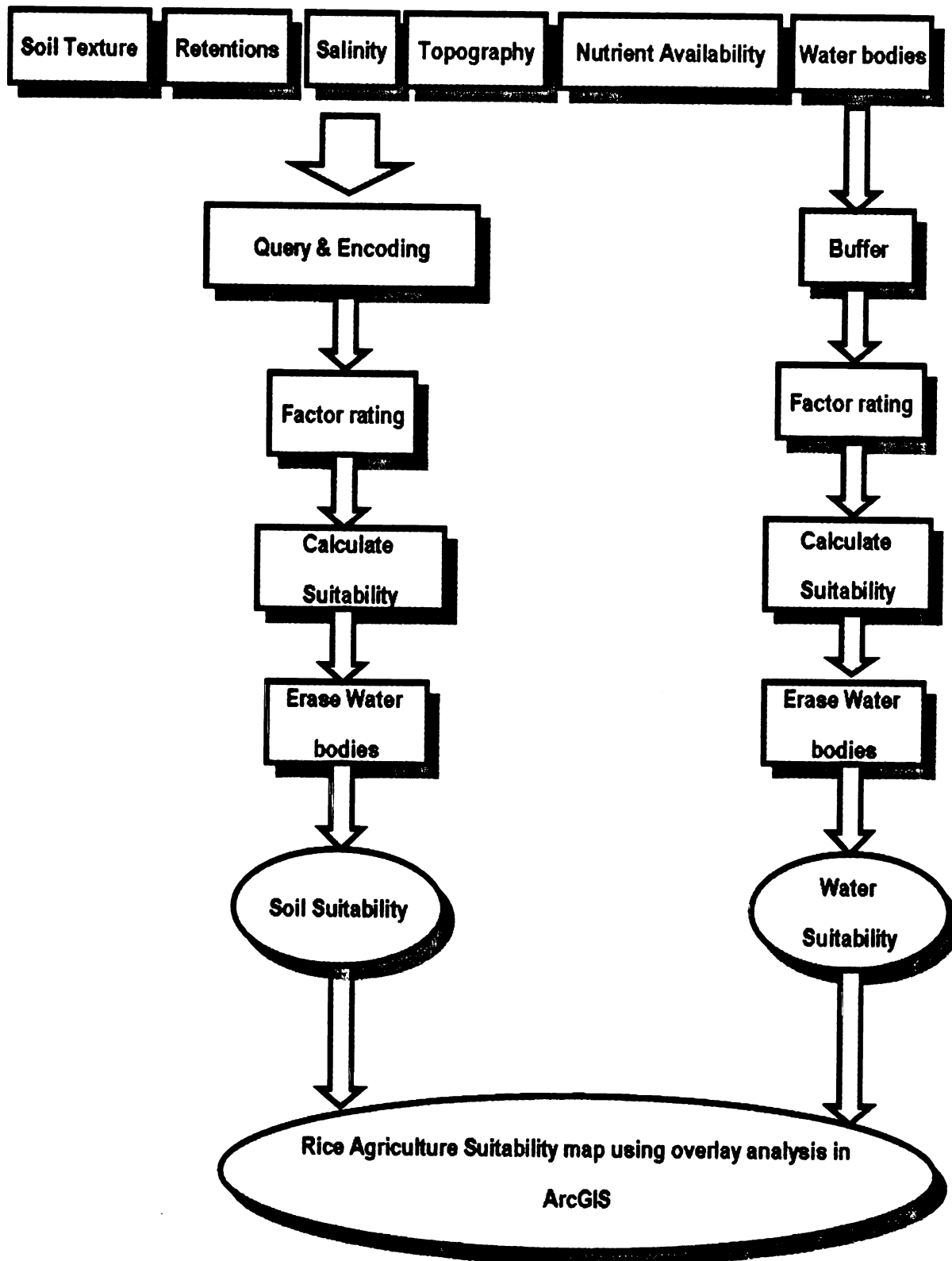


Figure 4.9 Land use suitability for rice farming

Table 4.4 Specific factors for rice agriculture suitability analysis

Land use requirements			Factor rating			
Land Quality	Diagnostic factor	Unit	1.0	0.8	0.5	0.2
Water availability (W)	Distance from water	meter	100	300	1000	> 1000
Nutrient availability index (NAI)	NAI		=0.60	0.40-0.60	0.10-0.40	<0.10
	N	%	>0.2	0.1-0.2	<0.1	—
	P	ppm	>25	10.25	<10	—
	K	ppm	>60	30.6	<30	—
	PH	—	5.6-7.3	7.4-7.8	7.9-8.4	>8.4
				5.1-5.5	4.0-5.0	<4.0
Water retention capacity (R)	Soil texture	—	CL, Si, SCL, SiL, C, AC	L, SiCL, SiC, SL	LS	G, S, SC
Root Conditions (D)	Soil depth	cm	>50	25-50	15-25	<15
Salt hazards (s)	Soil salinity Potential	—	Non-saline	Low	Medium	High
Topography (T)	Landform and slope	—	FL	LT	MT, HT, Fs, M slope < 5%	MT, HT, Fs, M slope > 5%

Notes

Soil texture: CL = Clay, L = Loam, Si = Silt, AC = Alluvial Complex, G = Gravel, S = Sand

Landform: FL = Floodplain, LT = Low Terrace, MT = Middle Terrace, HT = High Terrace, Fs = Foot Slope, M = Mountain

Table 4.5 Rice agriculture suitability score

Value	Class
=0.4	Very Highly suitable
0.25-0.39	Highly suitable
0.2-0.24	Moderately suitable
0.01-0.19	Marginally suitable
<0.01	Unsuitable

4.6 Models and simulations development

To understand the interactions of human behavior and LULCC, examination of the nature of feedback between the population and the environment is essential (Rindfuss et al., 2003). Past land use, current use patterns, the factors that influence or drive trajectories of land use change, and how people relate to spatial structure and change were studied. Here, the Agent Based Models were coded using the NETLOGO language and development environment with the GIS extension. Two separated models were built: 1) Settlement model and 2) Land-use model (Figure 4.10). These ABMs take into account factors including the road network, history of settlement, population dynamics, and results from the land use suitability for rice farming from the previous section. The Settlement model was used to explore the basic characteristics and activities of the agents corresponding to level of accessibility. The Land-use model was used to explore interactions between agents and different behavioral rules including organic urban expansion and dispersive growth. Both endogenous physical characteristics that support rice agriculture and exogenous factors such as crop prices in world markets were considered.

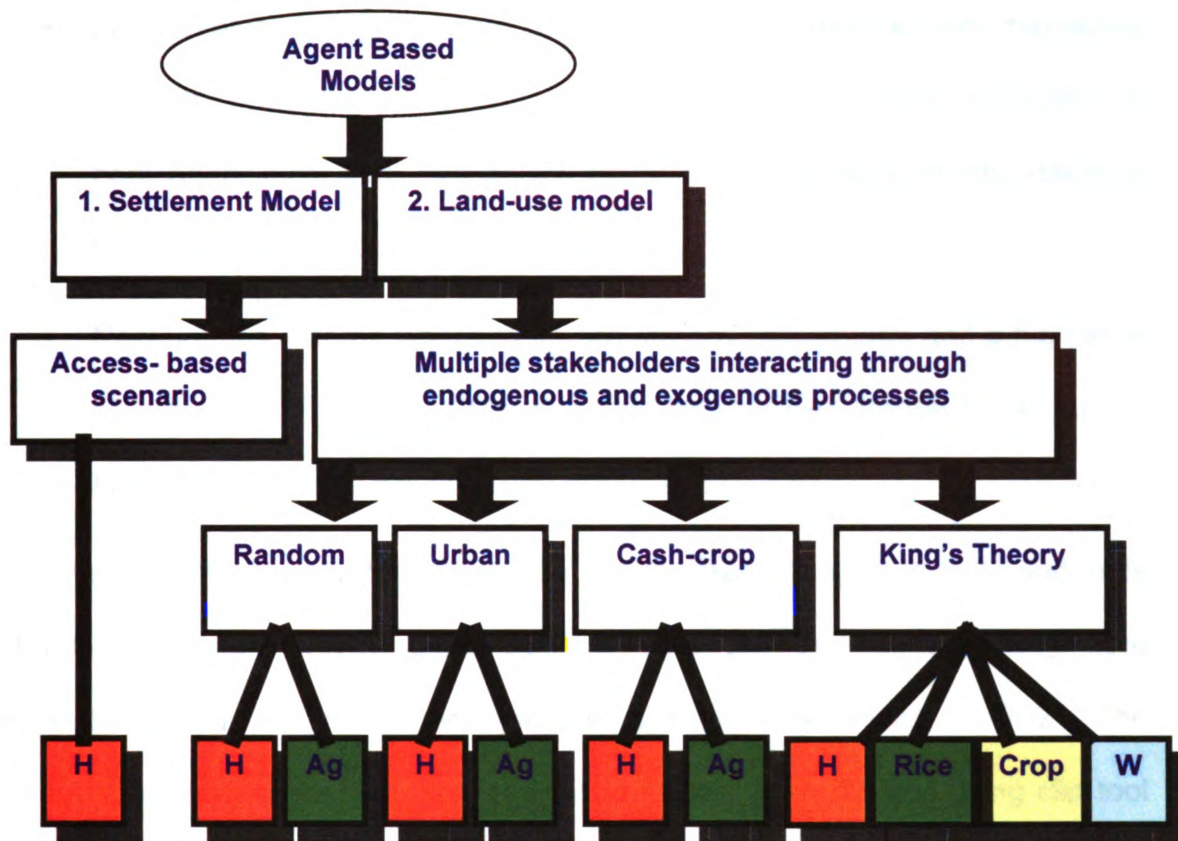


Figure 4.10 Agent Based Models conceptual framework

4.6.1 Settlement calibration model

The key questions that the settlement model address:

- Is it likely that the settlement will expand outward of the urban center along the road network where there is high level of road accessibility to the area where land is suitable for rice farming?
- Is it likely that if the population grows at the examined rate, land suitable for rice farming will be depleted?

The assumptions for the settlement model are:

- Land use/cover changes are driven by multiple stakeholders interacting through endogenous drivers and processes including changes in population, local land availability, distance from existing roads, distance from existing houses, and housing density (See 1.5).
- New houses emerge where there are already settlements and a high level of accessibility to roads. The potential for any new house to be built is higher closer to the existing road network (See 1.5).

For the Settlement calibration simulation, the simulation begins in 1967 and ends at 1994, the period of available of aerial photography. The model settings here were then used to calibrate the predicted settlement simulation for 2021. The Nang Rong town border was set and water bodies were deleted using clip tool from ArcGIS. The primary raster dataset used was the Euclidean Distance product, which measures distances from every pixel within the study site to the existing road network in 1967 (see section 4.4). The Euclidean Distance surface for each year was exported into the NETLOGO urban model using the GIS extension. Sample output is shown in Figure 4.11. In NETLOGO, each pixel in this display is called patch. In addition, the initial condition, the digitized 1,114 houses from 1967 were imported as another layer on top of the distance surface and used as the initial seed agents. The rules for this simulation dictated that new houses emerge near seed agents and in the direction of the minimum distance surface. One common rule was that new houses could not be built on the surface water areas.

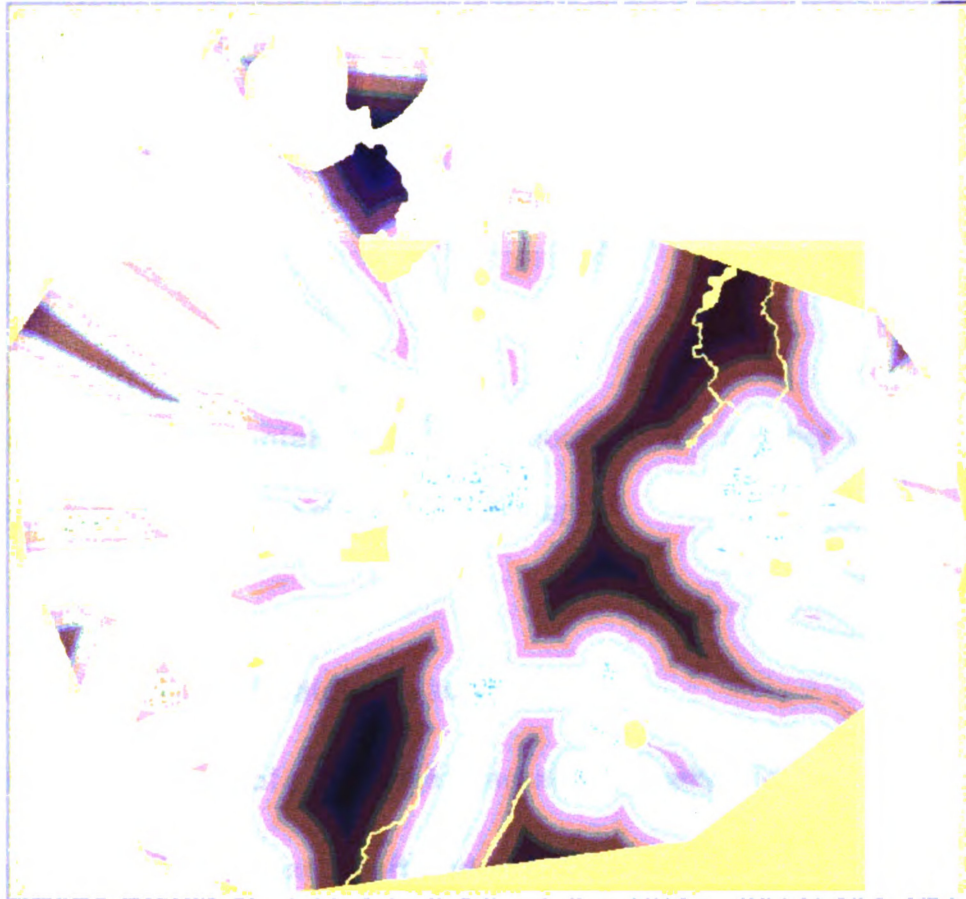


Figure 4.11 Start condition for the Settlement calibration model: these patches were colored in white to brown arranged from closest to furthest distance to road.

To start the simulation, the model randomly selected one existing house agent. The Euclidean Distance from the existing roads in different directions including at the patches ahead and other cardinal directions of the active agent were checked for possible new house locations. The new house agent emerged next to the existing house agent in the direction of lowest Euclidean Distance or shortest distance from the current roads. Next, the program randomly selected a new existing house agent and repeated the process so that 8511 houses were simulated and combined with the existing 1,114 houses to reach the actual

number of 9,625 houses in 1994. A subset of the code for the Settlement Model is below:

to Settle

ask houses

[ifelse (immigration-counter <= 0) Comments: If the number of new house agents is equal to 8,511, the simulation will stop.

[stop]

[let ahead [attraction] of patch-ahead 1

let myright [attraction] of patch-right-and-ahead seeker- search-angle 1

let myleft [attraction] of patch-left-and-ahead seeker-search-angle 1

let behind [attraction] of patch-ahead -1

Comments: This code sets the direction variables including in front of the existing house agent and the other cardinal directions.

[ifelse ((count houses-on neighbors) >= 0 and (count houses-on neighbors) <= neighborhood-threshold)]

Comments: This code checks the neighborhood of the active house agent. If the number of occupied neighborhoods is equal to a variable called neighborhood-threshold, the new house emerges randomly at a new location where there is no existing house.

Neighborhood threshold is the number of empty neighborhood pixels adjacent to active house agent. The threshold was tested by exploring the occupation of the neighborhood from empty to almost full (1 to 8 neighbor cells) and visual analysis of simulated house agent comparing to actual landscape. Parameter sensitivity was tested by repeated model runs. A neighborhood threshold of 8 created new developments that only clumped near urban centers, and there was no development along the road network, a very unlikely scenario. Neighborhood thresholds between 1 and 4 created too many new houses along the roads. Neighborhood thresholds of 5 to 7 behaved similarly with spaces close to urban cores filled first. A neighborhood threshold of 7 was selected as the closest rule to mimic reality and the most effective neighborhood structure to allow the development to expand based upon the locations of both existing houses and random locations along the road network. If 7 neighborhood pixels were occupied, a new house emerges at a new location where there was no existing house and the Euclidean Distance to the roads was minimized.

[ifelse ((myright < ahead) and (myright < myleft))

[hatch-houses 1

rt random seeker-search-angle

fd 1]

Comments: This code builds a new house agent on the right of the existing house, if it is the lowest Euclidean Distance from the road. This code repeats for the other cardinal directions.

[hatch-houses 1

setxy random-xcor random-ycor

move-to one-of patches with [attraction > 10 and attraction < distance_road]]

Comments: If 7 neighborhood pixels were occupied, a new house emerged randomly at a new location where there was no existing house within 10 to 50 pixels (100 to 500 meters) from the road. Thai Government law requires new development at least 100 meters away from any government road. Distance_road variable can be adjusted; however, here the setting 50 pixels was used. According to Entwisle et al (2008), the spatial reach of village households is directly tied to size, quality, and connectivity of road system. After the village had been primarily established, spatial extent of the secondary settlement for typical village is 500 meters radiating outwards from the village center where the central of road system occurs.

A total of 1,114 pixels from 1967 and the simulated 8,511 pixels were combined and compared with the actual 9,625 pixels in 1994. A Monte Carlo simulation of one hundred iterations was run, combined, and compared with the 1994 digitized

buildings to calibrate a predicted settlement in 2021 model. The final map from the Settlement calibration model was then compared with agriculture suitability map. One hundred results were processed and discussed in the model evaluation and raster analysis section 4.7.

4.6.2 Predicted settlement in 2021

For this predicted Settlement model, the simulation begins in 1994 and ends at 2021. It is not possible to determine population in 2021, therefore, this model assumed that the household number will double or increase another 8,511 pixels in the same amount of time (27 years) of the calibration period. The primary raster dataset used was the Euclidean Distance product, which measures distances from every pixel within the study site to the existing road network in 1994. This Euclidean Distance surface was the background layer or start point for the new settlement simulation. The initial condition, the digitized 9,625 houses from 1994 were imported as another layer on top of the background and used as the agents (Figure 4.12)



Figure 4.12 Start condition for the predicted settlement simulations of 2021, these patches were colored in white to brown arranged from closest to furthest distance to road.

To begin the simulation, the model randomly selected one existing house agent. The Euclidean Distances from the existing roads in different directions were checked as the previous Settlement calibration model. The new house agent emerged on a neighborhood pixel adjacent to the active house agent in the direction of lowest Euclidean Distance. If 7 neighborhood pixels were already occupied, a new house emerged randomly at a new location without existing houses and that minimized Euclidean Distance to the roads. Next, the program randomly selected a new existing house agent and repeated the process. A total

of 8,511 houses were simulated. The total area of the existing 9,625 houses in 1994 and the simulated 8,511 houses were combined. A Monte Carlo simulation of one hundred iterations was run, combined, and compared with the agriculture suitability map. One hundred results were processed and are explained in the model evaluation and raster analysis section 4.7.

4.6.3 Land-use model

The Land-use model explored a variety of different development schemes. These include: a) random change or diffusion scenarios, b) organic growth scenarios, c) globalization and exogenous pricing scenarios, and d) an instantiation of a sustainability scenario.

Four specific examples of these scenarios were simulated:

- New house and agriculture agents emerge spatially randomly. This scenario is based on the hypothesis that diffusive or dispersive growth promoted the random dispersed development of urban centers regardless of a fixed proximity function (Clarke et al, 1996).
- The urban expansion scenario takes into account the organic growth theory (Clarke, 1998). Organic growth describes the outward expansion of settlements from existing urban centers. The process is controlled by and based upon some of the tenants of central place theory as applied in rural contexts which stated that the demand for land is a function of linear distance from central market place (Hudson, 1985). Ricardo's theory

(1951) suggests that rural spatial structures depend upon the physical qualities and urban demand for land. Whenever demand for a certain good is high, it will be offered in close proximity to the population. Therefore, this scenario regulates that new house agents emerge near existing settlements. New agriculture agents emerge at the same rate as settlement development at specific distances from the corresponding house agents.

- The globalization cash-crop expansion scenario applies the organic growth theory and adds interactions between endogenous and exogenous capital processes. New house agents emerge near existing settlements. Agriculture agents emerge at specific distances from the corresponding house agents at a faster rate due to increasing world market demands for cash-crops; small-scale farmers sell farm lands to commercial sector actors rapidly, leading to more land converted to cash-crop field agriculture (Rojnkureesatien, 2006).
- The sustainability scenario applies the King's Theory model and takes into account the organic growth theory, interactions between endogenous and exogenous processes as well as the mixed land use models. Land parcel combinations of 4 land use classes including 3 rice farming pixels, 3 cash-crop pixels, 2 water pixels, and 1 housing pixel are generated. New house agents emerge near existing settlements. Other land use agents emerge adjacent to new houses. New land parcels are converted to the mixed land use (Jitsanguan, 2001).

The assumptions for the Land-use model are:

- Land use/cover changes are driven by multiple stakeholders interacting through endogenous and exogenous drivers. Endogenous physical characteristics that support rice agriculture such as water accessibility, soil quality, and elevation modify the nature and rate of urban and agricultural area change. Exogenous factors such as crop prices in world markets and labor markets modify the nature and rate of urban change. Both combined with population change, land availability, and proportion of land use by class, are factors influencing urban growth in Nang Rong. Factors including rice agriculture suitability score, population, proportion of land use, different land use scenarios, distance to existing settlement, and world market demand for cash-crop were considered (See 1.5).
 - Uncontrolled urban growth creates conditions where the area suitable for rice agriculture declines.
 - High global demand for cash-crops creates conditions where the area suitable for rice agriculture declines.

The program was coded in NETLOGO and the GIS extension used. Rice suitability was calculated separately as another GIS layer and used as an input for the Land-use model (Figure 4.13). To initialize the program, the rice suitability raster discussed in section 4.5 was converted to an ASCII file and used as an input. The pixel size was set to 10 * 10 meters. The suitability levels ranged from very highly suitable (suitability score = 0.4) to unsuitable (suitability

score < 0.01) for rice farming (Table 4.4). The study site boundary was demarcated. The ASCII file of the houses in 1967 was imported as another layer on top of the rice suitability surface. Random seed agents equal to number of houses in 1967 for agriculture area were generated and randomly placed where land was identified as very highly and highly suitable for rice farming. This is because early settlers acquired the available lands, and of course, preferentially selected the best lands with the best soil and water conditions first (Kaothien, 1991). An area where the rice suitability score was greater than or equal to 0.2 was defined as suitable for rice farming and for further simulation. The four scenarios described earlier were independently tested. The code for the program is in the appendix.

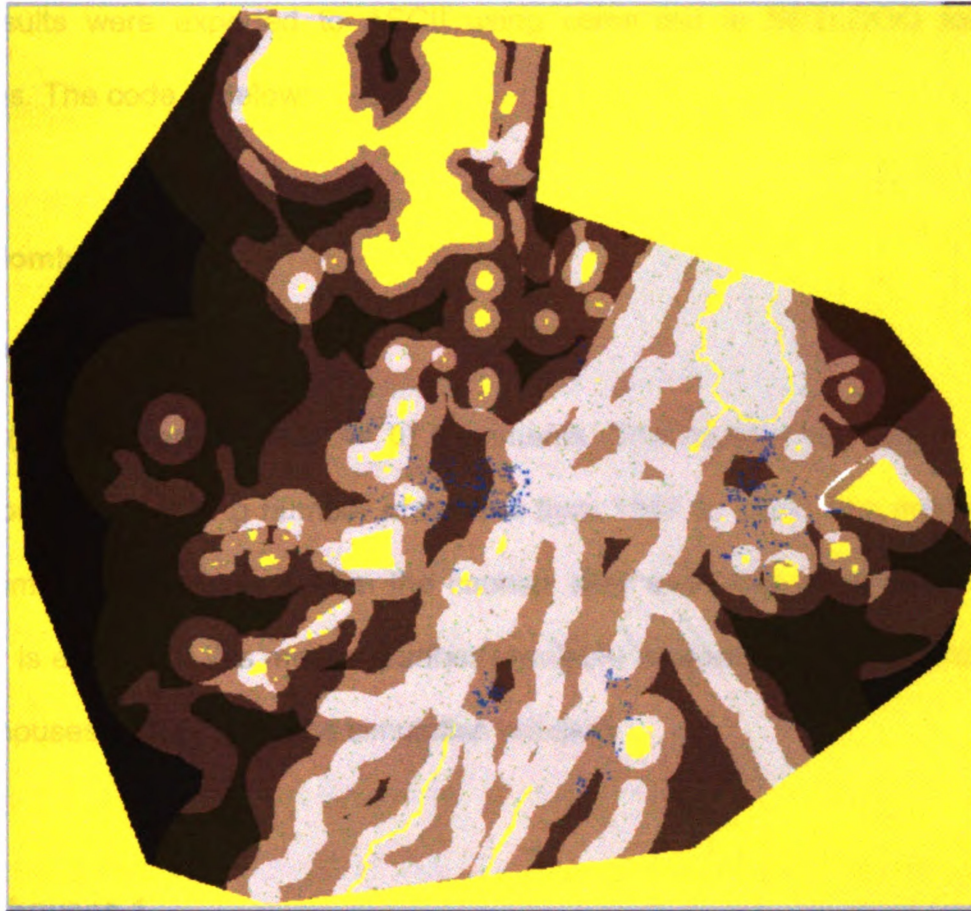


Figure 4.13 Start condition for the Land-use model: these patches were colored in light brown to dark brown arranged from very highly suitable to unsuitable for rice farming.

The first scenario, recall, was that new house and agriculture agents emerge randomly. To simulate, the 1967 number of 1,114 households was used as input. Both house and agriculture agents were randomly placed across the study site regardless of whether or not the area was suitable for rice farming. The program stopped when the total number of house and agriculture agents equaled the number of households in 1994. One hundred Monte Carlo simulations were run. The results present the range of probabilities of different outcomes occurring.

The results were exported to ASCII using command in NETLOGO for GIS analyses. The code is below:

to randommove

ask houses

[ifelse (immigration-counter <= 0) Comments: The counter was set to 8,511 based on the increasing number of houses from 1967 to 1994. The model runs 8,511 times and deducts 1 from the counter after each loop. If number of the counter is equal to 0 this means number simulated houses is equal to number of actual houses in 1994, and the simulation will stop.

[stop]

[hatch-houses 1

setxy random-xcor random-ycor

if any? turtles-here = true

[move-to one-of patches with [not any? turtles-here]]

Comments: This code creates new house agents and randomly places them. New house cannot be built on an existing house, house agent, water, or agriculture agent. Turtles-here is a command to call an agentset containing all the agents on the caller's patch. This code checks if the patch is already occupied, new house is then built on the next random location.

ask self

[hatch-aggs 1

setxy random-xcor random-ycor

if any? turtles-here = true

[move-to one-of patches with [not any? turtles-here]

set immigration-counter immigration-counter - 1]]]]

Comments: This code creates the corresponding agriculture agents, randomly places them, and subtracts one from the counter after each iteration.

The second scenario, urban expansion, applies the organic growth theory which represents spreading outward of settlements from existing urban centers. With this scenario, new house agents emerge near existing settlements. Agriculture agents emerge at the same rate as house agents and within a specified distance from the corresponding house agents. This model assumes that people will build their houses near existing settlements and establish their personal agricultural fields within a certain range from their respective houses. According to Entwisle et al (2008), the spatial extent of the secondary settlement for typical village is 500 meters radiating outwards from the village center. Therefore, a radial distance of 50 pixels was selected, and thus new agriculture agents emerged randomly within 50 pixels from the corresponding house and if land was not available, the new agent was randomly placed on more distant available land assuming the land ranged from very highly suitable to moderately suitable for rice

farming. However, if the new location was already occupied by another agent, the new agriculture agent was then placed where land is marginally suitable or unsuitable for agriculture. The program repeatedly simulated new house and agriculture agents until number of household agents was equal to 9,625. One hundred Monte Carlo simulations were run and the aggregated results were exported to ASCII and processed in section 4.7 similarly as earlier sections. The code is below:

to urbanmove

ask houses

[set neighborhoods random 360

[hatch-houses 1

move-to patch-at-heading-and-distance neighborhoods random closeness

Comments: This code creates new house in a random 360 degree direction from an existing house within the settled space. In Nang Rong district, villages are clusters of dwelling units surrounded by agricultural lands. Nang Rong people typically occupied lands and built homes in large part shaped by their desire to be close to existing family (Entwisle et al., 2008). The closeness variable in this model represents distance of any new house from an existing house. This value can be adjusted, here 5 pixels or 50 meters was used for consistency and to compare with the other scenarios.

if any? turtles-here = true

**[move-to one-of patches in-radius 50 with [not any? turtles-on neighbors
and not any? turtles-here]]**

Comments: If the neighborhood pixels are not available, the simulated house agent is moved to further available land within 50 pixels or 500 meters (see the previous section and Entwisle et al 2008).

ask self

[hatch-aggs 1

facexy random-pxcor random-pycor

fd random distance-to-house

Comments: This code creates an agriculture agent within 50 pixels from a corresponding house agent in a random direction. The variable, distance-to-house, can be adjusted.

if any? turtles-here = true

[move-to one-of sw with [not any? turtles-here]

Comments: sw variable identifies the area suitable for rice agriculture ranging from very highly suitable to moderately suitable. This piece of code checks if land within 50 pixels is available, if not the new agriculture agent is moved to beyond

50 pixels where land is available and where land quality ranges from very highly suitable to moderately suitable for rice farming.

if any? turtles-here = true

[move-to one-of patches with [not any? turtles-here]]

set immigration-counter immigration-counter - 1

Comments: This code checks if land suitable for rice farming is already occupied by another agent; if not a new agriculture agent emerges where land is marginally and unsuitable for agriculture. The counter is then reduced by one.

The third scenario tested the cash-crop expansion models and takes into account that Nang Rong people live in nuclear settlements and typically farm multiple plots with their lands arrayed outward surrounding the settlement core. This model simulated new house agents emerging nearby existing settlements. Agriculture agents emerged at a faster rate than settlement development due to cash cropping land conversion influenced by high demand for cash-crops in the world market. Also, in this scenario small-scale farmers sell land to the commercial sector. From interviewing during the fieldworks, small subsistence farmer would sell part or sometimes all of their land. According to Pookpakdi (1992), most of the small-scale farmers own land less than 6 rai (9600 m² or 96 pixels). However to promote inter-model comparison, this model selected a representation of 9 pixels per small-scale farmers' household property including 1

house pixel and corresponding 8 pixels of agriculture agents as the smallest parcel unit. The assumption here is that if small-scale farmers sell 8 pixels per household of their land and convert it to cash cropping field, the result will show declining in area suitable for rice agriculture. Consequently, a 96 pixels or 6 rai per household conversion process will show similar but more dramatic LULCC. This parcel unit rule was established to better compare with the sustainability scenario.

New houses emerge near existing settlements. However with this scenario, agriculture agents emerge at a faster rate than settlement agents where land is very highly suitable to moderately suitable for rice farming. Eight pixels of corresponding new house agent are then converted to commercial agriculture. This model assumes that people will establish their agricultural field within a specified distance from the corresponded house agents. If land near their house is unavailable, they will find land further away where land is suitable for agriculture. Again, a distance of 50 pixels radius was selected to be able to compare with the other scenarios. A new agriculture agent emerges randomly within 50 pixels from corresponding house and if land is not available, the new agent is moved to more distant available land ranging from very highly suitable to moderately suitable for rice farming. If land suitable for rice farming is already taken, the new agriculture agent emerges where land is marginally and unsuitable for agriculture within the study site. The program repeatedly simulates new house and agriculture agents until number of household agents equal to

9,625 and number of agricultural agents equal to 77,000. One hundred Monte Carlo simulations were run and the aggregated results were exported to ASCII and processed in section 4.7 similarly to the earlier sections. The code is below:

to commercialcrop

hatch-aggs agsize

[facexy random-pxcor random-pycor

fd random distance-to-house

Comments: This code creates agriculture agents of 8 pixels (agsize variable) per loop within distance of 50 pixels from the corresponding house agent. The variable distance-to-house can be adjusted. A value of 50 was selected for consistency.

if any? turtles-here = true

move-to one-of sw with [not any? turtles-here]

Comments: sw variable identifies the area suitable for rice agriculture ranging from very highly suitable to moderately suitable. This piece of code checks if land within 50 pixels is available, if not the new agriculture agent is moved to beyond 50 pixels where land is available and where land quality ranges from very highly suitable to moderately suitable for rice farming.

if any? turtles-here = true

[move-to one-of patches with [not any? turtles-here]]

Comments: This code checks if land suitable for rice farming is already occupied by another agent, the new agriculture agent emerges where land is marginally suitable or unsuitable for agriculture. The counter is then reduced by one.

The fourth, or sustainability, scenario explored the King's Theory of "Sufficiency Economy" with a mixed land use model: water, rice farming, cash-crop field, and housing area per parcel. Parcels of 9 pixels of mixed land use and new house agents were again simulated as an effectively "Field." Land parcel combinations of 4 land use classes including 3 rice farming pixels, 3 cash-crop pixels, 2 water pixels, and 1 housing pixel were selected and simulated. This model assumes that people will create mixed land uses near their house. New houses emerge near existing settlements. Eight pixels corresponding to each agent were simulated and placed at the corresponded house agent's neighborhood pixels. If the neighborhood pixels were not available, the new agriculture agent was moved to further available land. The program stopped when at 9,625 house agents. One hundred Monte Carlo simulations were run and the aggregated results were exported to ASCII and processed in section 4.7. The code is below:

to mixedlanduse

ask self

[set pathavailable neighbors

Comments: This code calls the active new house agent and sets available neighborhood pixels to variable called pathavailable.

if count ponds < seeker-house * pond-proportion

[hatch-ponds pond-proportion

[facexy random-pxcor random-pycor

fd 1

Comments: This code generates a water agent called pond and places it at the corresponding house agent's neighborhood. The code counts total number of water pixels. If number of water pixels is equal to number of proportion of water pixel per household multiplied by number of new house, the program will simulate next land use class.

if any? turtles-here = true

[move-to one-of patch-set pathavailable with [not any? turtles-here]]

Comments: If the neighborhood pixels were not available, the simulated water pixel is moved to the next available corresponding neighborhood.

ask one-of patch-set pathavailable with [not any? turtles-here]

[sprout-newaggs rice-proportion

Comments: This code generates a rice agriculture agent called newaggs and places it in the corresponding house agent's neighborhood. This code creates number of rice agriculture agents equal to input variable number called rice-proportion.

[if any? turtles-here = true

[move-to one-of patch-set pathavailable with [not any? turtles-here]]]]

Comments: If the neighborhood pixels were not available, the simulated rice pixel is moved to the next available corresponding neighborhood.

ask one-of patch-set pathavailable with [not any? turtles-here]

[sprout-cashcrops crop-proportion

Comments: This code generates a cash-crop agriculture agent called cashcrops and places it in the corresponding house agent's neighborhood. This code creates number of cash-crop agriculture agents equal to the input variable number called crop-proportion.

[if any? turtles-here = true

[move-to one-of patch-set pathavailable with [not any? turtles-here]

Comments: If the neighborhood pixels were not available, the simulated cash-crop pixel is moved to the next available corresponding neighborhood.

if any? turtles-here = true

[move-to one-of patches in-radius 50 with [not any? turtles-here]]

Comments: If the neighborhood pixels are not available, the simulated agent is moved to more distant available land within 50 pixels from the corresponding house agent. A value of 50 was selected for consistency.

4.7 Model evaluation and raster analysis

One hundred realizations were produced for each of six scenarios: 1) predicted settlement in 1994, 2) predicted settlement in 2021, 3) random change or diffusion scenarios, 4) organic growth scenarios, 5) globalization and exogenous pricing scenarios, and 6) an instantiation of a sustainability scenario. The result from each run was exported to ASCII. Each ASCII file from each model was converted to GRID format using ArcGIS as an integer data type. Each raster land use class including building, rice agriculture, water resource, and cash-crop agriculture was extracted based on a logical query using Extract by Attributes in Spatial Analyst Tools. After extraction, each land use class was intersected with Nang Rong boundary using the Mosaic tool. NODATA values within the extracted land use data set were replaced by the value 0. The Mosaic to New Raster tool in Data Management Tools was used to mosaic multiple raster datasets into a new raster dataset. The result yielded a data type of signed 16 bits automatically due to replacement of the -9999 value outside the boundary with 0. Next, due to the limited capability of the Weighted Sum in Spatial Analyst Tools, 10 mosaic land use rasters were overlaid at a time and summed. Finally, all 100 raster layers for

each land use class for each ABM model were combined together to yield a pixel-wise membership probability layer of each land use for each scenario. The corresponding total number of pixels per each land use for each scenario was calculated. Total number of pixels overlapping with each suitability category for agriculture was compared and summarized using the Thematic Raster Summary by Polygon Tool within Hawth's Tools (Beyer, 2004). Landscape pattern metrics were used to explore quantitatively for each realization using Fragstats. The Contagion (CONTAG) and Interspersion and Juxtaposition (IJI) indexes were selected. Contagion measures the tendency of patch types to be spatially aggregated or clumped (O'Neill et al, 1988). Contagion index is based on the probability of finding a cell of type i next to a cell of type j (Li and Reynolds 1993). Contagion index is high or close to 100 when the landscape consists of few large patches or when all patch types are maximally aggregated. In contrast, contagion index approaches 0 when the landscape is highly fragmented or when all patch types are maximally disaggregated (McGarigal et al, 2002). IJI is based on patch adjacencies instead of cell adjacencies. IJI closes to 0 when the corresponding patch type is generally neighbor to only 1 other type and increases to 100 when corresponding patch type is equally neighbor to all other patch types (McGarigal et al, 2002). Figure 4.14 below explains the process of this section.

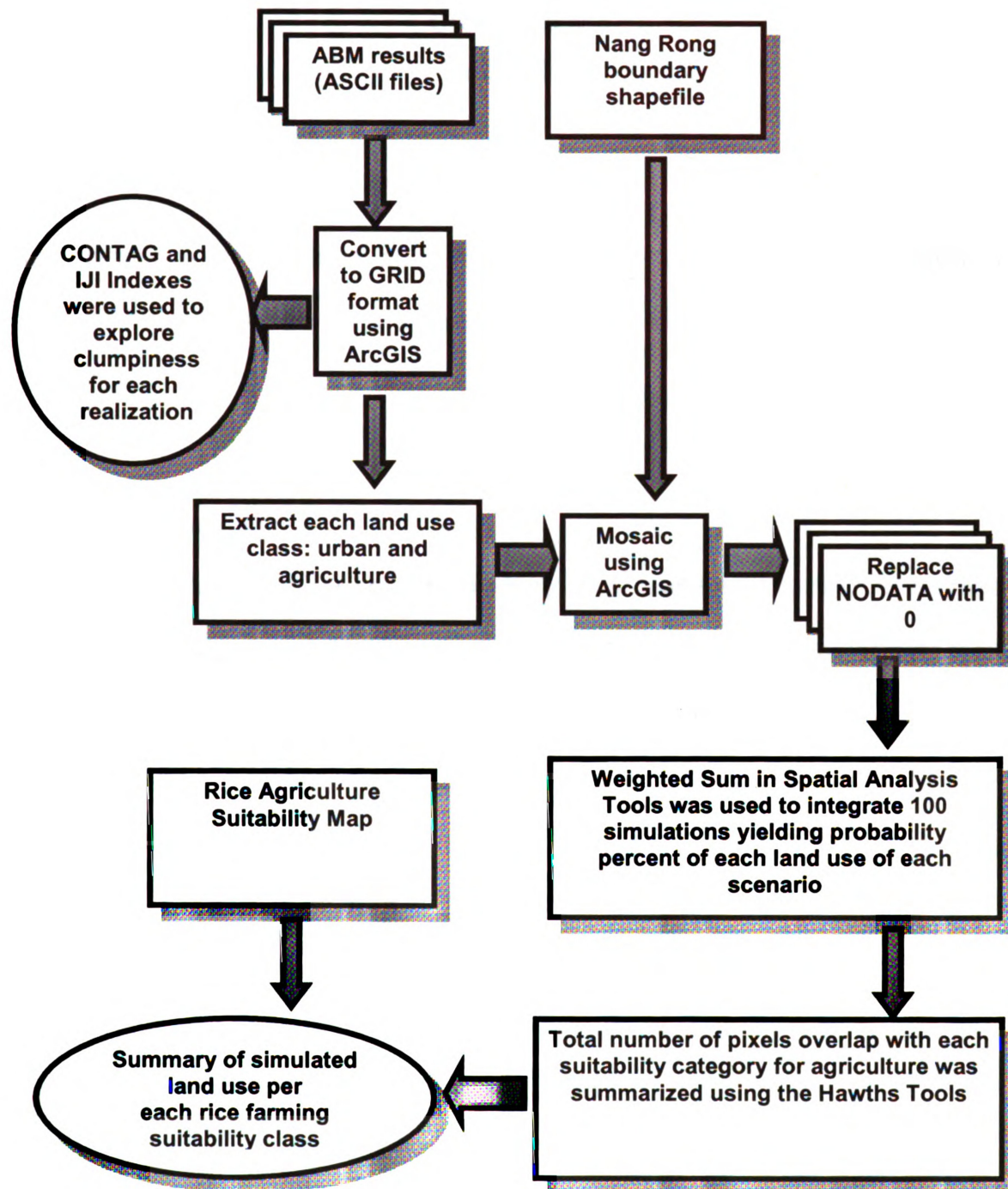


Figure 4.14 Raster analysis process

CHAPTER 5

RESULTS

5.1 Land use suitability for rice farming analysis

Rice farming is the dominant agricultural activity in Nang Rong. The biophysical drivers of rice suitability can be reduced to: 1) soil suitability and 2) water suitability.

5.1.1 Soil suitability

With a total area of 53.69 km² Nang Rong town contains 3.92 km² of surface water with a perimeter of 28,500 meters. Land use suitability for rice farming was subdivided into both soil suitability and water suitability components. Soil suitability for rice agriculture was determined via a combined UET (Ultimate Environmental Threshold) model and map overlays (Mongkolsawat et al., 1997). Multi Criteria Decision Analysis (MCDA) was used to create a suitability index and tabulate rice suitable areas based on soil parameters (Mongkolsawat et al., 1997). The result shows that the soil quality inside Nang Rong town boundary is suitable for rice agriculture (Table 5.1 and Figure 5.1).

Table 5.1 Soil suitability

Suitability (soil)	Area (sq. km.)	Percent
Highly suitable	24.7	52.9
Moderately suitable	22.0	47.2

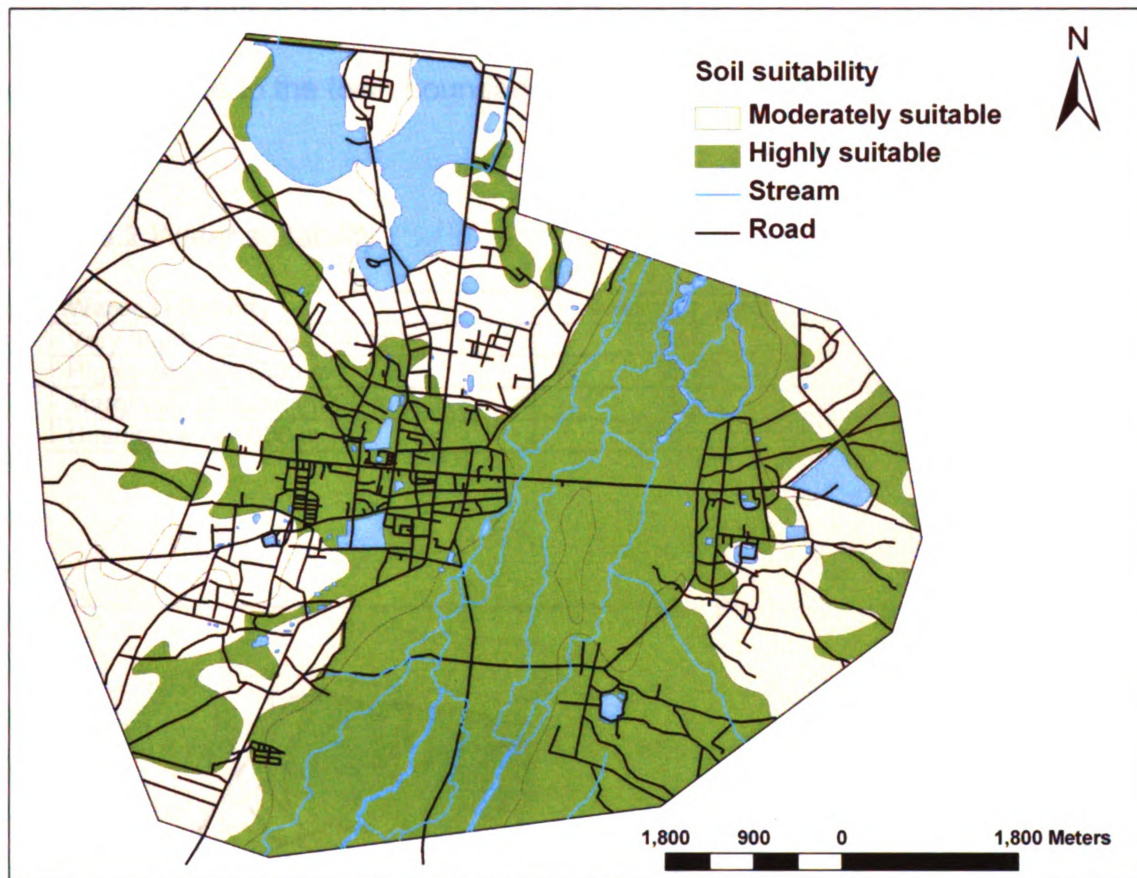


Figure 5.1 Result map from soil suitability analysis for rice agriculture

5.1.2 Water suitability

Water suitability was determined by water resource accessibility. Here, water resource access was restricted to distance from a surface water body. Following Yamamoto and Sukchan (2004), the areas within 100, 300, 1000, and greater than 1,000 meters from water sources were identified. The results show that the majority of the study site (58 percent) was located within 300 meters from a water resource. About 33 percent of the study site was located between 300 and 1,000 meters from a water resource. Only 9 percent of the study site was located

outside the 1,000 meter buffer (Table 5.2 and Figure 5.2). There were no water resources close to the town boundary leading to some edge effects.

Table 5.2 Water suitability

Water suitability	Area (sq. km.)	Percent
Very highly suitable (100 m.)	10.8	23.1
Highly suitable (300 m.)	16.2	34.8
Marginally suitable (1000 m.)	15.3	32.9
Unsuitable (> 1000 m.)	4.3	9.2



Figure 5.2 Areas within different buffer distances from a water body

5.1.3 Land suitability for rice

The identification of areas suitable for rice farming was created by overlaying the soil suitability layer with the water suitability layer using ArcGIS. Land suitability was categorized into rank 1 to 5: 1) very highly suitable, 2) highly suitable, 3) moderately suitable, 4) marginally suitable, and 5) unsuitable for rice farming. Rank 1 and rank 2 areas were combined and cover 45 percent of the study site or 21 square kilometers. These areas possessed good soil quality and were close to water resources. Rank 3 and rank 4 areas covered 25 percent and 20 percent of the study area respectively. The area evaluated as rank 5 (unsuitable) covered only 9 percent of the study area or 4.3 km². This result suggests that Nang Rong town is largely suitable for paddy rice cultivation, the most important local crop. The unsuitable areas for rice farming were universally defined by the accessibility to water resource criterion (Table 5.3 and Figure 5.3).

Table 5.3 Land suitability for rice farming

Land Suitability (soil and water)	Area (sq. km.)	Percent
Very highly suitable	8.0	17.2
Highly suitable	13.1	28.1
Moderately suitable	11.7	25.1
Marginally suitable	9.5	20.4
Unsuitable	4.3	9.2

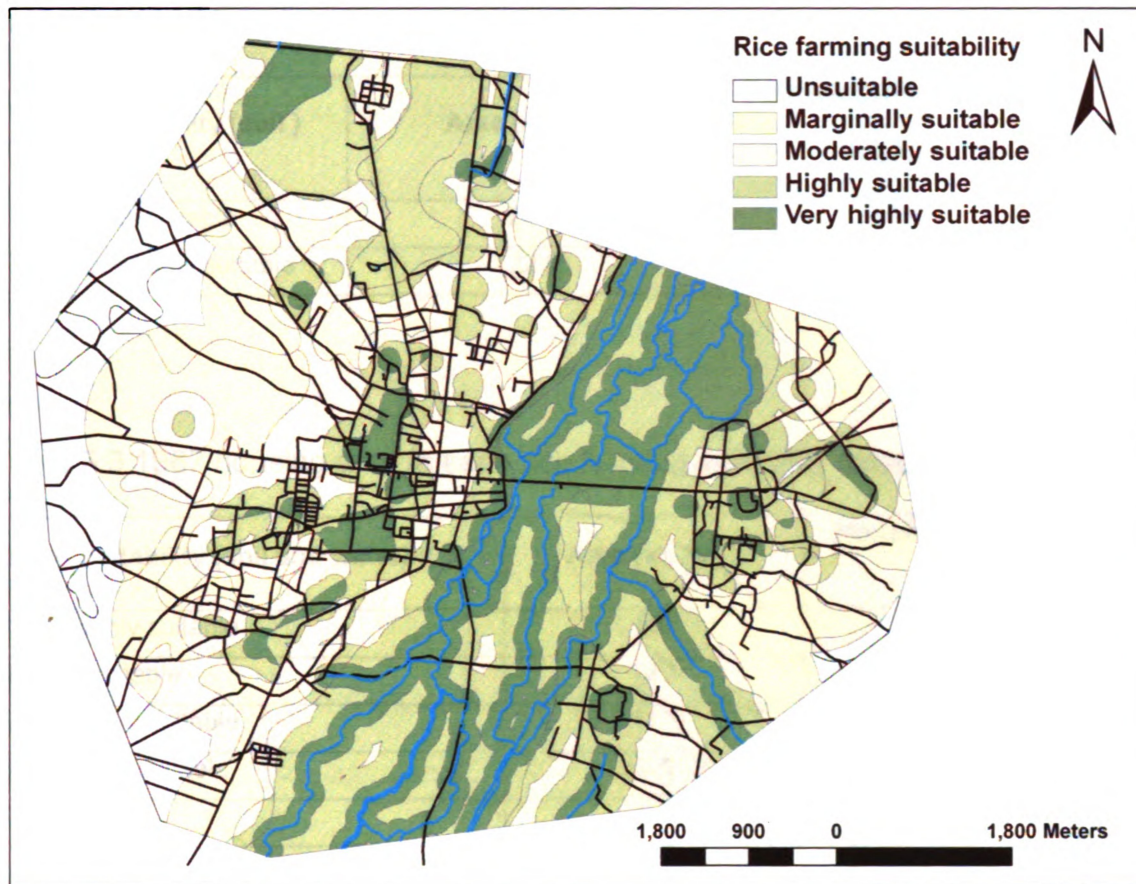


Figure 5.3 Result map from rice agriculture suitability analysis

5.1.4 Change in rice agriculture and land suitability from 1967 and 1994

In 1967, the total housing area in Nang Rong town covered 0.13 km². Housing areas located on moderately suitable soils for rice farming covered 0.115 km² and 0.019 km² on the high quality soils (Table 5.4). There were no households further than 1,000 meters from a surface water body. The result from the rice agriculture suitability analysis shows that the majority of housing in 1967 was located on land suitable for rice farming and covered 0.132 km². Table 5.5 shows housing area within each rice farming suitability category.

Table 5.4 1967 housing area in each soil suitability category

Suitability (soil)	Area (sq. km.)	Housing area in 1967 (sq.km.)
Highly suitable	24.7	0.115
Moderately suitable	22.0	0.019

Table 5.5 1967 housing area in each rice farming suitability category

Land Suitability (soil and water)	Area (sq. km.)	Housing area in 1967 (sq.km.)
Very highly suitable	8.0	0.024
Highly suitable	13.1	0.060
Moderately suitable	11.7	0.048
Marginally suitable	9.5	0.002
Unsuitable	4.3	0

By 1994 the total housing area in Nang Rong town had increased more than 7 times and covered 0.97 km² (Figure 5.4). Housing area in the moderately soil suitable for rice farming increased by 12 times and 7 times in high quality soil (Table 5.6).

In addition, there were approximately 0.01 km² of buildings at a greater distance than 1,000 meters from a surface water body. Due to land availability and urban expansion challenges, people in Nang Rong town had to settle further away from the natural water resources. If they could not settle along the edge of a river or nearby water resources, the settlers would look for a next place available - often quite distant from the ideal.

The suitability map for rice farming was produced by integrating the water availability layer and the soil suitability layer. The result from rice agriculture suitability analysis shows that the majority of housing in 1994 was located in very highly suitable, highly suitable, and moderately suitable land for rice farming and covered 0.9 km². Housing in 1994 increased approximately 7 times greater in area suitable for rice farming than the housing in 1967 (Table 5.7). Many small-scale farmers sold their land to investors and converted them into urban land covers. Consequently, urban expansion in land suitable for rice farming has increased with major developments along lands adjacent to roads. Therefore, land suitable for agriculture became less available. In addition, the results show that the expansion of housing also occurred further away from town center in unsuitable or marginally suitable areas for rice agriculture or areas outside 1,000 meters from water currently used for rice.

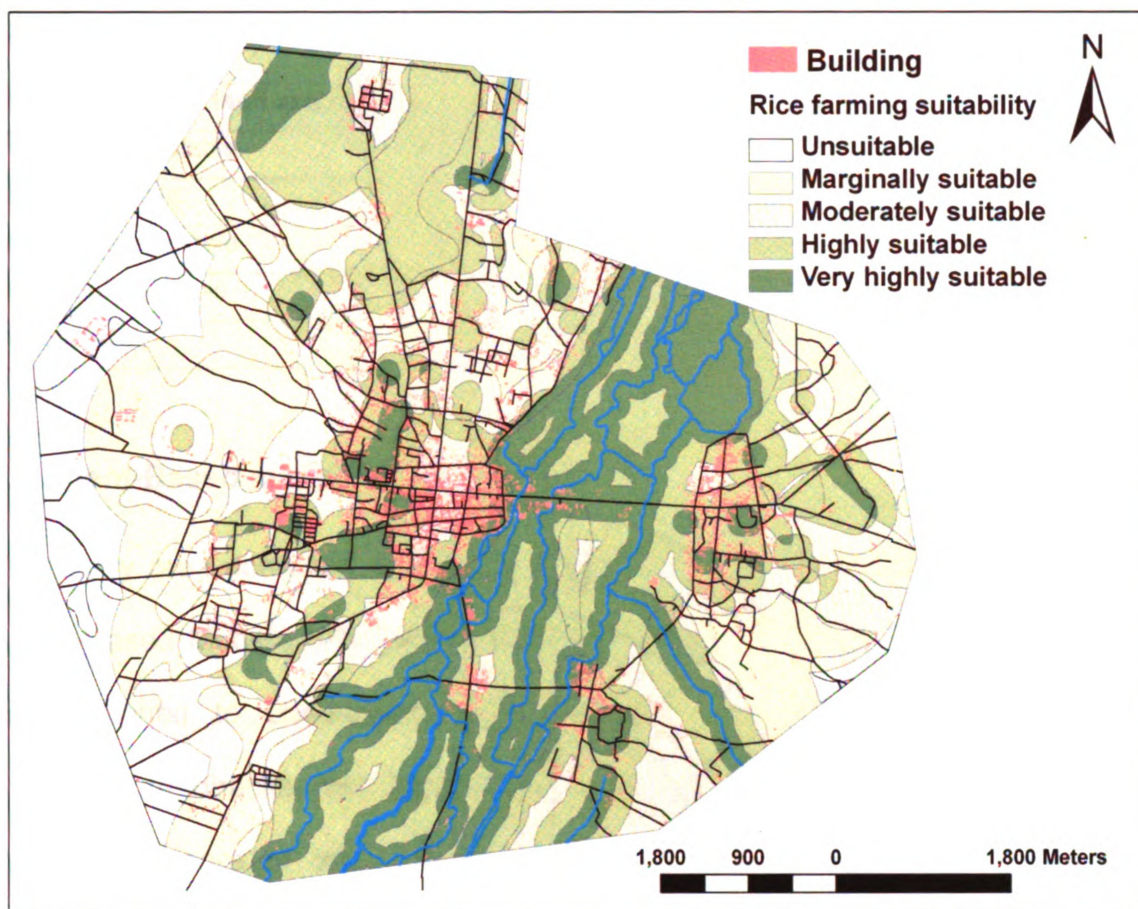


Figure 5.4 1994 housing location within different rice farming suitability category

Table 5.6 1994 housing area in each soil suitability category

Suitability (soil)	Area (sq. km.)	Housing area in 1994 (sq. km.)
Highly suitable	24.7	0.75
Moderately suitable	22.0	0.22

Table 5.6 1994 housing area in each rice farming suitability category

Land Suitability (soil and water)	Area (sq. km.)	Housing area in 1994 (sq. km.)
Very highly suitable	8.0	0.17
Highly suitable	13.1	0.42
Moderately suitable	11.7	0.31
Marginally suitable	9.5	0.06
Unsuitable	4.3	0.01

5.2 Agent-Based modeling and simulations

The study area comprise of 908 columns and 845 rows (767,260 pixels). Both Agent-Based Models (ABMs), the respective Settlement and Land-use models, are designed to characterize development given certain constraints, non-linearities, feedbacks, and human-environment interaction rules. As the models incorporate more of these factors and of greater variance, most modeling environments strain under the “complications.” Where cellular models are focused on landscapes and transitions, these two Agent-Based Models focus on human actions. Furthermore, these ABMs, like most, are dependent upon the initial conditions, and the simulated activities reflect an elementary unit of Agent-Based systems in which behavioral responses occur autonomously based on location rules. Here, properties and behavioral rules were assigned to each land use class agent set and used as basic building blocks. The characteristics of agents within the system change over time due to interactions among agents or their adaptation to dynamic environment.

5.2.1 Results from the Settlement model

5.2.1.1 Settlement calibration model

The results from the Settlement model yielded 100 predicted landscapes for 1994. The initial condition was based on the 1,114 pixels each representing a house in 1967. Each pixel is $10 * 10 \text{ km}^2$. After combining 100 simulations and extracting simulated house agents, the final result (Figure 5.5) is a probability map of household settlement with probabilities at any specific location or pixel. The result shows 2 pixels were repeatedly settled the highest at 93 times near the town center. An area of 0.14 km^2 close to the town center and within 300 meters from the major highway was settled 61 to 90 times. The majority 60 percent of pixels (34,918 out of 57,904 pixels) were settled at the same location 1 to 10 times occupying an area of 3.5 km^2 further away from the major highway, within approximately 600 meters. Figure 5.5 shows that the high probability of predicted settlement in 1994 was likely to occur where the urban core and the majority of the road network were located. Areas of lower probability of settlement extended outward of the urban center along the road network. The model captured 3 major developments highlighted in blue circles. These predicted settlements emerged close to villages settled previous to 1967 and along the existing road network. However, this model does not include newly developed roads. Circles 1 and 2 captured the two distinct cores of Nang Rong town, which remained separated by agricultural land and rice paddies. This area in the middle of these cores is lowland and is seasonally flooded. Circle 3 captured a small area of development at another village center. In addition, this

model identifies a total area of 44 km² where there was no settlement at all. This area has a probability of 0 for repeated settlement. The majority of this area is dominated by agriculture and is partially in flood plains.

Table 5.8 Probability of house agent settled at repeated location

Percent	Pixels	sq.km.
0	439503	43.9503
1-10	34918	3.4918
11-20	8861	0.8861
21-30	4716	0.4716
31-40	3021	0.3021
41-50	2290	0.2290
51-60	1687	0.1687
61-70	1298	0.1298
71-80	852	0.0852
81-90	258	0.0258
91-100	1117	0.1117

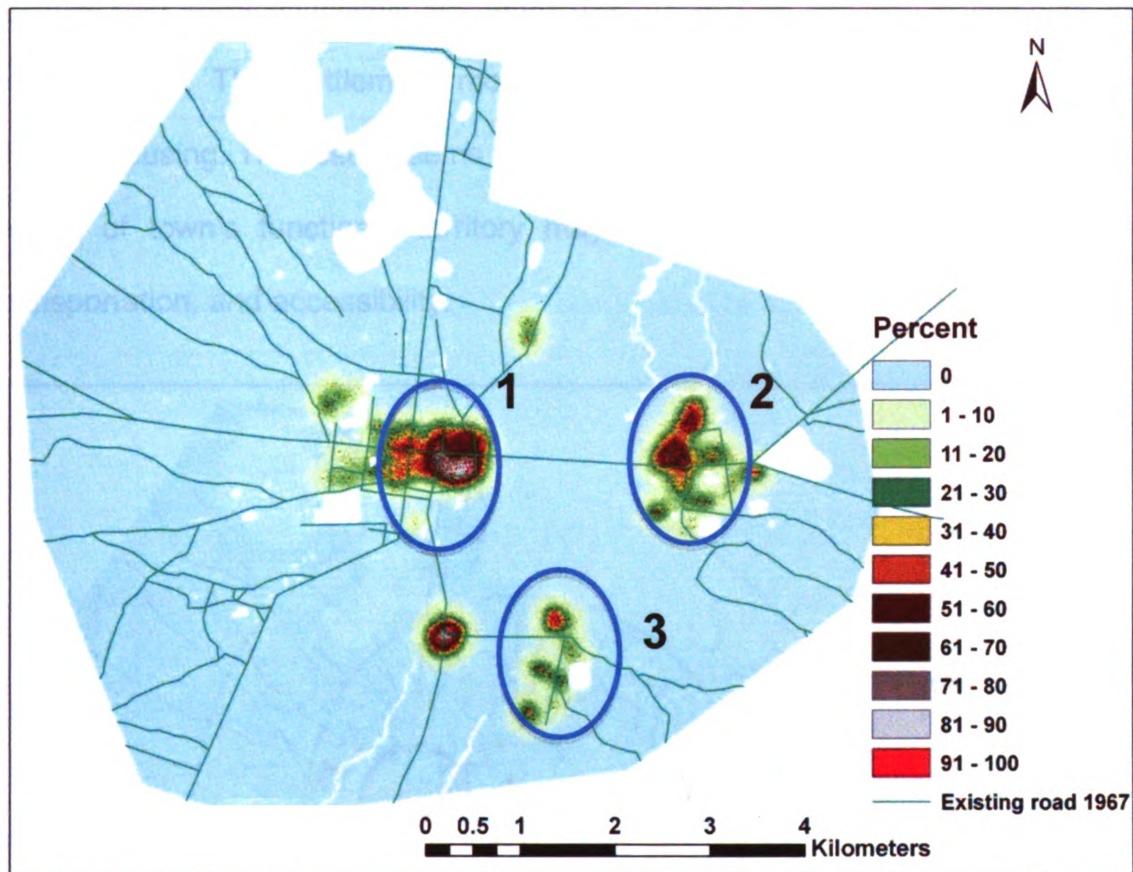


Figure 5.5 Result map from the Settlement model

By comparison with the 1994 numbers (Figure 5.6) and using the thematic raster summary function in Hawth's tools in ArcGIS, a 63 percent match between the predicted urban area pixels and actual 1994 urbanized area pixels was found. Digitized building locations (6,023 out of 9,625) were co-located with the probability map produced by the Settlement model (Table 5.9). Twenty two percent of matched household pixels were at probability of 50 to 100. The majority of buildings matched were inside the urban core and along the road network. Circles 1 and 2 show the majority of co-location between the actual and predicted settlements. Thirty seven percent or 3,602 household pixels

mismatched were diffusively scattered along the road network outward of the urban center. The Settlement model does not capture diffusion of very low density housing. The result seems to suggest that the orientation and geographic extent of town's functional territory may depend on existing urban centers, transportation, and accessibility.

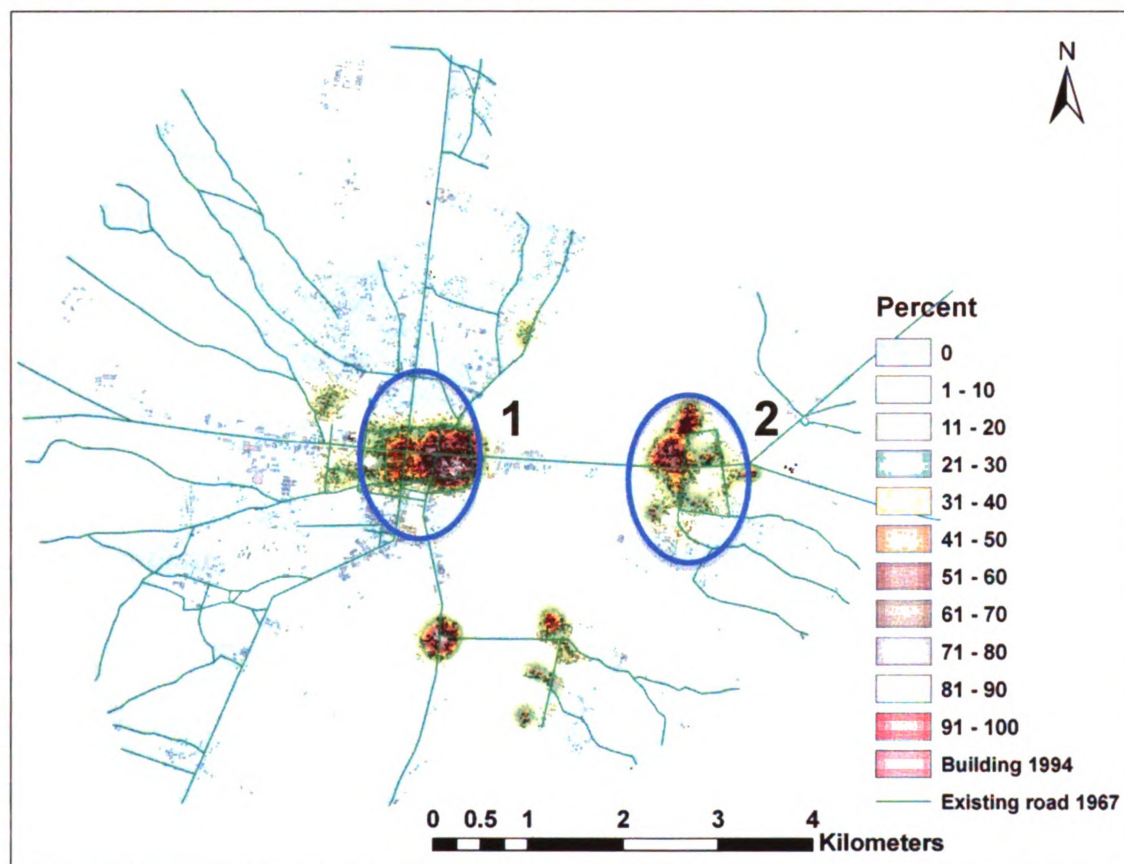


Figure 5.6 Comparing between predicted urban area and digitized building 1994

Table 5.9 Probability of house agent settled at repeated location compared to digitized buildings in 1994

Percent	Buildings 1994 (pixels)
0	4491
1-10	1470
11-20	821
21-30	618
31-40	544
41-50	477
51-60	349
61-70	340
71-80	220
81-90	68
91-100	1116

5.2.1.2 Predicted settlement in 2021

For the predicted Settlement model, the simulation begins in 1994 and ends in 2021. The initial condition started in 1994 which represents houses as 9,625 pixels. This model assumed that the household number will roughly double or increase another 8511 pixels in the same number of years (27 years). The model predicted the probability of 31 to 63 repeated settlement pixels or an area of 0.21 km² (Table 5.10) close to the urban core and road network. Figure 5.7 shows that the high probability of predicted settlement in 2021 will occur where the urban core and majority of road network were located. The simulated houses are mostly clustered and surrounded by agricultural spaces, recalling a traditional nuclear pattern. Circle 1 shows an expanding area of settlement in an east-west

direction along the major highway. Circle 2 shows the predicted settlement expanding north-south direction also due to the road network. The settlement did not expand along the major highway and bridge the gap between the two urban cores primarily due to presence of lowland and flood plains between the cores. Circle 3 shows that the settlement may be continuing to develop along some corridors along the roads expanding outward from the urban center and bridge the gap between 2 clusters. These corridors have percentages of 1 to 10. These low probability areas might be regarded as transitional areas where new development is likely to take place.

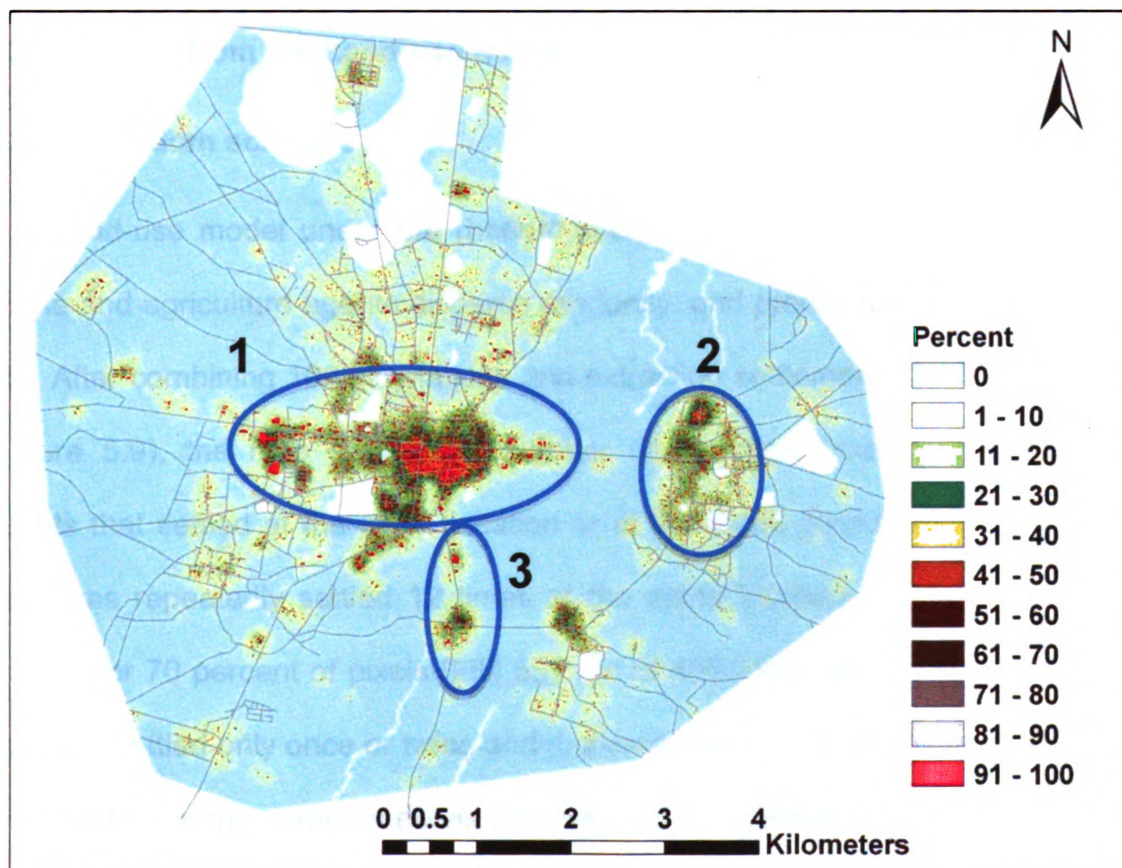


Figure 5.7 Predicted settlement in 2021

Table 5.10 Probability of house agent occupation in 2021

Percent	Pixels	sq.km.
0	340723	34.0723
1-10	128488	12.8488
11-20	16560	1.656
21-30	4053	0.4053
31-40	1318	0.1318
41-50	706	0.0706
51-60	150	0.0150
61-70	1	0.0001
100 (starting locations)	9625	0.9625

5.2.2 Results from the Land-use model

5.2.2.1 Random scenario

The Land-use model under the random scenario (Figure 5.8) shows that both house and agriculture agents disperse randomly, and predictably, over the study site. After combining 100 simulations and extracting settlement land use classes (Figure 5.9), the map shows the number of repeated household settlement agents that settled at the same location or at the same pixel (Table 5.11). One pixel was repeatedly settled 12 times at the same location (Table 5.11). The majority or 70 percent of pixels (284,557 out of 405,915 pixels) or an area of 28 km² was settled only once or twice and dispersed widely. Thirty percent of pixels were settled at the same locations between 3 and 12 times. The result shows a very low probability of repeated settlement under the random scenario. This scenario does not effectively capture the potential locations for new settlement.

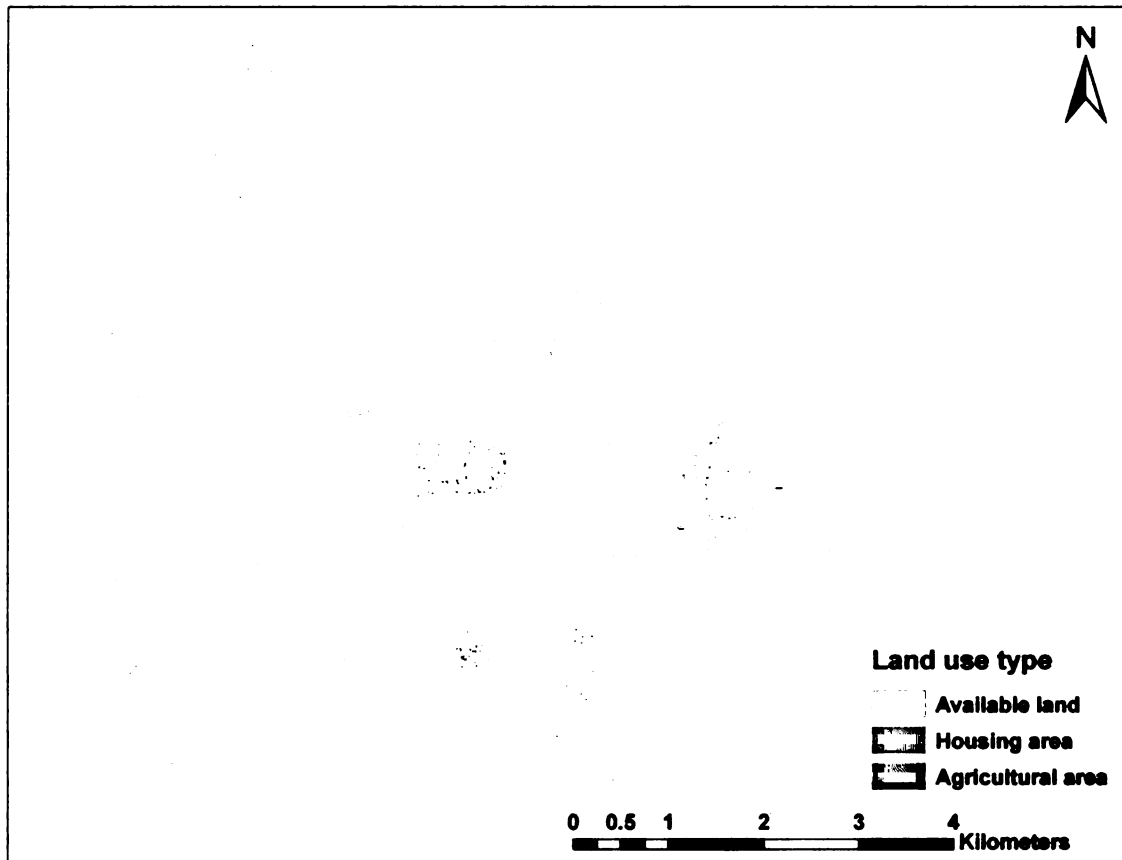


Figure 5.8 A single simulation result from the random simulation scenario

Table 5.11 Probability of house agent settled at repeated location

Percent	Pixels	sq.km.
0	90706	9.0706
1	152684	15.2684
2	131873	13.1873
3	74837	7.4837
4	32097	3.2097
5	10651	1.0651
6	2942	0.2942
7	653	0.0653
8	145	0.0145
9	29	0.0029
10	3	0.0003
12	1	0.0001
100	1114	0.1114

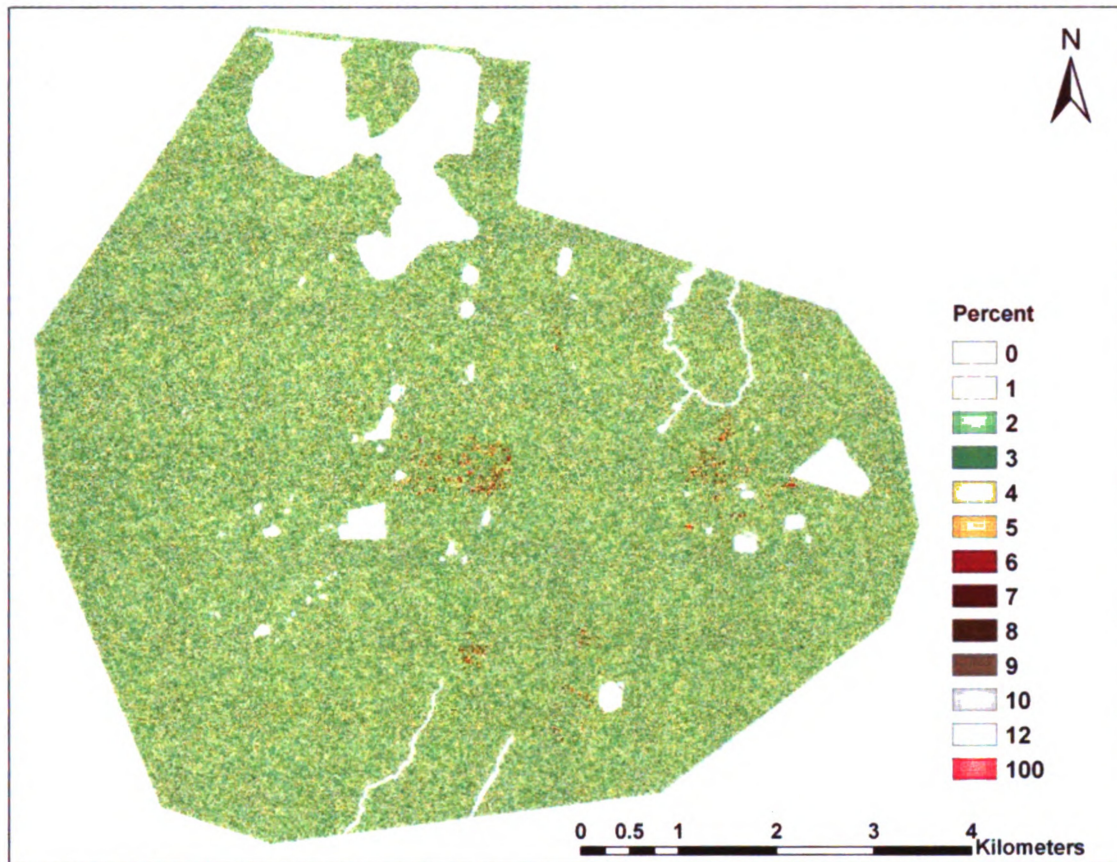


Figure 5.9 Probability map of repeated settlement in random simulation scenario

The results from the Land-use model (Figure 5.10) under the random scenario show that agriculture agents disperse randomly over the study site. After combining 100 simulations and extracting agricultural land use classes, the results (Table 5.12) show that the number of agriculture agents occupied land at the same locations between 1 and 13 times. One pixel was repeatedly occupied 13 times. The majority or 64 percent of pixels (270,771 out of 422,042 pixels) were occupied only once or twice. Thirty six percent of pixels were settled 3 to 13 times. The results show a very low probability of agriculture agent occupation at repeated locations under random scenario. However, figure 5.10 shows a

darker zone in the middle due to random seed agents equal to the number of houses in 1967 for agriculture area were generated and randomly placed along this zone where land was identified as suitable for rice farming. Early settlers acquired the available lands, and of course, preferentially selected the best lands with the best soil and water conditions first where it is a floodplain.

Table 5.12 Probability of agriculture agent occupation at repeated location

Percent	Pixels	sq.km.
0	75693	7.5693
1	138128	13.8128
2	132643	13.2643
3	85680	8.568
4	41940	4.194
5	16206	1.6206
6	5425	0.5425
7	1523	0.1523
8	382	0.0382
9	90	0.009
10	20	0.002
11	2	0.0002
12	2	0.0002
13	1	0.0001

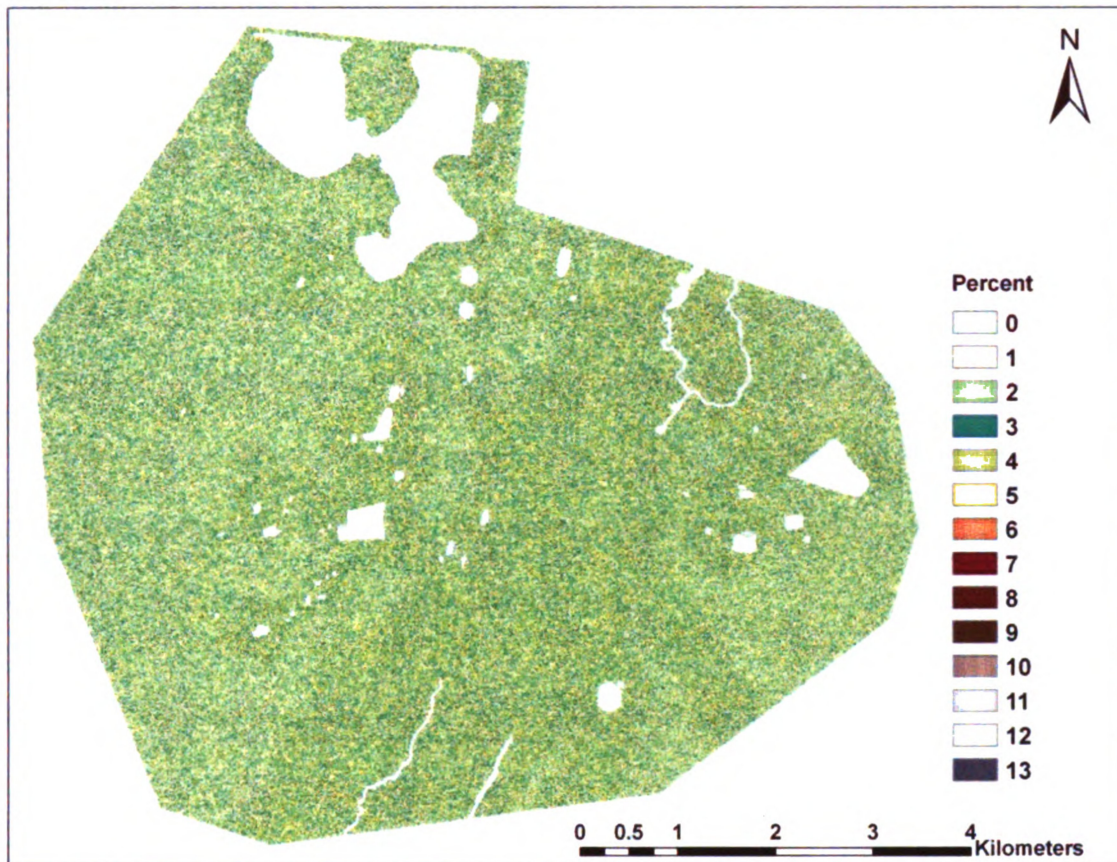


Figure 5.10 Probability map of repeated agricultural settlement under the random simulation scenario

5.2.2.2 Urban expansion scenario

The result from the Land-use model (Figure 5.11) under the urban expansion scenario shows house and agriculture agents clumped nearby each other. The final results yield a settlement probability map (Figure 5.12). The result (Table 5.13) shows that four pixels were settled 50 times, the highest rate, at the same locations. Forty nine percent of pixels (65,013 out of 135,497 pixels) or an area of 6.5 km² settled once or twice at the outer core of the town approximately 1 km from the major highway through town. One percent of pixels were settled 33 to 50 times within 400 meters of major highway. The result suggests a high

probability of repeated settlement in the area nearby major roads and existing settlements. There is an expansion potential outward to 1 km away from the major highway. This model is likely to capture the area that new settlements may occur in close proximity to the town center and roads; even though, the area is suitable for rice farming or is a flood plain. If this scenario continues with an absence of a centralized urban planning framework, development may sprawl over the best quality agriculture lands and/or lands not suitable for housing. This urban expansion is more likely to create problems associated with exhaustion of area suitable for agriculture especially for rice.

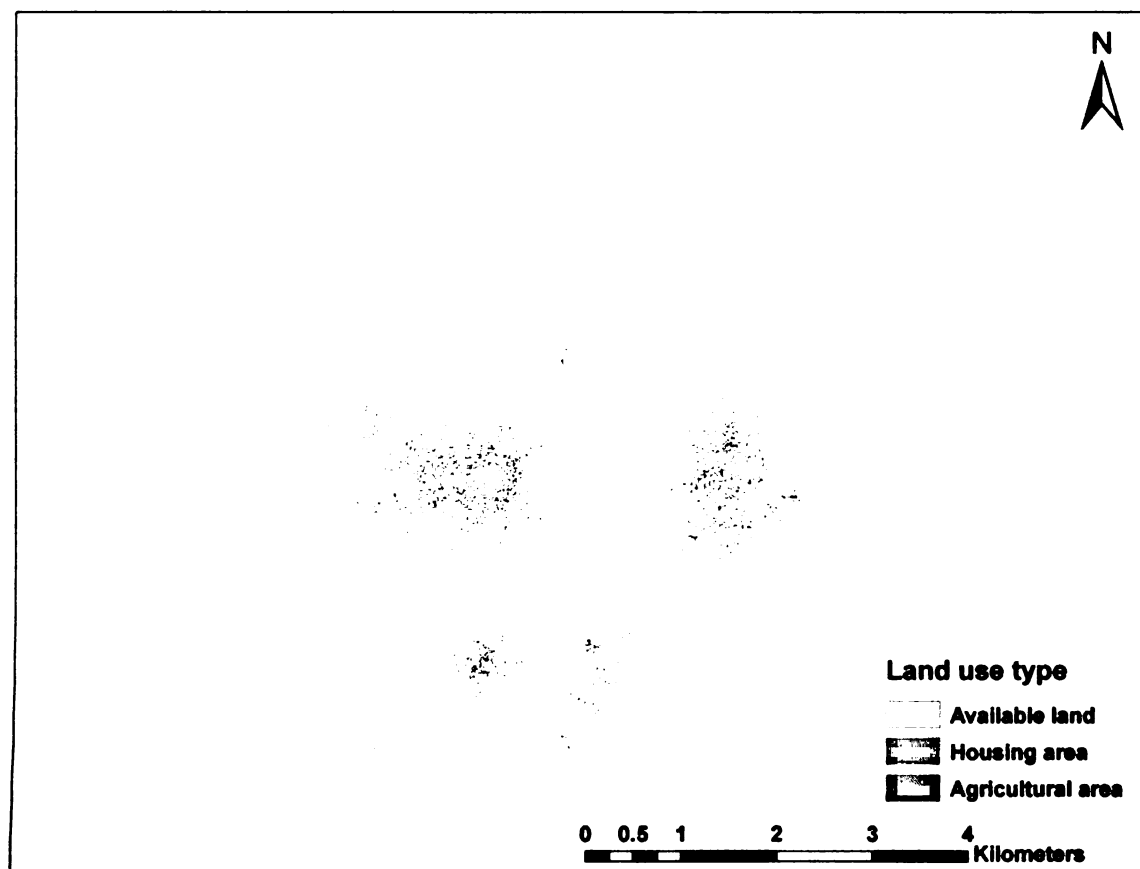


Figure 5.11 An example result from the urban simulation scenario

Table 5.13 Probability of house agent settled at repeated location

Percent	Pixels	sq.km.	Percent	Pixels	sq.km.
0	361124	36.1124	26	745	0.0745
1	47380	4.738	27	709	0.0709
2	17633	1.7633	28	621	0.0621
3	10884	1.0884	29	595	0.0595
4	8069	0.8069	30	543	0.0543
5	6415	0.6415	32	440	0.044
6	5347	0.5347	33	425	0.0425
7	4502	0.4502	34	397	0.0397
8	3808	0.3808	35	303	0.0303
9	3236	0.3236	36	250	0.025
10	2758	0.2758	37	237	0.0237
11	2416	0.2416	38	194	0.0194
12	2114	0.2114	39	152	0.0152
13	1763	0.1763	40	106	0.0106
14	1567	0.1567	41	97	0.0097
15	1458	0.1458	42	68	0.0068
16	1277	0.1277	43	54	0.0054
17	1228	0.1228	44	13	0.0013
18	1080	0.108	45	16	0.0016
19	1082	0.1082	46	8	0.0008
20	1009	0.1009	47	3	0.0003
21	967	0.0967	48	2	0.0002
22	933	0.0933	49	3	0.0003
23	911	0.0911	50	4	0.0004
24	850	0.085	100	1114	0.1114
25	790	0.079			

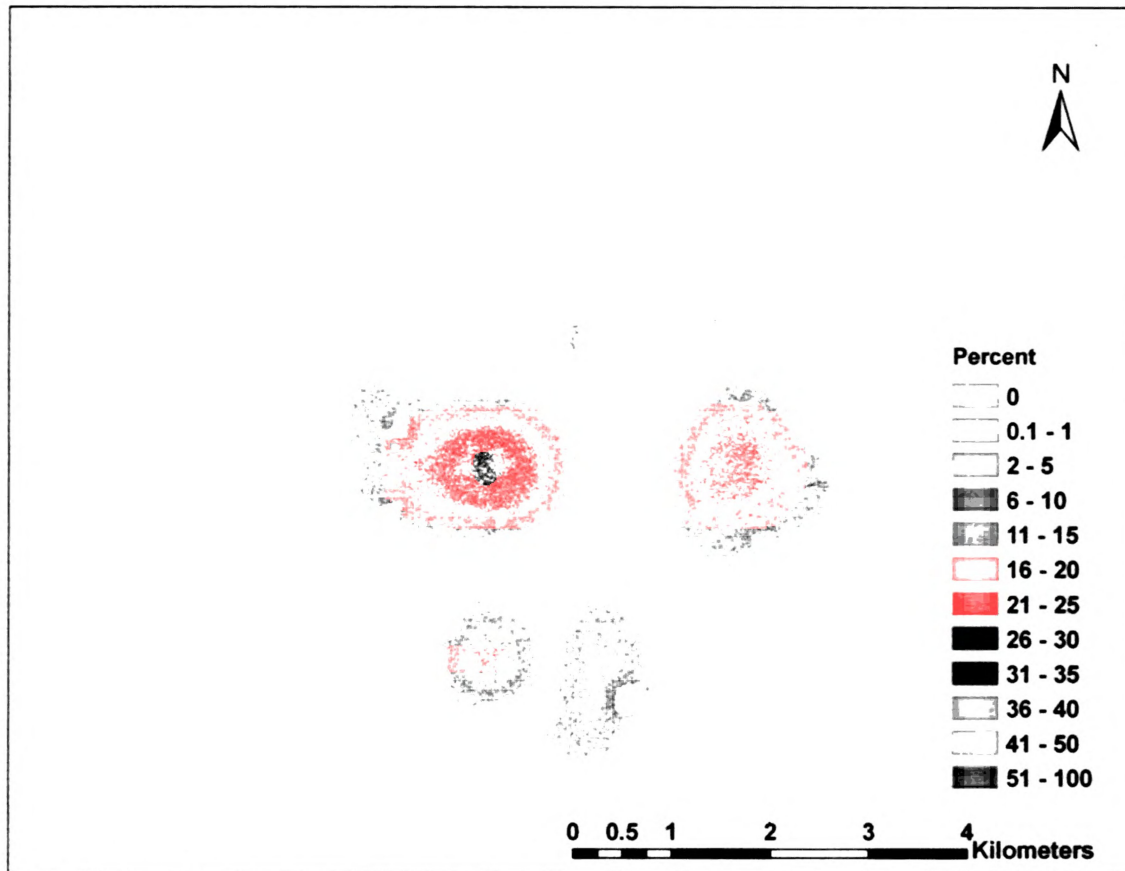


Figure 5.12 Probability map of repeated settlement under the urban simulation scenario

Agriculture agents were simulated within 50 pixels from new simulated house agents. This model assumes that people will build their houses nearby their respective agricultural fields first. The result from the Land-use model under the urban expansion scenario yields the predicted agricultural landscape in Figure 5.13. The result (Table 5.14) shows number of agriculture agents occupied land at the same pixels between 1 and 76 times. One pixel was occupied 76 times. Sixty one percent of pixels (100,133 out of 163,052 agents) or area of 10 km² were occupied only once or twice. One percent of pixels were settled 48 to 76 times. The result suggests a high probability of agricultural agents occupying the

areas nearby major roads, close to housing agents' locations. According to the rules for this scenario, agriculture agents emerged at the same rate as house agents and within a close proximity to the corresponding house agents. Therefore, the model suggests that there is potential for agricultural expansion outward to 1 km away from the major highway similar to housing expansion. This model is likely to capture the areas where new agriculture should occur. In addition, the model suggests that if the agricultural occupations were limited to the same rate as the settlement development, land would be more available for future generations. Small-scale farmers were not influenced by increasing world market demands for cash-crops; therefore, they did not have to sell farm lands to commercial sector actors or convert land to cash-crop field agriculture. This scenario suggests similar results to house agents occupation patterns. The results suggest a high probability of repeated settlement in the area nearby major roads and urban cores represented by blue circles. These high probability spots are similar to Figure 5.5 due to model constraints. Agriculture agents emerge within close proximity to corresponding house agents which emerge near existing settlements.

Table 5.14 Probability of agriculture agent occupation at repeated location

Percent	Pixels	sq.km
0	334683	33.468
1-10	138776	13.8776
11-20	11952	1.1952
21-30	4881	0.4881
31-40	3313	0.3313
41-49	2148	0.2148
50-56	1126	0.1126
57-62	563	0.0563
63-76	293	0.0293
77-90	0	0

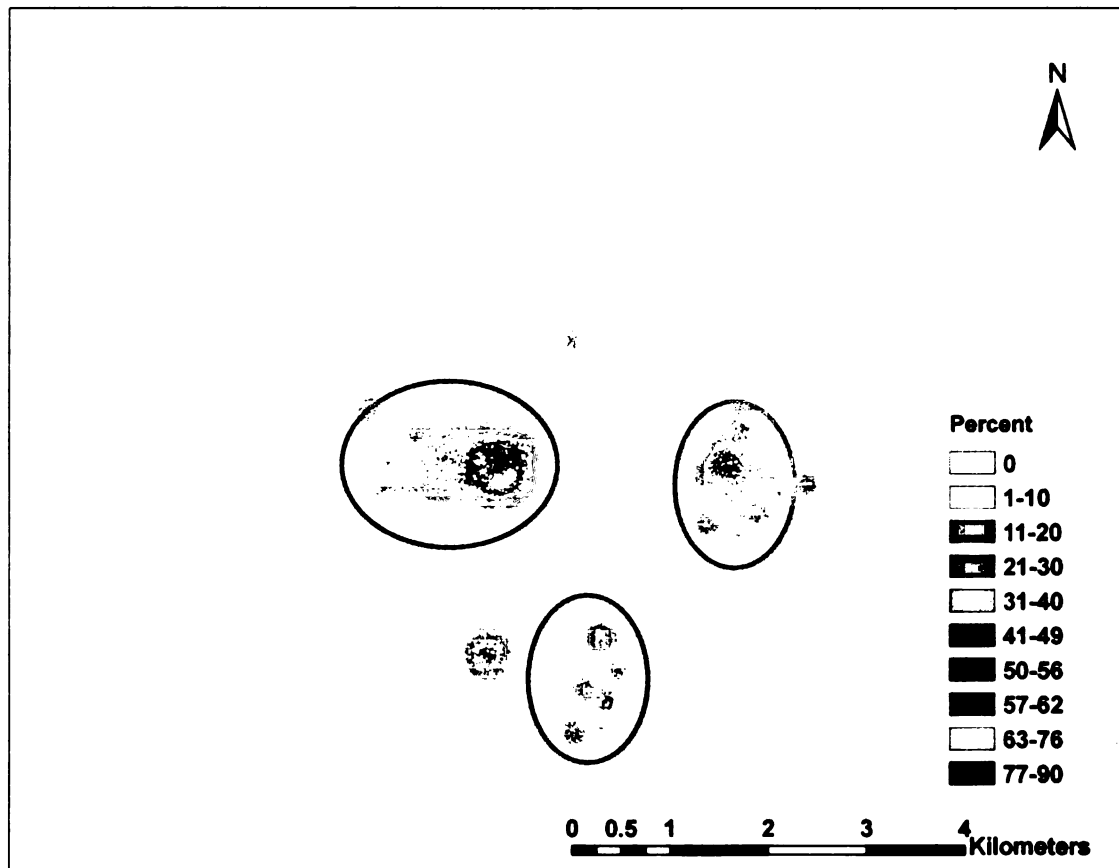


Figure 5.13 Probability map of repeated agricultural settlement under the urban simulation scenario

5.2.2.3 Cash-crops expansion scenario

The Land-use model (Figure 5.14) under the cash-crops expansion scenario shows house agents clumped nearby each other, but agriculture agents mainly occupy land suitable for rice agriculture (Figure 5.15). Table 5.15 shows 1 pixel settled 67 times. Forty seven percent of pixels (57,117 out of 120,578 pixels) or an area of 5.7 km² were settled once or twice at the outer core of the town approximately 1 km from the major highway. One percent of pixels were settled 41 to 67 times within 400 meters of major highway. The result suggests a high probability of settlement in the area nearby major roads and existing settlements. There is a lower probability potential of expansion outward to 1 km away from the major highway. This model is likely to capture the area where new settlement should occur within close proximity to town center and roads. It also suggests that the settlement occupied area suitable for rice farming especially lands on flood plains similar to the urban scenario results. This scenario is more likely to create problems associated with exhaustion of area suitable for agriculture especially for rice.

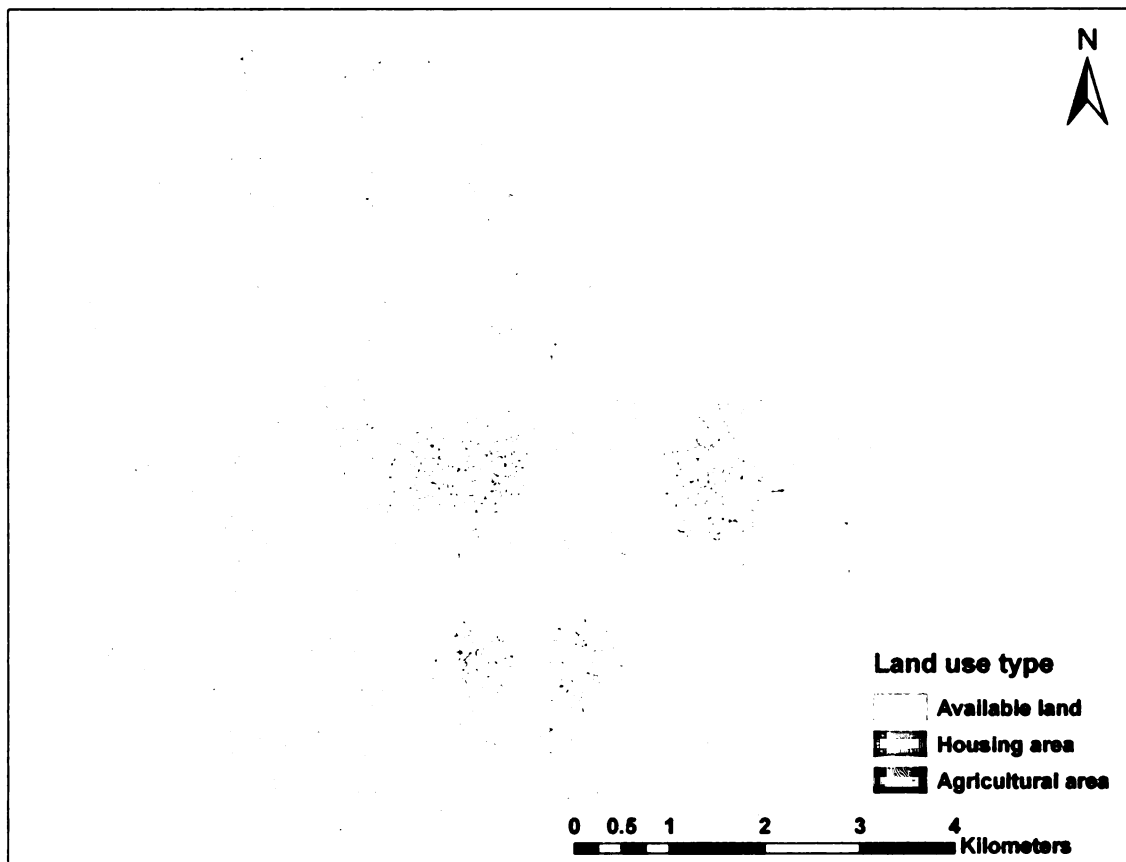


Figure 5.14 An example result from cash-crops simulation scenario

Table 5.15 Probability of house agent settled at repeated location

Percent	Pixels	sq.km.	Percent	Pixels	sq.km.
0	376043	37.6043	33	390	0.039
1	43305	4.3305	34	365	0.0365
2	13812	1.3812	35	349	0.0349
3	8766	0.8766	36	325	0.0325
4	6719	0.6719	37	323	0.0323
5	5501	0.5501	38	269	0.0269
6	4596	0.4596	39	232	0.0232
7	3895	0.3895	40	243	0.0243
8	3338	0.3338	41	216	0.0216
9	2883	0.2883	42	189	0.0189
10	2604	0.2604	43	206	0.0206
11	2158	0.2158	44	187	0.0187
12	1888	0.1888	45	143	0.0143
13	1689	0.1689	46	148	0.0148
14	1436	0.1436	47	142	0.0142
15	1300	0.13	48	111	0.0111
16	1245	0.1245	49	128	0.0128
17	1093	0.1093	50	92	0.0092
18	970	0.097	51	83	0.0083
19	949	0.0949	52	71	0.0071
20	879	0.0879	53	67	0.0067
21	818	0.0818	54	40	0.004
22	794	0.0794	55	42	0.0042
23	692	0.0692	56	22	0.0022
24	704	0.0704	57	22	0.0022
25	630	0.063	58	13	0.0013
26	557	0.0557	59	12	0.0012
27	597	0.0597	60	5	0.0005
28	508	0.0508	61	4	0.0004
29	485	0.0485	63	2	0.0002
30	501	0.0501	64	1	0.0001
31	429	0.0429	67	1	0.0001
32	394	0.0394	100	1114	0.1114

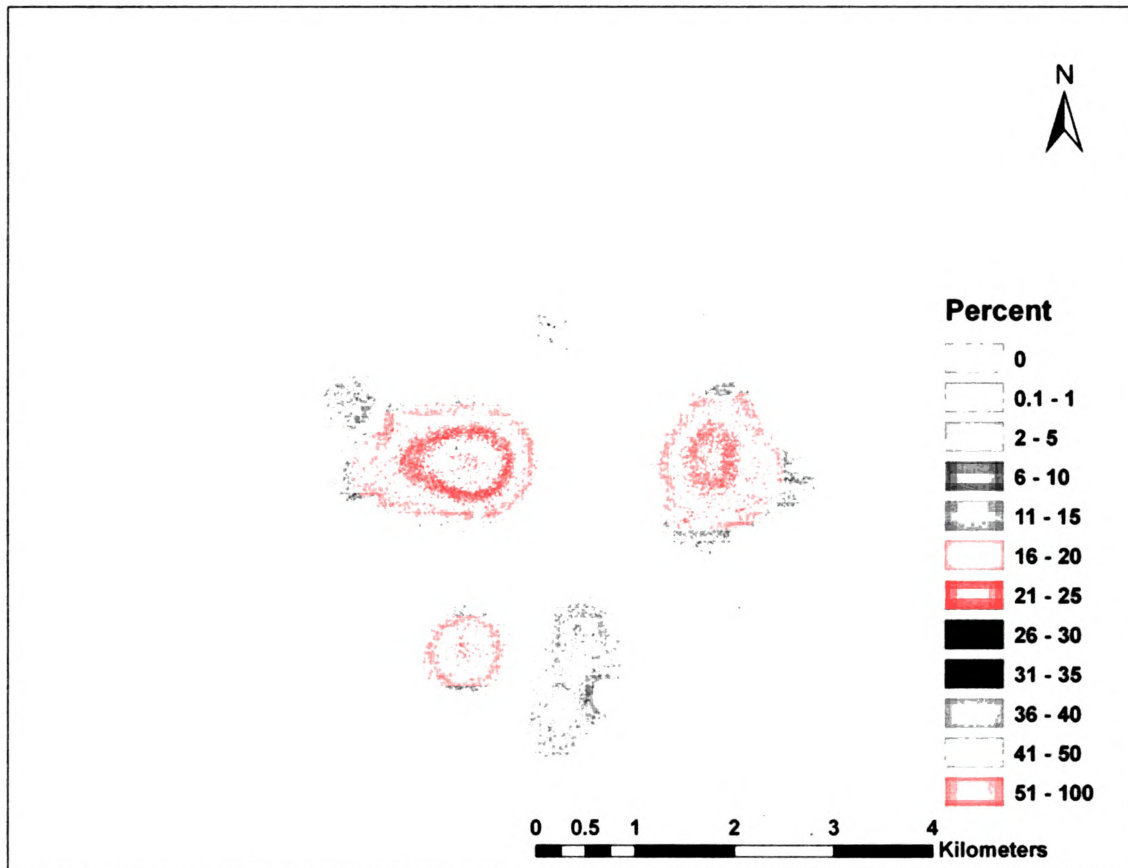


Figure 5.15 Probability map of repeated settlement under the cash-crop simulation scenario

This model simulated new agriculture agents emerging at a faster rate than housing development due to cash crop land conversions influenced by high demand for commercial crops from the world market. This model assumes that people will farm their land near their existing settlements first before finding further land for agriculture. The location rules for this scenario try to mimic the reality that land suitable for rice farming is usually taken first during the settlement processes. Agriculture agents were parameterized to occur 8 times faster than the urban scenario. The probability map from the Land-use model under the cash-crop expansion scenario is found in Figure 5.16. The result

(Table 5.16) shows one pixel settled 35 times. Only 0.15 percent of pixels (716 out of 493,364 pixels) or an area of 0.07 km² was occupied once or twice. Ten percent of pixels were occupied 1 to 6 times mostly on lands marginally suitable for rice farming. Eighty two percent were occupied 7 to 20 times on lands moderately to very highly suitable for rice farming. The number of repeated settlement sites for agriculture agents seemed to peak at 14 to 16 times and are found in the brown area (Figure 5.16), which is dominated by flood plains. 8 percent of the pixels were settled 22 to 35 times, also in the brown area. The shape of the brown region represents the area of land moderately to very highly suitable for rice farming (see e.g., Figure 5.3).

Figure 5.16 suggests a high probability of agriculture agents occupying areas suitable for rice farming rather than areas with lower quality soils and limited access to water. Even though the area in close proximity of Nang Rong town center is suitable for rice farming, the areas circled in blue have lower probability of agricultural settlement due to previous settlement and generally limited land availability. Therefore, people will travel further to find lands for agriculture. This model is likely to capture the areas in which new agriculture should occur, if the demands for cash-crop in the world market keep increasing. In addition, the model is likely to capture the potential changes within the areas suitable for rice farming.

Table 5.16 Probability of agriculture agent occupation at repeated location

Percent	Pixels	sq.km.
0	4371	0.4371
1	114	0.0114
2	602	0.0602
3	1893	0.1893
4	4414	0.4414
5	8407	0.8407
6	13301	1.3301
7	18373	1.8373
8	22479	2.2479
9	25592	2.5592
10	28379	2.8379
11	30997	3.0997
12	33666	3.3666
13	36631	3.6631
14	39280	3.928
15	39688	3.9688
16	39216	3.9216
17	35941	3.5941
18	31281	3.1281
19	25482	2.5482
20	19372	1.9372
21	14262	1.4262
22	9499	0.9499
23	6229	0.6229
24	3809	0.3809
25	2119	0.2119
26	1122	0.1122
27	645	0.0645
28	310	0.031
29	145	0.0145
30	68	0.0068
31	29	0.0029
32	12	0.0012
33	3	0.0003
34	3	0.0003
35	1	0.0001

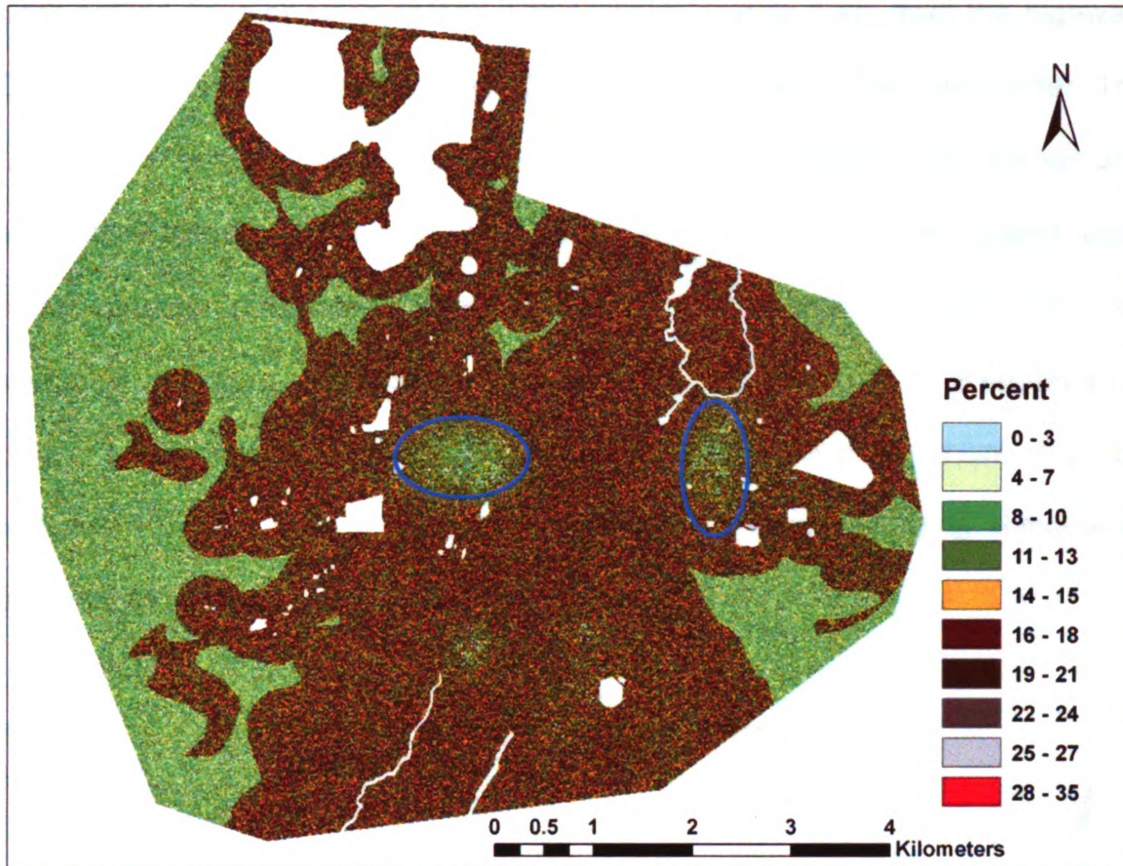


Figure 5.16 Probability map of repeated agricultural settlement under the cash-crop simulation scenario

5.2.2.4 The King's Theory scenario

The King's Theory scenario is a mixed land use per parcel scenario. Here, land parcel proportions of 4 land use classes including 3 rice farming pixels, 3 cash-crop pixels, 2 household ponds, and 1 housing pixel were simulated. A sample result from the Land-use model under the King's theory scenario is shown in Figure 5.17. The map shows a ring-shaped housing pattern due to the expansion from existing settlements rather than dispersive growth. The final probability map for settlement is in Figure 5.18. Table 5.17 shows 1 pixel was settled 30 times. Fifty four percent of pixels (158,842 out of 295,266 pixels) or an area of 16 km²

were settled once or twice spread within approximately 3 km from the highway. One percent of pixels were settled 10 to 30 times closer to the town center. The Land-use model under the King's theory scenario shows both house and agriculture agents distributed evenly across the study site. House agents were more sparsely distributed compared to both the urban and the cash-crop scenarios, but more clustered than the random scenario. Figure 5.18 shows a big cluster of predicted settlement circled in blue. The red circle shows that the settlement pattern may be inhibiting development close to existing settlements and bridging the gap between the two town cores.

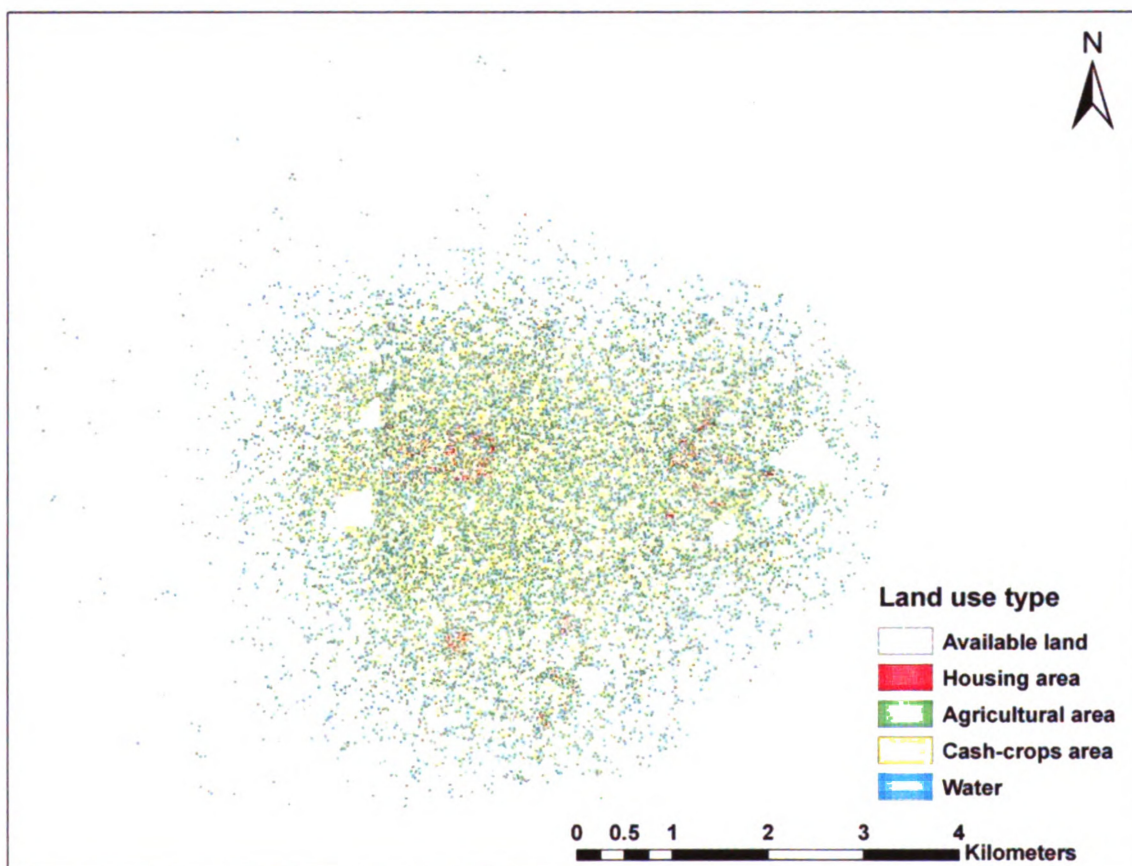


Figure 5.17 An example result from King's Theory simulation scenario

Table 5.17 Probability of house agent settled at repeated location

Percent	Pixels	sq.km.
0	201355	20.1355
1	96434	9.6434
2	62408	6.2408
3	47985	4.7985
4	35337	3.5337
5	22779	2.2779
6	13709	1.3709
7	7629	0.7629
8	4028	0.4028
9	2027	0.2027
10	1152	0.1152
11	641	0.0641
12	388	0.0388
13	277	0.0277
14	179	0.0179
15	94	0.0094
16	66	0.0066
17	46	0.0046
18	27	0.0027
19	19	0.0019
20	15	0.0015
21	11	0.0011
22	6	0.0006
23	2	0.0002
24	1	0.0001
26	3	0.0003
27	1	0.0001
29	1	0.0001
30	1	0.0001

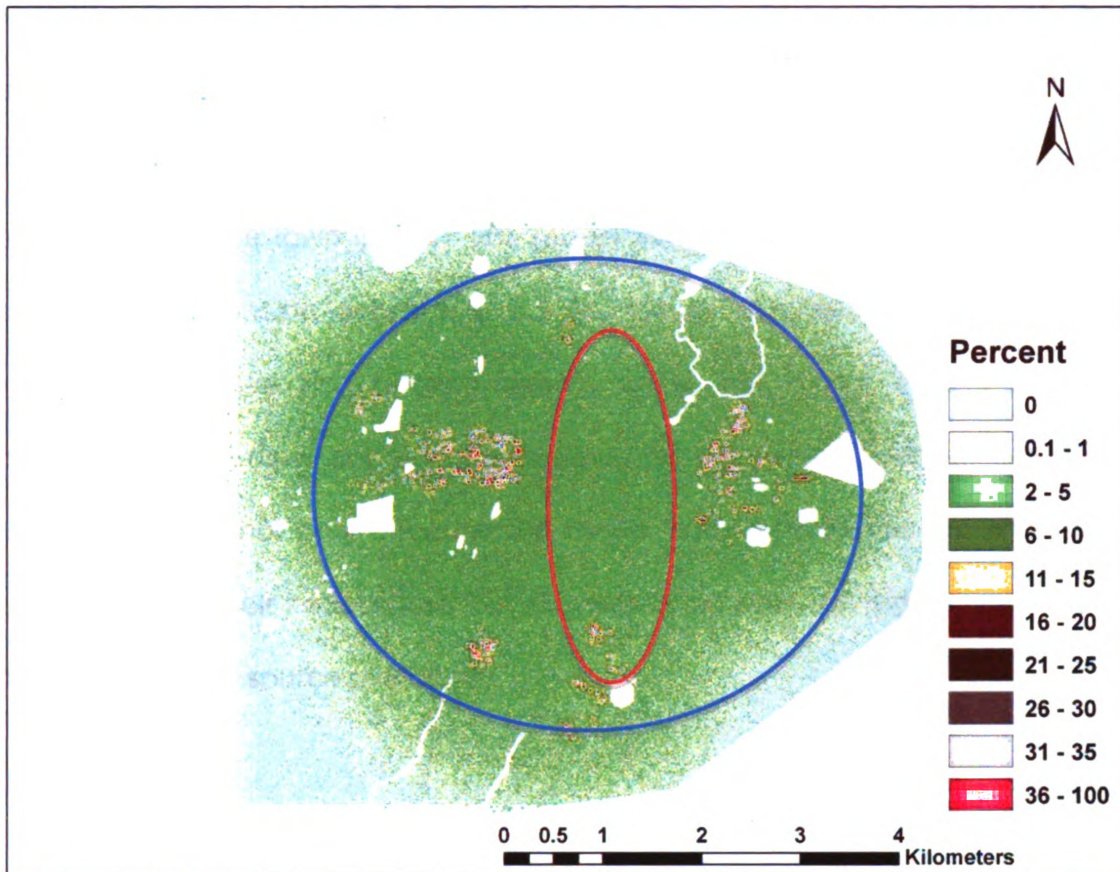


Figure 5.18 Probability map of repeated settlement under the King's Theory simulation scenario

Agriculture agents in the King's Theory scenario were categorized into: 1) rice farming and 2) cash crop agents. Both rice and cash-crop agents were simulated. The probability map for rice farming from the Land-use model under the King's Theory scenario is shown in Figure 5.19. The pattern here could not arise in any single realization but arise after combining 100 realizations. This map shows potential area for each land use class. Actual urban structure will differ. Table 5.18 shows only 1 pixel was settled the highest 39 times. Thirty percent of pixels (121,594 out of 399,255 pixels) or area of 12 km² were occupied once or twice and all of which were located at the outer ring of

simulation, approximately 3.5 kilometers from the urban center. Twenty two percent of pixels or area of 9 km² were occupied 11 to 20 times and closer to the town center. One percent of pixels were settled 21 to 39 times next to existing settlement near the town center. The model suggests that there is potential for rice farming expansion outward to 3.5 km away from the urban center. The results suggest that rice farming agents under the King's Theory scenario occupied less marginal and unsuitable lands for agriculture than the cash-crop scenario. This is not only because the model constraint farmers to plant their agriculture near their houses first, but also the mixed land use scenario promotes improving water resource availability.

Table 5.18 Probability of rice agent occupation at repeated location

Percent	Pixels	sq.km.	Percent	Pixels	sq.km.
0	98510	9.851	20	1820	0.182
1	76377	7.6377	21	1179	0.1179
2	45217	4.5217	22	809	0.0809
3	30329	3.0329	23	557	0.0557
4	24954	2.4954	24	324	0.0324
5	22941	2.2941	25	275	0.0275
6	22021	2.2021	26	165	0.0165
7	21717	2.1717	27	106	0.0106
8	21202	2.1202	28	90	0.009
9	20692	2.0692	29	56	0.0056
10	19780	1.978	30	41	0.0041
11	18259	1.8259	31	23	0.0023
12	16568	1.6568	32	11	0.0011
13	14364	1.4364	33	6	0.0006
14	11519	1.1519	34	3	0.0003
15	9143	0.9143	35	2	0.0002
16	7045	0.7045	36	1	0.0001
17	5253	0.5253	37	1	0.0001
18	3676	0.3676	38	2	0.0002
19	2696	0.2696	39	1	0.0001

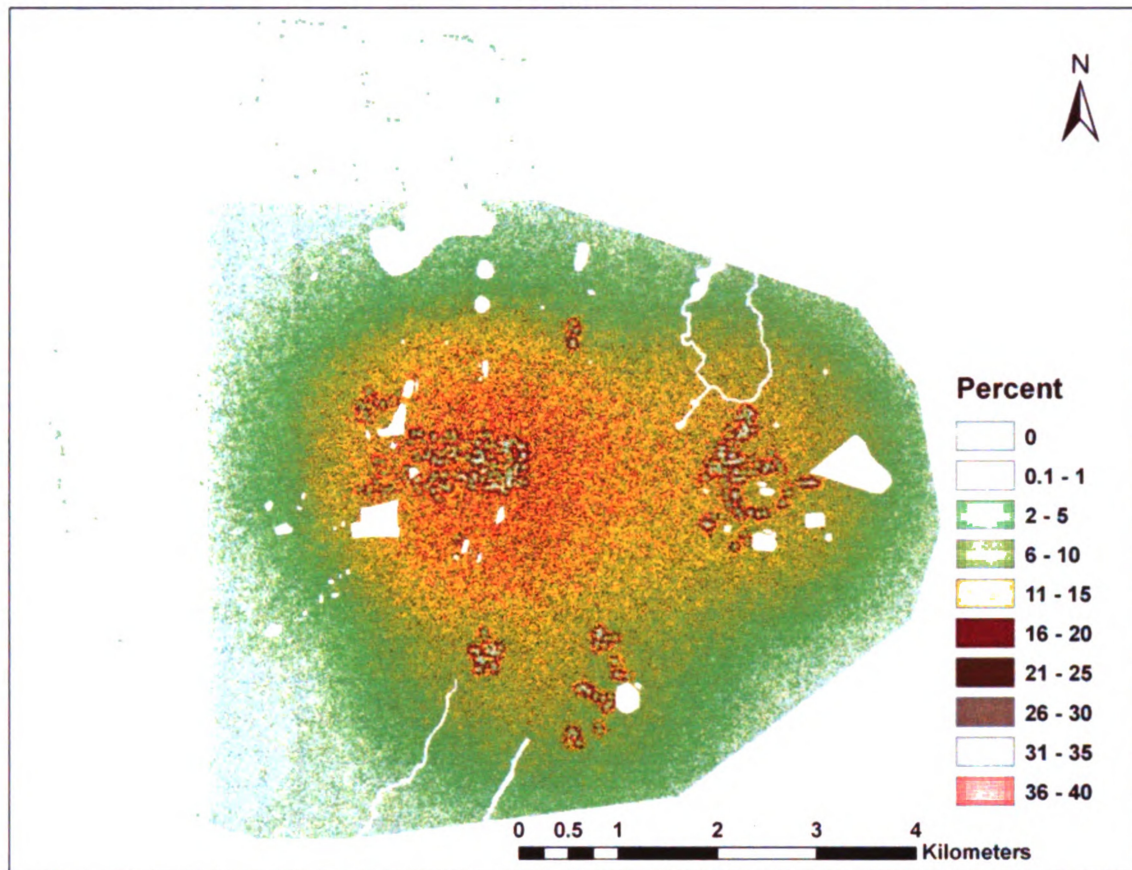


Figure 5.19 Probability map of repeated rice farming under the King's Theory simulation scenario

The probability map for cash-crop farming for the Land-use model under the King's theory scenario is shown in Figure 5.20. Table 5.19 shows that 1 pixel was occupied 30 times, the highest number. Thirty percent of pixels (115,463 out of 387,618 pixels) or an area of 11.5 km² were occupied once or twice and located at the outer ring of simulation approximately 3.5 kilometers from the urban center. One percent of pixels were settled 19 to 30 times and were located near the town center. The results suggest that cash-crop agents under the King's Theory scenario occupied less marginal and unsuitable lands for agriculture than the cash-crop scenario.

Table 5.19 Probability of cash-crop agent occupation at repeated location

Percent	Pixels	sq.km.
0	110117	11.0117
1	74227	7.4227
2	41236	4.1236
3	29196	2.9196
4	24462	2.4462
5	22879	2.2879
6	22105	2.2105
7	22074	2.2074
8	21574	2.1574
9	21147	2.1147
10	20379	2.0379
11	18918	1.8918
12	16730	1.673
13	14118	1.4118
14	11658	1.1658
15	8866	0.8866
16	6376	0.6376
17	4396	0.4396
18	2966	0.2966
19	1859	0.1859
20	1097	0.1097
21	679	0.0679
22	331	0.0331
23	180	0.018
24	85	0.0085
25	50	0.005
26	15	0.0015
27	12	0.0012
28	2	0.0002
30	1	0.0001

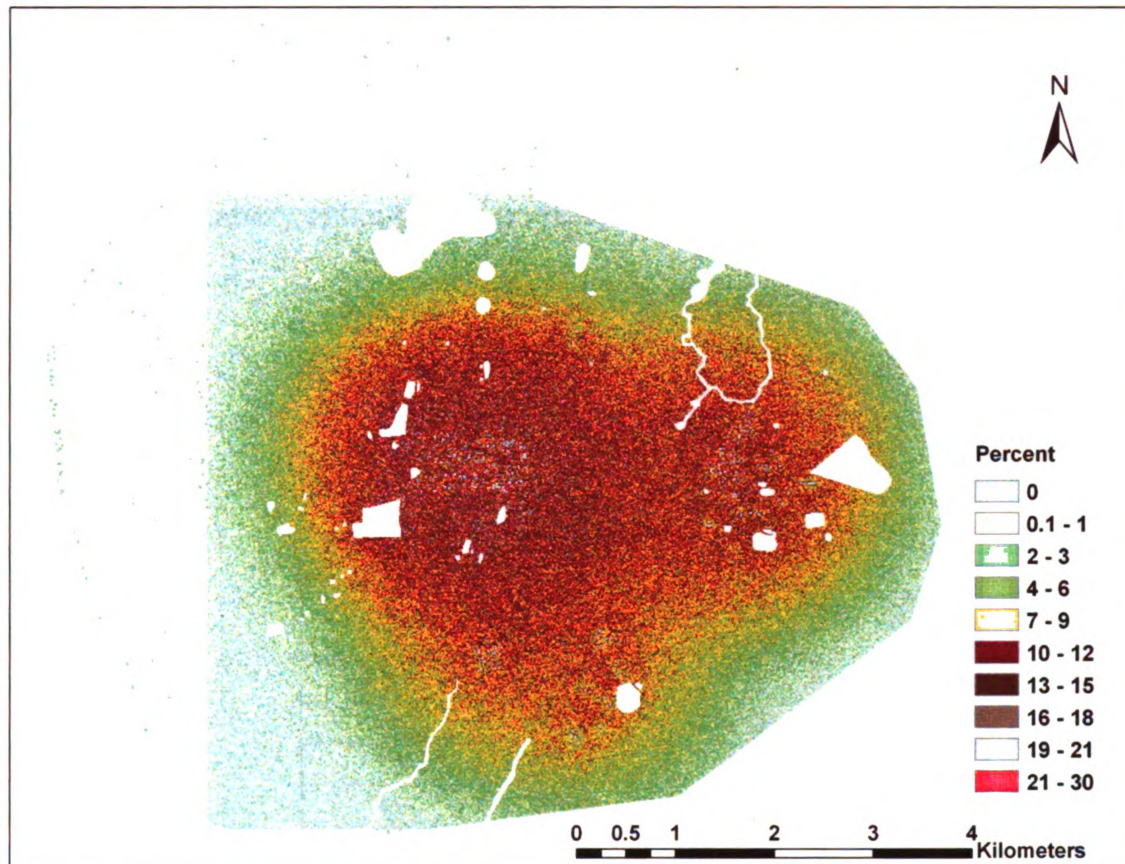


Figure 5.20 Probability map of repeated cash-crop farming under the King's Theory simulation scenario

The result from the Land-use model under the King's Theory scenario yields a probability map for household ponds (Figure 5.21). The result (Table 5.20) shows 1 pixel occupied 28 times. Thirty six percent of pixels (127,552 out of 358,679 pixels) or area of 12.7 km² were occupied once or twice and were located at the outer ring of simulation approximately 3.5 kilometers from the major highway. Roughly one percent of all pixels were settled 15 to 28 times and were located at the inner ring of simulation and near the town center. The King's Theory seemed to provide better access to water for people live within 3.5 km from the town

center and agricultural lands than current used of available seasonal water surface.

Table 5.20 Probability of household pond agent occupation at repeated location

Percent	Pixels	sq.km.
0	139056	13.9056
1	80961	8.0961
2	46591	4.6591
3	36609	3.6609
4	33351	3.3351
5	31487	3.1487
6	28660	2.866
7	25418	2.5418
8	21723	2.1723
9	16988	1.6988
10	12541	1.2541
11	8864	0.8864
12	5868	0.5868
13	3783	0.3783
14	2388	0.2388
15	1433	0.1433
16	871	0.0871
17	454	0.0454
18	286	0.0286
19	190	0.019
20	94	0.0094
21	57	0.0057
22	27	0.0027
23	18	0.0018
24	9	0.0009
25	6	0.0006
27	1	0.0001
28	1	0.0001

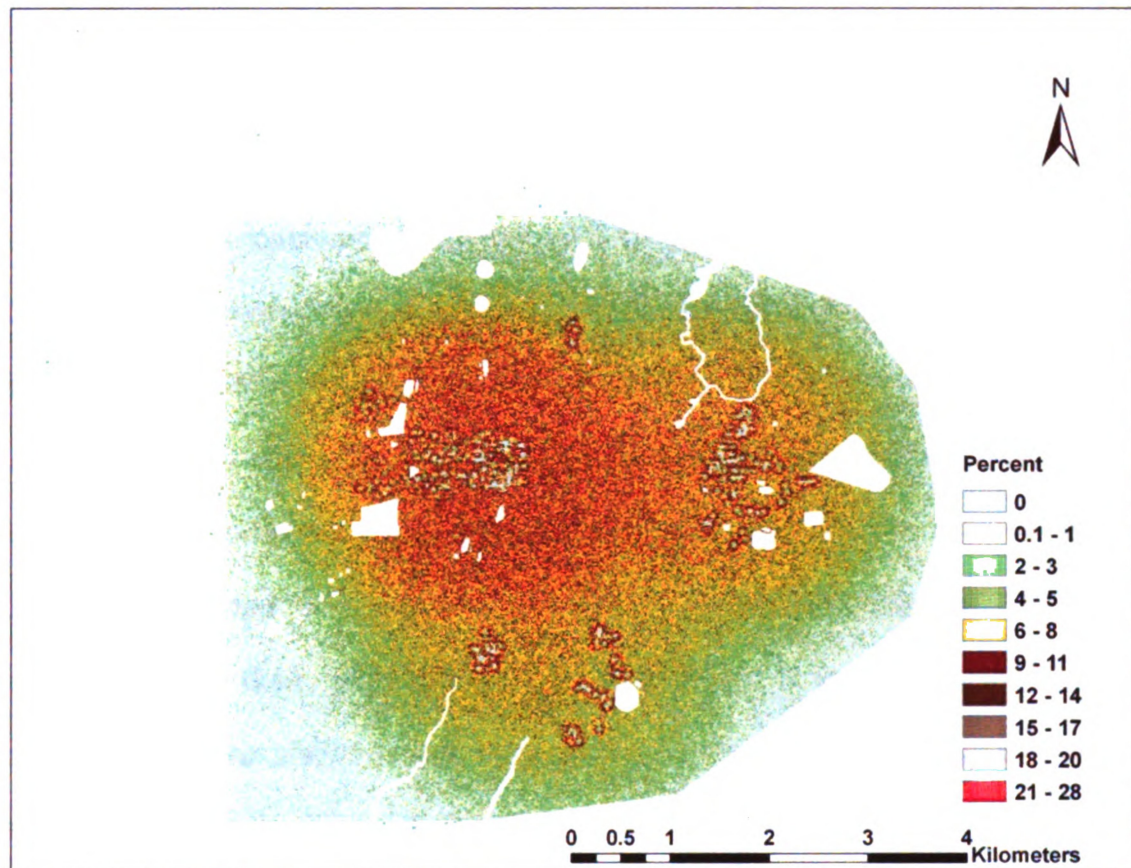


Figure 5.21 Probability map of household ponds under the King's Theory simulation scenario

5.3 Landscape Pattern Metrics

Landscape pattern metrics were used to explore quantitatively for each realization including: Contagion (CONTAG) and Interspersion and Juxtaposition (IJI) indexes. 100 Arc Grid raster layers under the cash-crop and the King's Theory simulation scenarios were imported into the Fragstats and calculated using the 8 cell rule and Landscape Metric Output Statistics. These two scenarios are different; number of classes (pond pixels) but also represent the most appropriate pair for comparison. Direct comparison of pattern metrics is not

typical when the numbers of classes are different, but in this case is the best method for expressing the landscape level differences between the two scenarios. The result (Table 5.21) shows average of both CONTAG and IJI indexes under the cash-crop scenario were lower than under the King's Theory. CONTAG index shows that under the cash-crop scenario, adjacent cells seem to be a little more different type than under the King's Theory. A single class under the King's Theory scenario occupied larger percentage of landscape than under the cash-crop scenario. Same class under the King's Theory seems to be spatially aggregated or clumped. Figure 5.22 shows distribution of CONTAG index of 100 Arc Grid raster layers under the cash-crop and the King's Theory scenarios. IJI index shows higher value under the King's Theory. This means all patch types under the King's Theory was more equally adjacent to all other patch types than under the cash-crop scenario. Figure 5.23 shows distribution of IJI index of 100 Arc Grid raster layers for both scenarios. IJI is based on patch adjacencies, not cell adjacencies like CONTAG (McGarigal et al, 2002).

Table 5.21 four of the LES one has been used in Average of CONTAG and IJI indexes

	Cash-crop	King's Theory
CONTAG	55.28	61.76
IJI	36.8	78.39

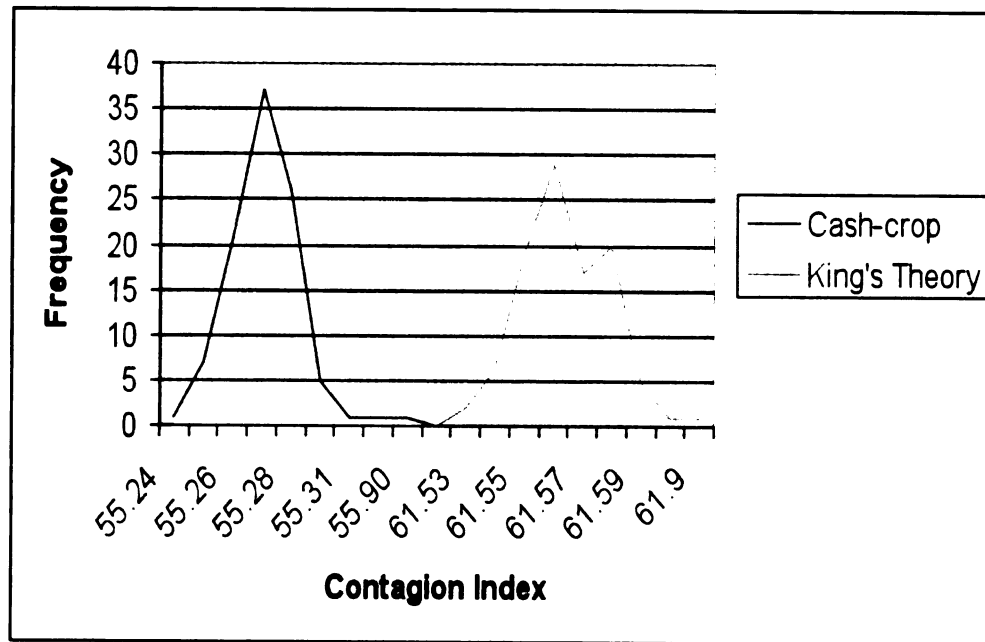


Figure 5.22 Distribution of CONTAG index

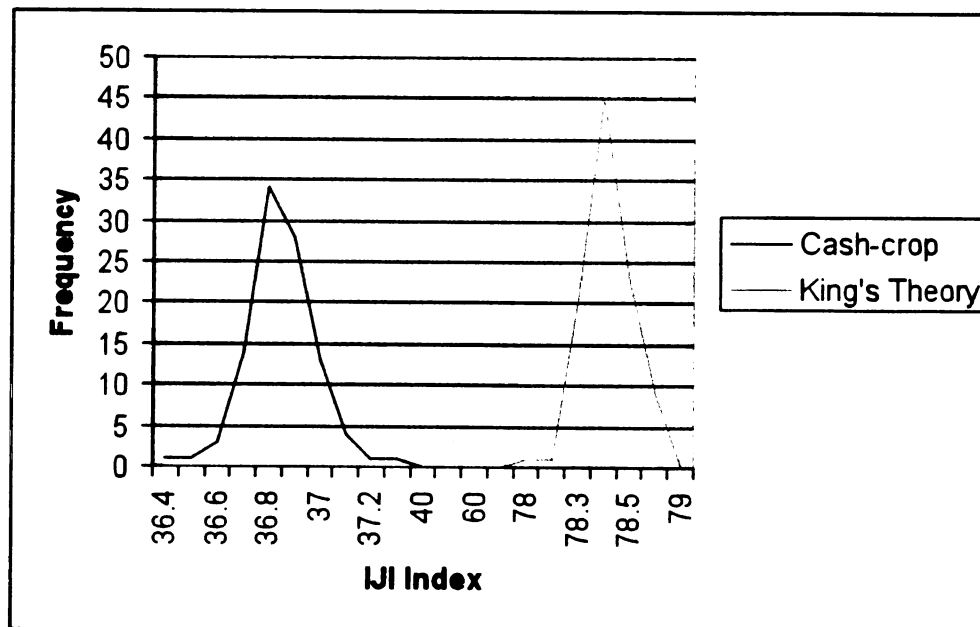


Figure 5.23 Distribution of IJI index

CHAPTER 6

CONCLUSIONS

Under globalization contexts, the expansion of the free market economy has resulted in a more competitive and complex system for land use in Thailand. Over the past 30 years, the expansion and extensification of commercial agricultural land use in many rural towns across Thailand occurred as a direct result of increasing domestic and international demand for upland field crops. With frequent and often reverse migratory patterns, rural towns function in the context of often declining population densities combined with increasing urbanization and transformation of adjacent natural and agricultural lands. The study site, Nang Rong town, has experienced rapid land use and demographic changes often moving in uncorrelated and unsustainable trajectories.

The ability to link the process of land use change to biophysical processes and feedbacks and to model decision-making process is important in land use studies. The models in this research emphasize spatial patterns and location of change rather than predicting the rate of change. The models offer the possibility to test the sensitivity of land use patterns to different strategies of resource allocation and land management scenarios. In general, urban models focus on land or infrastructure units such as land parcels, land use, and land cover (Benenson and Torrens, 2005). This research provides an interesting case of modeling at household level. The models focus on human actions and agent behaviors.

To better understand the complex interactions between people and land use/land cover change, two Agent Based models were built to link population and environment data and to predict the patterns of urban growth with particular reference to Nang Rong town, Thailand. Base data included Thai government maps, aerial photography and satellite imagery. Using selected GIS layers including water availability, nutrient availability, landform, soil texture, and soil salinity, land suitability maps for rice farming maps were created. Field research was conducted for one month during each summer in 2004 and 2006. A collection of over 150 Thai government cadastral maps, zones, and the corresponding property ownership data for each address in the cadastral maps were collected and used during the spatial data development process. Road networks, buildings and agricultural farming from the respective 1967 and 1994 aerial photos were digitized and attributed. The property ownership records and cadastral maps zones were used to determine the building locations and year built. Road network and building layers were created and converted to raster format for ABMs inputs. Agent Based Models were created using the NETLOGO program with the GIS extension. Two specific models were built: 1) Settlement Model and 2) Land-use model. A Monte Carlo simulation of one hundred iterations per scenario was run, combined, and compared allowing us to map probabilities.

The hypothesized drivers of landscape change in Nang Rong are organic urban expansion, diffusive or dispersive growth, and accessibility. Organic growth

describes the spreading outward of settlements from existing urban centers and essentially represents the tendency of cities to expand. The second type, diffusive or dispersive growth, promotes the random dispersed development of urban centers regardless of a fixed proximity function (Clarke et al., 1996). This type of growth simulates the settlement of a region based upon change drivers like unoccupied land. The third driver of landscape change in the study region is transportation and accessibility influenced growth. Access-based development encourages anthropomorphized cells to manifest along the transportation network and in close proximity to the central city and other nodal communities. The development of rules defining the network effect focuses on the social surveys, fieldwork validation of travel surfaces, and image interpretation. For this research, all 3 types of growth rules were used. Type 1 (organic) and type 2 (dispersive) were applied in the Land-use models. Type 3 (access development) was applied in the Settlement model. In addition, properties and behavioral rules were assigned to each type of land use agent set and used as basic building block. These parameterizations of behavior and system rules were derived from the data collections and literature reviews. The two ABMs were used to explore the basic characteristics and activities of the system within the context of sustainability.

The first hypothesis explored the notion that primary drivers of landscape change in Nang Rong town are endogenous physical characteristics such as road accessibility, previous settlement patterns and organic urban expansion. These

factors modify the nature and rate of urban change expressed as expansion, retraction, or morphology in Nang Rong town. Current development takes place haphazardly and often sprawls over the best quality agriculture lands and/or lands not suitable for housing. LULC conversion process is a land cost that affects the stability between social and ecological systems. Over the past half-century, human settlement and agricultural activities have encouraged deforestation in Nang Rong (Entwisle et al., 2008). Frontier settlers moved into the region and converted available land to agriculture for minimal cost. With rapid population growth during recent decades, the built environment in Nang Rong town rapidly increased (NRMO, 2003; NRMO, 2006). These developments have affected on land availability and reduced the available quantity of good quality agricultural land. Housing expansion with concomitant declining population densities reduced overall resource use efficiency per capita (Entwisle et al., 2005). The increasing numbers of independent households also has implications for LULC conversion to cash-crop farming. With limited land availability, land prices and ultimately value of agricultural land rents must rise (Brueckner, 2000). These increasing rents promoted the conversion of land from agriculture to urban uses. In addition, the improvement of general accessibility created increasing urban land rents. Consequently, these costs of land uses influenced landowners in the decision making process.

These urban and road expansions are more likely to create problems associated with exhaustion of area suitable for agriculture especially for rice. Land suitability for rice farming was analyzed and the Settlement model was created to test this

first hypothesis. From aerial images, the number of buildings increased almost 9 times between 1967 and 1994. The majority of this expansion, or approximately a rate 7 times that of other suitability classes, occurred on lands suitable for rice farming. Many small-scale farmers sold their respective lands to investors, which were subsequently converted into urban land covers. Much of the urban expansion in land suitable for rice farming has occurred along lands adjacent to roads. This urban expansion is likely to be unsustainable as it replaces areas suitable for rice agriculture with low density residential sprawl.

Access-based development encourages anthropomorphized cells to manifest along the transportation network and in close proximity to the central city, Nang Rong town, and just as likely other nodal communities. The Settlement model which takes into account road accessibility and previous settlement patterns, predicted the probability of repeated settlement. Distances to road network were used to investigate deeper underlying driving forces such as price of urban land use. In comparison with the digitized aerial imagery, the Settlement model captured 63 percent of the total urban area in 1994. The majority of buildings matched were inside the urban core and along the road network. This model and parameter set were used to predict settlement in 2021, based on the assumption of a constant expansion rate. The results show that the settlement will continue to expand along some corridors and begin to bridge the gaps between villages. The model appears to capture transitional areas where new development is likely to take place. The results suggest that if the simulated settlement pattern,

assuming a high level of accessibility, and close to previous settlement, continues, there is a high probability that development will sprawl onto lands suitable for agriculture, especially for rice. The highest to moderate quality rice cultivatable land under this scenario will likely be reduced by 12.7 km² or 24 percent of the total area. If these scenarios are repeated in every town across the region, shortages in land and natural resources may arise causing regional instability.

The second hypothesis explored the notion that multiple stakeholders interacting through endogenous and exogenous processes are the drivers of landscape change in Nang Rong town. Endogenous physical characteristics that support rice agriculture such as water accessibility and soil quality modify the nature and rate of urban change. Exogenous factors such as crop prices in world markets and labor markets modify the nature and rate of urban change. The Land-use ABM was created to test the second hypothesis. Three scenarios were explored including 1) random, 2) urban expansion, and 3) cash-crop expansion. The Land-use model under the random scenario shows that both house and agriculture agents disperse randomly, predictably so, over the study site. The model predicted house agents would occupy 41 km² of the area in 2021. 29 km² or 71 percent of total predicted areas were on lands suitable for rice farming (Table 6.1). The model predicted agriculture agents occupying land 42.6 km². 30.9 km² or 73 percent of total predicted areas were on lands suitable for rice farming. The result shows a very low probability of repeated settlement under the random

scenario. This scenario does not effectively capture the potential locations for new settlement.

The Land-use model under the urban expansion scenario applies organic growth theory and endogenous physical characteristics including soil quality, water accessibility, elevation, and distance to road. The model predicted house agents would occupy 13.8 km² of the area in 2021. 13.5 km² or 98 percent of total predicted areas were on lands suitable for rice farming (Table 6.1). The model predicted agriculture agents would occupy 16.4 km². 16.2 km² or 99 percent of total predicted areas were on lands suitable for rice farming. Both house and agriculture agents preferentially occupied very highly and highly suitable lands for rice farming. Both house and agriculture agents were clustered compared to the random scenario. This model is likely to capture the area that new settlements occupy in close proximity to the town center and roads, even if the area is suitable for rice farming or is on a flood plain. This can be inferred that endogenous factors modify the nature of urban form and LULCC. If this scenario continues with an absence of a centralized urban planning framework, development will sprawl over the best quality agriculture lands and/or lands not suitable for housing. This urban expansion is more likely to create problems associated with exhaustion of area suitable for rice agriculture especially and increase the population risks associated with severe flood events.

The Land-use model under the cash-crop expansion scenario takes into account the organic growth theory, endogenous factors, and adds interactions between endogenous and exogenous processes. In this scenario, agriculture agents emerged at a faster rate than settlement agents due to cash crop land conversion influenced by high demand for cash-crops in the world market. The model predicted house agents occupying 12.3 km² of land. 97 percent of this area was on lands suitable for rice farming (Table 6.1). The probability maps show that if this settlement pattern is repeated, there is a high probability of urban area expansion in close proximity to Nang Rong town center, even though much of the high probability area is on flood plains and other areas suitable for agriculture and unsuitable for urban expansion. This scenario is more likely to create problems associated with exhaustion of area suitable for agriculture especially for rice and the flooding mentioned previously. The model predicted agriculture agents would occupy 49.8 km² of the area in 2021. 35.6 km² or 71 percent of total predicted areas were on lands suitable for rice farming. Much of this land is likely to be converted to cash-crop fields. Agriculture agents were more widely dispersed across lands suitable for rice farming. In this scenario, people tended to travel further away from the Nang Rong town centers and roads to find agricultural land. This model is likely to capture the area that new agriculture will occur, if the demands for cash-crops in the world market continue to increase. It can thus be inferred that exogenous factor such as world market demands for cash-crops modify the nature of urban form and LULCC. If this scenario continues, the area suitable for rice agriculture will be depleted or may

not even be available for rice farming creating scenarios of land misallocation in Nang Rong town.

The third hypothesis explored the notion that to create sustainable development in the Nang Rong context, one must consider maintaining equity. Given different sets of schemes, the Sufficiency Economy theory proposed by the King of Thailand focuses on providing equitable access to natural resources including water and fertile soils. The concept attempts to equally distribute natural resources and promote individual and community sustainability. New Theory farming is one step on the sustainable development path promoted by the Sufficiency Economy. The most important concept of New Theory farming is mixed uses of land and effective allocation of land to serve the different needs of farm households. The area allocated to each kind of land use can be flexible, according to local resources.

The Land-use model under the King's Theory scenario combines the organic growth theory, interactions between endogenous and exogenous processes as well as the mixed land use model. The Land parcel combination included 4 land use classes of which there were 3 rice farming pixels, 3 cash-crop pixels, 2 household pond pixels, and 1 housing pixel. The model predicted house agents would occupy 30 km² of the area in 2021. 85 percent of total predicted areas were on lands suitable for rice farming (Table 6.1). The model predicted rice farming agents would occupy 40 km². 80 percent of total predicted areas were

on lands suitable for rice farming. The model predicted cash-crop agents would occupy 39.2 km². 79 percent of total predicted areas were on lands suitable for rice farming. Finally, the model predicted household pond agents would occupy 35.5 km². 81 percent of total predicted areas were on lands suitable for rice farming. Under this scenario, agriculture agents were separated into rice and cash-crop agents. The results show that rice and cash crop agents occupied land at similar locations within approximately 3.5 kilometers from urban centers. Therefore, one can be used as a representative of agriculture agent to compare with the cash-crop scenario. In this case, rice agents occupied 32 km² of lands suitable for agriculture. This means that 80 percent of simulated rice agents occupied lands suitable for rice farming. On the other hand, 71 percent of agriculture agents occupied land suitable for rice farming under the cash-crops scenario. The result and table 6.1 suggest that agriculture agents under the cash-crop scenario occupied more marginal and unsuitable lands for agriculture creating scenarios of land misallocation than the King's Theory scenario. In addition, the King's Theory scenario provided more access to water than other scenarios and the current situation. The water accessible area will cover at least 35.5 km² or 81 percent on suitable land and 19 percent on land unsuitable for agriculture. In contrast, other scenarios only used available seasonal surface water and there were only 22 permanent dams on streams and wells for irrigation built between 1965 and 1994 (Figure 3.6). The results from the water suitability analysis show that only an area of 27 km² was located within 300 meters from water resource. Therefore, the King's Theory seemed to provide much better

access to water for Nang Rong people who live close to both of the town centers and outlying agricultural lands than the current available water sources. This can be inferred that small-scale farmers who live further from Nang Rong town may have more equitable access to water resources. The Sufficient Economy could be considered a better path for land allocation and as an alternative development strategy for Nang Rong town.

Table 6.1 Percentage of each Land use agent occupying land in 1994 under each rice farming suitability category under 4 different scenarios

Suitability	Random		Urban		Cash-crop		King's Theory			
	House	Agriculture	House	Agriculture	House	Agriculture	House	Rice	Cash-crop	Water
1. Very high	22	23	39	41	35	22	30	26	26	28
2. High	26	27	43	45	42	26	32	30	29	29
3. Moderate	23	23	16	13	20	23	23	24	24	24
4. Marginal	19	18	1	0.5	2	19	11	15	15	14
5. Unsuitable	10	9	1	0.5	1	10	4	5	6	5
6. Total percentage 1-3	71	73	98	99	97	71	85	80	79	81

The agricultural areas digitized from the 1994 data (29.29 km²) were compared with the predicted agricultural areas and summarized using the Thematic Raster Summary by Polygon Tool within Hawth's Tools. Table 6.2 shows the actual area of agricultural land in 1994 and predicted agricultural occupation under each scenario. The model under the cash-crop scenario predicted agriculture agents would occupy 49.8 km² of the area in 1994. 29.27 km² of predicted land were co-located with actual agricultural area in 1994. The model seemed to capture agricultural areas on flood plains highlighted in blue and extending through areas suitable for rice farming (figure 6.1). To compare with the results from the Land-use model under the cash-crop scenario, one agriculture agent type under the King's Theory scenario was selected. The model under the King's Theory scenario predicted a potential agricultural area of 20.59 km² co-located with the actual agricultural area in 1994. The model under the King's Theory seemed to capture agricultural area on flood plains highlighted in blue circle 1 (figure 6.2). However, this scenario seems to be a better option than the cash-crop scenario and the current situation for several reasons. First, people do not have to travel as far from town center and existing roads to find available land for commercial agriculture. The results from the Land-use model under the King's Theory scenario show that rice farming agents occupied lands approximately within 3.5 kilometers from urban centers, while the agriculture agents under the cash-crop scenario occupied lands out to 5 km from urban centers. People can live close to town and their community under the King's Theory scenario and the areas outside the red circle are still available for next generations.

The findings are transferable. If cassava or global cash crops are not important and something else becomes more important, people still have other land types to select. Under the King's Theory, people only need to produce foods and other products limited to the level adequate for family consumption not for large-scale commercial activities. They can live within their means and independently from global trends. This advances the idea of production not just for profit maximization but also for sustainable development for the individual, the household, and the larger community. Second, the King's Theory model promotes the idea of limited production for the purpose of saving the environment and conserving scarce resources especially soil and water. The circle 2 (figure 6.2) shows that area suitable for rice farming and land on flood plains are still available to next generations compared to the cash-crop scenario and the current land use patterns.

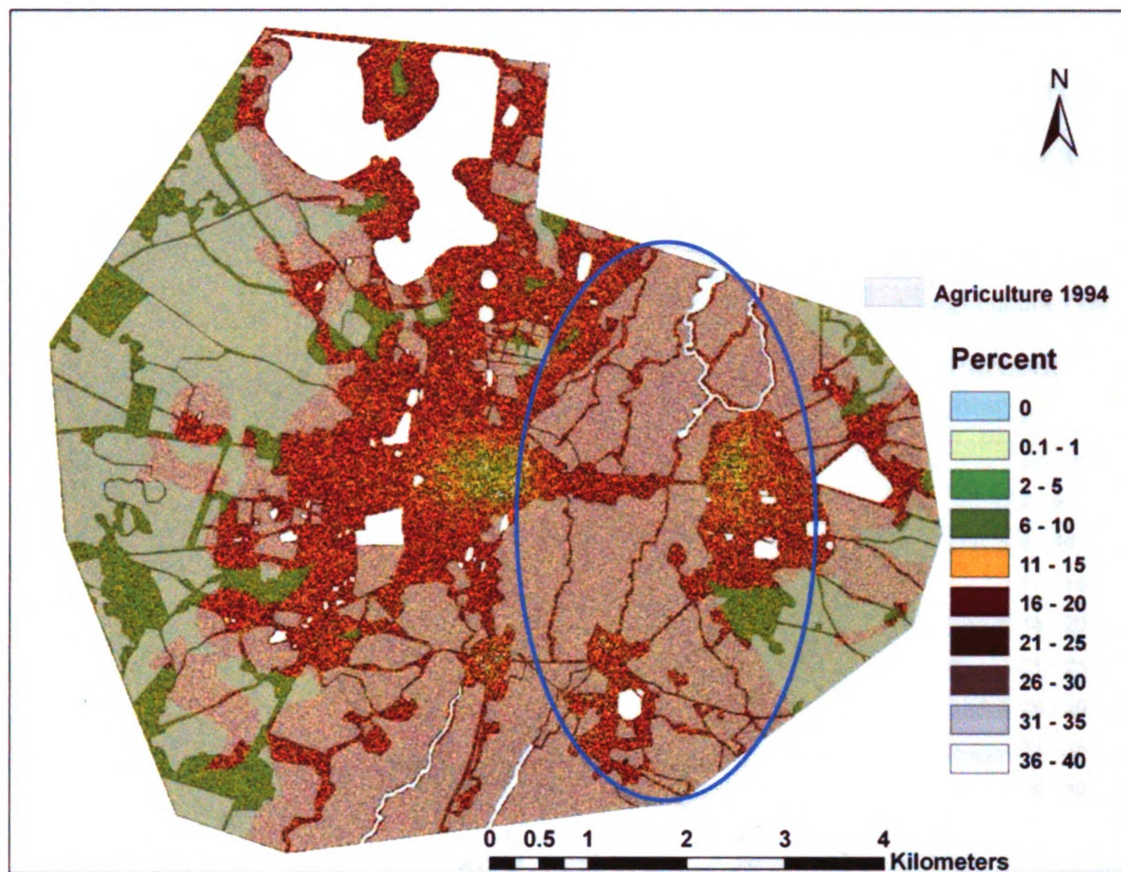


Figure 6.1 Co-location areas between agriculture in 1994 and predicted agriculture under the cash-crop scenario. Agriculture in 1994 was represented in gray on top of probability map of repeated agricultural settlement represented in percent.

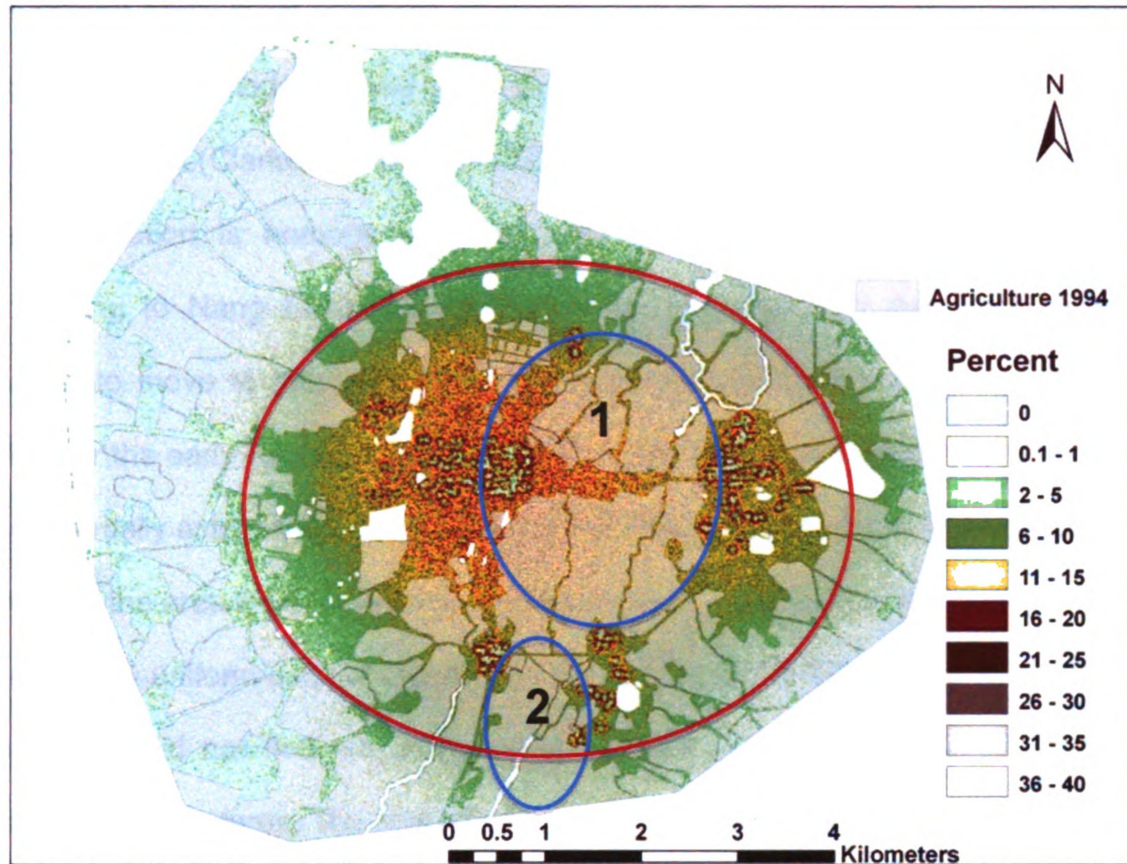


Figure 6.2 Co-location areas between agriculture in 1994 and predicted agriculture under the King's Theory scenario. Agriculture in 1994 was represented in gray on top of probability map of repeated agricultural settlement represented in percent.

Table 6.2 Area of agriculture agents occupying repeated locations compared to digitized agriculture

Scenario	Co-location with actual agriculture	Mismatch area
Random	25.01	17.6
Urban	8.1	4.2
Cash-crop	29.27	20.53
King's theory	20.59	19.81

In addition, process-based and statistical models were used as complementary in this research. The Monte Carlo simulations produced useful images of potential

urban and agricultural locations and were coupled with the variance estimates. Monte Carlo methods allowed clear confidence limits to be placed on predicted urban patterns (Clarke and Gaydos, 1998). However, the models do assume that the population is homogenous and making the similar sorts of decisions. According to Nang Rong district documents, it is believed that Thai people started to move to this area many centuries ago during the Sukhothai (1238-1438) or the early Ayutthaya period (1350 – 1767) and that Nang Rong town was then formally established as a regional administrative center. The previous ethnic group in the area including Khmer and Mon-Khmer were mixed with Thai creating a generally uniform cultural identity (NRDO, 2006). From field work and literature reviews, I did not find any marginalized groups outside the legal and formal community structures. The majority of population (95 percent) was in agriculture sector (NRDO, 2006). The population seemed to behave similarly to each other within Nang Rong town.

In order to understand the structure within the Monte Carlo simulations, quantitative measurement and summary statistics for each realization were generated using Contagion and IJI indexes. The King's Theory farm size and mixed land use scenario affect the results. Differences in the number of pixels for each class influence on the number of patches. The results from Landscape Pattern Metrics confirmed that the King's Theory promotes intermixing of patch types and might increase level of water accessibility to other patch types.

Therefore, households and agriculture lands in Nang Rong town can have more equitable access to water resource.

The King's Theory scenario adapted in Thailand attempts to minimize population impacts and preserve water and soil quality, as well as preserve remaining forests. Land can be reallocated to specific land use types based on suitability. Waste discharges can be converted into environmentally useful or ecologically neutral materials. Natural resources are used more effectively, and excess production beyond the needs of the household can be redistributed (RDPB, 2004). Many farmers in Nang Rong adopted the King's concept by changing from monocrop agriculture to mixed-farming. They produced for their own needs and using surplus resources to produce for the appropriate market. They earned increased income from selling surplus agricultural products including rice, seasonal fruits, and fish (Interview, 2006). The extra income was also a result from the dissemination of knowledge and new techniques by the Royal Development Center for making organic fertilizer from livestock's waste. The local farmers established groups and exchanged resources and labor through cooperatives within the larger Nang Rong district (Interview, 2006). New crafts and products were made and sold through new marketing channels both in town and other cities. The average annual income for people in Nang Rong town increased from 34,348 baht in 2005 (1,108 US dollar) to 41,729 baht (1,346 US dollar) in 2006, which coincides with the time frame of the implementation of the King's plan (NRDO, 2006).

Other national / regional factors such as national plan and local budget plan may additionally influence the Nang Rong urban form. After implementing principles of water supply from the Sufficiency Economy in the Nang Rong town plan, the local irrigation system was expanded to increase its support from 3,978 households in 2003 to 4,945 households in 2006. The local branch of the Royal Irrigation was able to produce approximately 107,145 cubic feet of clean water in 2003 and increased to 211,888 cubic feet in 2006 (NRMO, 2006). The villages in the Nang Rong District received extensive funds for the Sufficiency Economy projects, including 141 million bahts or 4.5 million US\$ (1 US dollar = 31 bahts) for agriculture, 29 million bahts for household development projects, and 21 million bahts for local economic activities (NRDO, 2006). Two dams were also built to supply water during the dry season in Nang Rong Town. Rivers and streams were dredged to help with water distribution and channel flow (NRMO, 2006). Budgets for the Nang Rong town irrigation system increased from 2,598,300 for 3 years plan (2005/2007) to 3,968,835 bahts (2007/2009). Funding for environment management and planning also increased, with 4 million baht budgeted for monitoring the quality of local resources, including water and soil quality, and sixty one million baht targeted to solving inequality issues within Nang Rong town (NRMO, 2006). Consequently, people may stay in the region due to the improvement of accessibility to resources and sense of equitability of resource distributions.

Sustainable development is scalable. Global sustainability requires regional sustainability, and regional sustainability requires local sustainability. The old adage, “think globally, act locally” certainly applies. The King’s plan for the Sufficiency Economy starts at the family or household level, but this program also scales up to the community, Nang Rong town, and broader regions. Many communities around the country adopted the King’s Theory and showed significant improvements both economically and environmentally (RDPB, 2004). Land was allocated to agricultural activities and other land use type. Forests were replanted to promote symbiotic co-existence between man and nature. The major development focused on improving soil and water resources (RDPB, 2004). The activity included construction of small dams with rows of dirt embankments in order to control water flow and conserve soil moisture. For example, 15 villages within Phanom Sarakarm district adopted the King’s Theory from the Khao Hin Sorn Royal Development Study Centre. The activities included rehabilitation of forest, improvement of soil and water sources, and setting up the land management system according to the concept of the King’s Theory (RDPB, 2004). The King’s Theory is scalable to other places depending on specific biophysical characteristics and needs of each region.

The concept of moderation is also transferable to other towns at different scales. For example, the King’s plan was adapted to promote investment in business in Bangkok with the private sector was encouraged to use funds not exceeding the company’s assets. This philosophy encouraged spending restraint and controlled

expansion of activities and purposefully tried to limit the use of scarce resources (Isarangkun and Pootrakool, 2004). The Sufficiency Economy is also being strengthened through government plans and legislation both nationally and locally. For example, the current constitution of Thailand is the supreme law of the Kingdom and an interim constitution was promulgated on the October 2006, which stated that the government must encourage the Sufficiency Economy in order to ensure the economic, social, and sustainable development of the country (TEI, 2008). The King's plans can also be applied to other regions, especially in other Buddhist regions where "The Middle Path" principle is commonly understood. As the King stated in a Royal Speech on December 4, 1998, "If one is moderate in one's desires, one will have less craving. If one has less craving, one will take less advantage of others. If all nations hold this concept of moderation, without being extreme or insatiable in one's desire, the world will be a happier place." (www.reflectedknowledge.com, 2008)

To conclude, the models developed for this research could easily be applied to any rural setting. Urbanization in developing countries is occurring, at least by rates, most quickly in the smaller urban centers. Nang Rong has a long history of settlement, abandonment and resettlement. While it is difficult to foresee a scenario whereby the town is abandoned again, it certainly is possible and a worthwhile research question. More likely Nang Rong will continue to aggressively expand both spatially and by population density creating a larger impact footprint throughout the region. The models developed here give us a

better understanding of the pattern and process of urban expansion, and will guide more systematic and effective resource management and preservation plans. Regardless, future fieldwork including built regions validation, ground-truthing, interviews with villagers, empirical evidence of the application of the King's Theory, and archival research are still required for a more systematic and complete project. More population characteristics such as number of people per household, income, and education should also be taken into account in future works to improve the accuracy of simulation. Though ABM models are not perfect, hopefully a sustainable development can be achieved through experimentation with these models as tools aiding decision-making process.

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