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AREA SELECTION FOR SOLID WASTE DISPOSAL AT CHANGWAT SONGKHLA

Mr. Rottana Ladachart

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By	Mr. Rottana Ladachart
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Thesis Advisor	Associate Professor Chaiyudh Khantaprab, Ph.D.
Thesis Co-advisor	Supichai Tangjaitrong, Ph.D.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

……………………………………………….. Dean of Faculty of Science

(Associate Professor Wanchai Phothiphichitr, Ph.D.)

THESIS COMMITTEE

……………………………………………….. Chairman

(Assistance Professor Veerote Daorerk, M.Sc.)

……………………………………………….. Thesis Advisor

(Associate Professor Chaiyudh Khantaprab, Ph.D.)

……………………………………………….. Thesis Co-advisor

(Supichai Tangjaitrong, Ph.D.)

……………………………………………….. Member

(Associate Professor Thanawat Jarupongsakul, Ph.D.)

……………………………………………….. Member

(Montri Choowong, M.Sc.)

โรธนา ลดาชาติ: การเลือกพื้นที่สำหรับการฝังกลบขยะมูลฝอย ที่จังหวัดสงขลา (AREA SELECTION FOR SOLID WASTE DISPOSAL AT CHANGWAT SONGKHLA) อาจารย์ที่ปรึกษา: รศ.ดร.ชัยยุทธ ขันทปราบ อาจารย์ที่ปรึกษาร่วม: อาจารย์ ดร.ศุภิชัย ตั้งใจตรง, 147 หน้า ISBN 974-17-3361-5

ปัญหาการกำจัดมูลฝอย เป็นปัญหาสิ่งแวดล้อมที่สำคัญซึ่งทวีความรุนแรงขึ้นเรื่อย ๆ จากการเพิ่มของประชากร การดำเนินกิจการต่าง ๆ ของมนุษย์ และการขยายตัวของเมือง เนื่องจากการกำจัดมูลฝอยส่วนใหญ่ยังใช้วิธีการกำจัดแบบกองทิ้งในที่โล่งแจ้งและแบบฝังกลบ ซึ่งมีโอกาสเกิดความเสื่อมโทรมต่อสิ่งแวดล้อมจากน้ำชะมูลฝอยซึ่งมีค่าความสกปรกสูงไหลลงสู่ดิน แหล่งน้ำผิวดิน และแหล่งน้ำใต้ดิน ทำให้เกิดการปนเปื้อนแก่ดินและแหล่งน้ำในบริเวณที่กำจัดมูลฝอยตลอดจนบริเวณพื้นที่ใกล้เคียง อีกทั้งขาดแคลนพื้นที่กำจัดมูลฝอย และไม่สามารถรองรับปริมาณมูลฝอยที่เพิ่มขึ้นในอนาคตได้ จึงควรมีการวางแผน และเตรียมการหาพื้นที่กำจัดมูลฝอยให้สอดคล้องกับการขยายตัวและพัฒนาเมืองเป็นสำคัญ

การศึกษาในครั้งนี้ได้พัฒนาเพิ่มเติมเทคนิคในการคัดเลือกพื้นที่สำหรับฝังกลบขยะ เพื่อให้ได้กระบวนการคัดเลือกพื้นที่ที่มีความเหมาะสมยิ่งขึ้น โดยแบ่งขั้นตอนการเลือกพื้นที่ออกเป็น การหาขนาดของพื้นที่ที่เหมาะสมในการฝังกลบขยะมูลฝอยที่สามารถรองรับปริมาณขยะที่เกิดขึ้นจากประชากรในระยะเวลา 20 ปี (พ.ศ.2545-2565) ซึ่งได้ทำการประเมินทั้งกรณีการเพิ่มขึ้นของประชากรอย่างสูงสุด ปานกลาง และ ต่ำสุด การคำนวณหาขนาดพื้นที่ฝังกลบโดยใช้ปริมาณขยะที่ประเมินไว้เป็นเกณฑ์ และการหาพื้นที่ศักยภาพ โดยการนำระบบสารสนเทศทางภูมิศาสตร์ (GIS) มาช่วย โดยพิจารณาปัจจัยต่าง ๆ ทางกายภาพ อันได้แก่ ความลาดชัน แหล่งน้ำผิวดิน แหล่งน้ำใต้ดิน ลักษณะทางธรณีวิทยา พื้นที่เสี่ยงต่อภาวะน้ำท่วม แหล่งชุมชน การใช้ที่ดิน การคมนาคม ทำการหาความเหมาะสมของด้วยวิธี positive/negative-mapping โดยแบ่งปัจจัยที่พิจารณาออกเป็น ปัจจัยด้านลบ และปัจจัยด้านบวก โดยเฉพาะปัจจัยด้านบวกนั้นได้ใช้การสร้างแนวขอบเขตทางธรณี ที่พัฒนาขึ้นมาในการศึกษานี้หา geological barrier ซึ่งจะเป็นแนวป้องกันการแพร่ของน้ำเสียจากแหล่งฝังกลบลงสู่ชั้นน้ำใต้ดิน

ผลจากการศึกษาในครั้งนี้ จากพื้นที่ศึกษาทั้งสิ้น 7,400 ตารางกิโลเมตร สรุปได้ว่าพื้นที่ที่มีศักยภาพสำหรับการเป็นที่ฝังกลบขยะสูง มีพื้นที่โดยรวมเท่ากับ 106 ตารางกิโลเมตร โดยพื้นที่ที่มีขนาดที่ใหญ่เป็นอันดับ 1 ถึง 5 คลอบคลุมอยู่บริเวณ ตำบลคลองหอยโข่ง ทุ่งหมอ และสำนักขาม ซึ่งอยู่ทางตะวันตกของพื้นที่ มีขนาด 10.114 9.916 6.282 3.610 และ2.997 ตารางกิโลเมตร ตามลำดับ

ภาควิชา……………ธรณีวิทยา……….......ลายมือชื่อนิสิต..

สาขาวิชา…………..ธรณีวิทยา……………ลายมือชื่ออาจารย์ที่ปรึกษา...

ปีการศึกษา...............2545.......................ลายมือชื่ออาจารย์ที่ปรึกษาร่วม...

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The problem of solid waste disposal becomes a serious problem of environmental concerns because most solid waste is disposed either by open dumping or sanitary landfill. This can badly affect the environment if landfill leachate contaminate soil or water resources. The increasing of population, human activities, and city expansion make a deficit for selecting potential areas for landfill in the future.

This study has extended a landfill selection technique by incorporating geological characteristics of groundwater percolation into the analysis. Firstly, the calculation of area required for solid waste disposal in the next 20 years was carried out. This was done under the scenarios of maximum, mean, and minimum population growth rates. Then, GIS was used to analyze suitability of areas for solid waste disposal. The selecting criteria included slope terrain, surface water, groundwater, geological features, flood prone areas, community areas, land use, and transportation. The identification of landfill area was conducted by positive/negative- mapping. For the positive map, information on geological barrier, which was introduced in this study, was considered as a natural prevention of groundwater contamination from landfill leachate.

The study found that from 7,400 km^2 of the study area, 106 km^2 are highly suitable candidate for waste disposal.. The 5 five biggest patches of these high suitability areas, are in Tambon Khlong Hoi Khong, Tambon Thung Mo, and Tambon Samnak Kham. They are situated in the western part of Songkhla with area of 10.114 9.916 6.282 3.610 and2.997 km^2, respectively.

Department……..Geology…….. Student's signature………………………………………………

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CHAPTER I

INTRODUCTION

The management of the municipal waste that our society procedures every day is one of the major tasks that scientists and technicians have to cope with in the future to prevent an environmental collapse. The municipal waste and its management has been a problem in the industrialized countries of the modern western world already for decades. It is the focus of many NGOs, local environmental groups, and heavily debated wherever it becomes a topic of the political agenda. The public and the people are aware of the problems that a waste treatment facility will cause in general and specifically to surrounding they live in. This is now the case in all of those countries, the level of global market challenge, and this means, that it has become a matter of the public debate in Thailand.

Many of these economic developments have taken place without taken their environmental impacts into account problems. The waste management problem has risen to one great threat of the natural environment, and one has to be aware, that urgent sufficient solutions are required. The figures are frightening as Piyapongpan (1997) calculates the amount of waste in Thailand for 1996 of about 13.15 Million tons/year, compared to 10.78 Million tons/year in 1993. The increase of waste was almost one-third in only four years. In the study in this thesis, Changwat Spngkhla, the generation of waste in year 2000 just by the city of Hat Yai and Songkhla are about 109.0 and 70.5 tons/day, respectively.

Only scientific and technical approach is a reliable basis for developing environmental management proposal, particularly area selection for waste disposal. And, perhaps even more important, every approach has to be an open and transparent process, that avoids the suspicion and misunderstanding that other than technical and scientific reasons contributed to the solutions of the waste management problems. In this thesis, a series of scientific processes were fundamental as tool for waste disposal area selection.

1.1 The Study Area

Songkhla province is situated in the southern part of Thailand covering an area of about 7,394 km^2. It lies between latitude 6° 17′ N - 7° 56′ N, longitude 100° 01′ E - 101° 00′ E. The ground surface is approximately 4 m from mean sea level. The eastern boundary of the area is the coastline of the Gulf of Thailand. The northern boundary is Changwat Nakorn Si Thammarat and Changwat Pattalung. It is bounded by Changwat Satun and Changwat Pattalung in the west and Changwat Yala, Changwat Pattani and Malaysia in the south, The road distance from Bangkok to Songkhla along Petchkaseam road is about 950 km. The boundary and location are presented in figure 1.1.

1.2 Objective of the Study

The study is aimed to acquire, analyze, and evaluate the physical environment and the socio-economic parameters of required for identifying suitable areas for municipal waste disposal with at least 20-years life span using Geographic Information System (GIS).

1.3 Methods and Scopes of Work

The method of the present study can be divided into 7 main steps including collecting of the data and information, preparation of the database and analysis, solid waste characterization and projection, field observation, geological barrier identification,

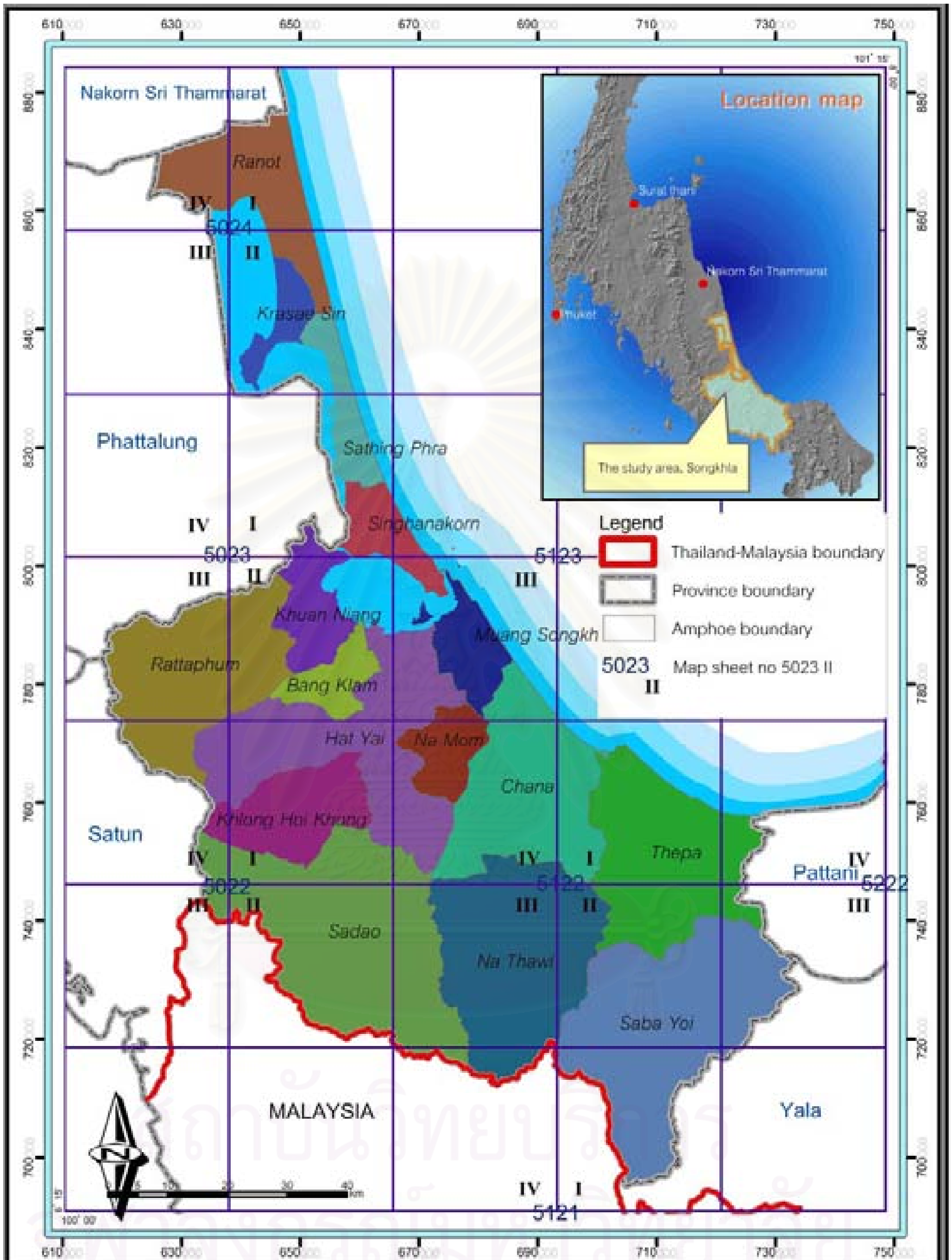


Fig 1.1 The location map of Songkhla: The study area and it's topographic map boundaries of 1:50,000.

Area Selection for Solid Waste Disposal in Songkhla, Southern Thailand

Rottana Ladachart Department of Geology, Faculty of Science, Chulalongkorn University, 2002 suitable area selecting, and reporting. The schematic diagram for methodology system is illustrated in figure 1.2, and will be described as follows:

1. Collecting of data and information

At first, the basic data and information, library researches, and literature studies were collected and arranged into data system

2. Preparation of database and analysis

The second step involved the development of area selection criteria for solid waste disposal by the sanitary landfill method. Many methods were selected to compare for suitable method for identification of the landfill area, such as, negative/positive-mapping, rating method, and weight-rating method as well as the GIS, which have been integrated for the present study.

3. Solid waste characterization and projection

The third step is the characterization and analysis of the solid waste in term of quantity and quality within the study area. The present conditions as well as the next 20 years scenario of urban wastes have been assessed based on the population growth and lifestyle.

4. Geological barrier identification

The forth step is the identification for the geological barrier, which is a barrier for protecting contamination of landfill leachate to groundwater.

5. Suitable area selecting

From the results from 2nd, 3rd, and 4th step were concluded with field observation the area will be selected in this step.

6. Field observation

The reconnaissance field investigation will be undertaken for some direct observations. After the completion of the analysis, some potential areas were selected for site observation.

7. Reporting

Finally; embraces the conclusion, recommendation, reporting, and presentation of the study. Emphases have been given to a series of thematic maps as well as the suitable area for solid waste disposal in Songkhla.

Scopes of work in this study are as following;

1. The study area covers Changwat Songkhla, Southern part of Thailand.
2. Solid waste quantity was calculated from people who live in Songkhla.
3. Physical environment and socio-economic parameters were used to select the suitable area using the technique of GIS.
4. The word "Solid waste" in the study covers only municipal waste, excluded hazardous and radio-active waste.
5. The identification for the geological barrier was used for this study.
6. Life span of landfill site is at least 20 years.

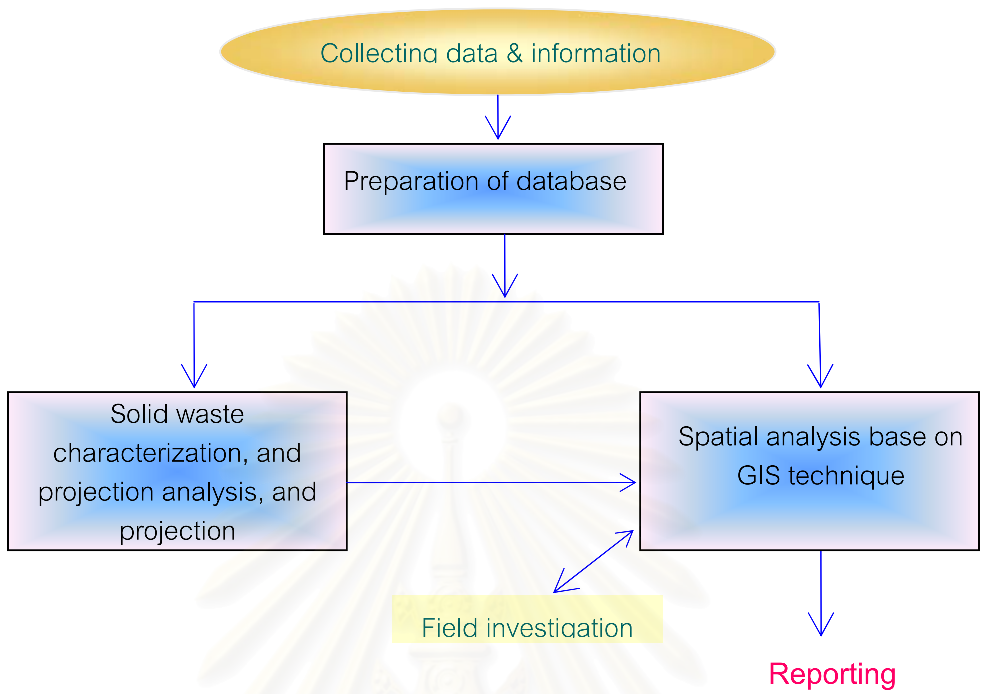


Figure 1.2 Flowchart illustrating method of the study

1.4 Previous Investigation

Wright, et al. (1989) recommended that the selection of disposal site must be completely considered. Factors used to decide are topography, surface water, groundwater, soil characteristics, geology, sensitive area, population, and transportation.

Disathein (1992) selected disposal sites in Saraburi province. She used eight physical factors, such as, slope, type of soil, soil depth, soil permeability, geology, ground water level, surface water flow and land use as primary factors. The equation employed in the study is as follows:

$$S=W_1R_1+W_2R_2+...+W_nR_n$$

Where; S = score of all factor

W_1 to W_n = importance value of each factor

R_1 to R_n = capability value of each polygon.

However, additional secondary factors, such as, road, railway, river and canal are also employed in her study. Finally, the GIS is used in delineating three levels of suitability of disposal sites, namely, high, medium, and low.

Van der Wall and others (1992) selected domestic waste disposal sites in hilly area surrounding of the Batujajar and Bandung Plains. The site selection was based on a scheme, which consists of four steps. Step I, the negative-/positive-mapping included parameters of the natural environment, land use and geology. Hydrogeology were also considered. The second step, economic parameters are considered. Then, in step III, a screening of the information and a description of the site are observed in field observation. In the last step, the remaining sites fulfilling the minimum demands for a suitable waste disposal site plus additional five sites, which were found during the field observation were rated by modified German Standard, which was created by considering the specific Indonesia conditions, for example in climate and land use/infrastructure.

Department Mineral Resources (1995) conducted the preliminary study on potential sites for solid waste disposal in Ubonrachathani province using positive/negative-mapping model. The geology and subsurface water quality are used to choose the site along with these criteria: (1) the area free from frequent flood, (2) the area without ground water well, (3) the area without economic mineral deposit, (4) the area underlain with impervious soil layer, (5) the area with deep water-table and less groundwater yield., and (6) the area underlain by bed rock with high strength. In addition to these six positive factors earlier outlined, an attempt has been made to take other negative factors into consideration included, river line, flood-prone area, national park, road, and historical sites. Finally, the potential sites are classified as most suitable, moderately suitable, and less suitable.

Jearapattranon (1996) applied the GIS for the land use planning in Saraburi municipality. Among one of the land use planning aspects is the potential sites for solid waste disposal using positive/negative-mapping model. The factors employed in the site selection of solid wastes are, including, soil depth, soil permeability, soil texture. Besides, the negative factors, notably, natural forest, class 1 and 2 watershed, human settlement, steep-slope area.

Boonlue (1998) selected and investigated potential areas for sanitary landfill, which lifespan is at least twenty years. Solid waste is generated from seven sanitary of Amphoe Mae Chan, Amphoe Mae Sai, and Amphoe Chiang San. The physical parameters included geology, topography, soil characteristics, water resources, hydrogeology, landuse, forest use, etc. are considered. Consequently, selected potential areas were selected from physical parameter consideration. Then, a weight-rating technique was employed to rank the potential area into the highest score, which could be a potential area to site investigation. Finally, semi-detailed site investigation was performed.

Kerdput (1999) selected potential areas for sanitary landfill in Pathum Thani province. Overlay technique and weight rating system were employed in identifying the potential areas. Solid waste defined under her study is only domestic waste, which will be generated in the next ten years. The physical parameters included the topography, soil characteristics, geology, water resources, hydrometeorology, administration, and transportation. In addition, land use and urban planning of the Pathum Thani province are considered.

Boonruang (2001) applied GIS for site selecting the sanitary landfill in Chachoengsao province, that used the physical environmental geology parameters for suitable landfill site identification by negative/positive-mapping on GIS application. After that, the suitable areas were calculated by socio-economic parameters for potential area priority using weight-rating system. The weight factors were assigned and directly expressed their relative important factors, as well as the higher number to other more important factors.

Department of Mineral Resources (2001) presented the new way for selecting the landfill site in Thailand in the name of "Site Searching Process". The main aim of the Site Searching Process is to find out areas with a suitable **geological barrier**. Those are areas, where the following geological situation is given. Rocks or sediments should have;

- Low permeability: $k_f < 10^{-7}$ m/s, i.e. (in unconsolidated sediments) mainly clay or silt,
- Homogeneous structure of this sediment layer with no gaps of higher permeability,
- Large thickness (more than 5 m),
- Low effective porosity,
- High natural retention capacity for hazardous substances,
- Wide lateral extension,
- High depth to groundwater, and
- Thin coverage with other sediments (less than 2 m),

CHAPTER II

BASIC CONCEPTS OF SOLID WASTE DISPOSAL

According to definitions in the Public Health Act B.E. 2484 (1941) amended by the Public Health Act (No.3) and B.E. 2497 (1954), "solid wastes" mean pieces of paper, cloth, food, commodity, ash, animal remains, including other objects collected from roads, markets and other places, as reported by the Environmental Quality Standard Division (1989)

Residential, commercial and industrial activities generate a wide variety of wastes that have different effects on water and soil qualities. Although general categories might include garbage, rubbish, construction wastes, abandoned vehicles, and other kinds of materials, it is more useful to deal with the individual component of constituents. In a general way, these can be broken down into food or organic wastes, paper products, metals, glass, plastics, cloth, brick, rock and dirt leather and rubber, yard wastes and wood, with organic wastes and paper products constituting almost 75 % of the total weight.

Some of these materials, such as brick, rock, and glass are essentially inert and pose less pollution problems. Organic matter, however, needs to be decomposed and, therefore, reguires a significant amount of oxygen. With decomposition, methane and carbon dioxide increase the hardness and acidity of water, which may lead to solution and leaching. Ashes are generally rich in potassium, nitrates, phosphates and other elements that can be leached out by percolating water. The nature of solid wastes and the concentrations of leacheates are important in determining the potential threat to the hydrologic environment.

Hoowichit (1986) described the sources and types of solid wastes related to land use and activities (Table 2.1). In municipality, solid wastes are generated from both residential and commercial zones. They are food wastes, rubbish, ashes, special wastes, demolition and construction wastes, and hazardous wastes.

In this study, solid wastes are defined as wastes arising from human activities in residential and commercial zones. Solid wastes are food waste, leaf or branch of tree, paper, plastic, rubber or leather, clothes, glass, metal, stone or brick, and others.

Table 2.1 Sources and types of solid wastes (Hoowichit, 1986)

Sources	*Land use/activities*	*Type of solid wastes*
Residential Zones*	Single-family, multifamily dwellings, apartments, condominiums, etc.	Food wastes, rubbish, ashes, special wastes
Commercial Zones*	Shops, stores, restaurants, markets, office buildings, repair shops, hospitals, etc.	Food wastes, rubbish, ashes, demolition and construction wastes, special wastes and hazardous wastes.
Industrial Zones	Construction, mining, textile industries, etc.	Food wastes. Rubbish, ashes, demolition and hazardous wastes.
Public Areas	Streets, parks, beaches playgrounds, recreation areas, etc.	Special wastes, rubbish
Agricultural Zones	Farms and fields	Agricultural wastes, rubbish, hazardous wastes.

Note : * Municipality covers both of residential and commercial zones.

: The description of material comprised in municipal solid waste are solution in table 2.2.

2.1 Classification of Solid Wastes

According to the earlier mentioned terminology, definition of municipal solid wastes can be classified (Peavy, et al. 1988) as presented in Table 2.2. The quantity of generated solid wastes depends upon the influence of five major factors. They are:

(a) geographic location,

(b) economic status,

(c) activities of population,

(d) living standard, and

(e) public health attitude.

Decision making and planning of solid waste management system thus requires data on these components. Under the present study, the hypothetical quantity of solid wastes is defined as average generation rate of solid waste per person multiply by the number of population in Songkhla.

2.2 Treatment and Disposal of Solid Wastes

There area 3 mainly types for sanitary disposal of the municipal solid wastes. Each technique has different conditions as follows;

2.2.1 Composting

Pavoni, et al. (1975) defined that composting is biochemical degradation of organic factor of the solid waste material. Its end product is humus like substance that is used primarily for soil conditioning.

Lohani (1984) stated that composting is the oldest method of organic waste disposal and dented as decomposition of heterogeneous organic matters by microorganisms in moist warm, aerobic environment, resulting in degradation and reduction of organic matter into a sanitary nuisance-free humus like material, which can be use as fertilizer, soil conditioner, bulking agent for reclamation cover material for the landfill.

Table 2.2 Classification of materials comprised in municipal solid wastes.

Components	*Description*
Food wastes	The animal, fruit, or vegetable residues (also called garbage) resulting from the handling, preparation, cooking, eating of foods. Because food wastes are putrefiable, they decompose rapidly, especially in warm weather.
Rubbish	Combustible and noncombustible solid wastes, excluding food wastes of other putrefiable materials. Typically, combustible rubbish consist of materials such as paper, cardboards, plastics, textiles, rubber, leather, wood furniture, and garden trimmings. Noncombustible rubbish consists of items such as glass, crockery, tin cans, aluminium cans, ferrous and non-ferrous metals, dirt, and construction wastes.
Ashes and residues	Materials remaining from the burning of wood coal, coke and other combustible wastes. Residues from paper plants normally are not included in this category. Ashes and residues are normally composed of fine, power materials, cinders, clinkers, and small amounts of burned and partially burned materials.
Demolition and Construction wastes	Wastes from razed buildings and other structures construction wastes are classified as demolition wastes. Wastes from the construction, remodeling, and similar structures are classified as construction wastes. These wastes may include dirt, stones, concrete, bricks, plaster, lumber, shingles, and plumbing, heating and electrical parts.
Special wastes	Wastes such as street sweeping, roadside litter, catch-basin debris, dead animals and abandoned vehicles are classified as special wastes
Treatment-plant wastes	The solid and semi-solid wastes from water, wastewater, and industrial wastes treatment facilities are included in this classification.

Source: Peavy, et. al. (1988)

2.2.2 Incineration

Rtmberg (1975) stated that incineration is the controlled process of burning of solid waste in furnace, boiler, or specially designed container for this purpose. The end products being ashes and the gases. Theodore and Reynolds. (1987) described that incineration involves the oxidative conversion of the combustible material to gases to be released to the atmosphere. The harmful gases must be removed before releasing to the air.

Willing (1979) stated that incineration is the waste treatment process with great particulate and gaseous emissions. Therefore, dust extractor and flue gas scrubbers are required which involve a large amount of capital expenditure and higher operation and maintenance cost. Bemt (1991) stated that the capital cost for the control of air pollution is about 10 to 20 % of the total investment cost.

2.2.3 Sanitary Landfill

Different methods of treatment, processing and disposal are applied to the countries of Asia and Pacific region. The most widely used method is landfill or open dumping. In larger cities, the availability of land for waste disposal is the major problem. In Japan and Singapore, about 65 % of the wastes is incinerated with energy recovery. Waste characteristics of these countries have relatively high calorific value due to presence of high percentage of paper, plastic, and other combustibles and low moisture content. Low-income countries of Asia Pacific region are given in Table 2.3.

A Sanitary landfill (Pavoni et al., 1975) is a solid waste disposal facility wherein refuse is placed at the greatest possible density (in the smallest possible space) for final deposition; no open burning, no water pollution, and daily cover of deposited refuse with earth are requisites of the method.

Table 2.3 Disposal methods for municipal wastes in selected countries in ESCAP region. (Asian Development Bank, 1995)

Country	Disposal Methods (%)			
	Land Disposal	Incineration	Composting	Others
Australia	96	1	-	3
Bangladesh	95	-	-	5
Brunei Darussalam	90	-	-	10
Hong Kong	65	30	-	5
India	70	-	20	10
Indonesia	80	5	10	5
Japan	22	74	0.1	3.9
Korea	90	-	-	10
Malaysia	70	5	10	15
Philippines	85	-	10	5
Singapore	35	65	-	-
Sri Lanka	90	-	-	10
Thailand	80	5	10	5

According to Kreith (1994), the general features of a sanitary landfill are illustrated in Figure 2.1. The term cell is used to describe the volume of material placed in a landfill during one operating period, usually one day (see Figure 2.1b). A cell includes the solid waste deposit and the daily cover material surrounding it. Daily cover usually consists of 6 to 12 inch of native soil or alternative materials such as compost, foundry sand, or auto shredder fluff that are applied to the working faces of the landfill at the end off each operating period. A lift is a complete layer of cells over the active area of the landfill.

Typically, landfills comprise a series of lifts. A bench (or terrace) is typically used where the height of the landfill will exceed 50 to 75 feet. Benches are used to maintain slope stability of the landfill, for the placement of surface water drainage channels, and for the location of landfill gas recovery piping. The final lift includes the landfill cover layer. Landfill liners are materials (both natural and man-made) that are used to line the bottom area and below-grade sides of a landfill (see Figure 2.1a). Liners usually consist of successive layers of compacted clay and/or geosynthetic material designed to prevent migration of landfill leachate and landfill gas. The final landfill cover layer is applied over the entire landfill surface after all landfilling operations are completed (see Figure 2.1c).

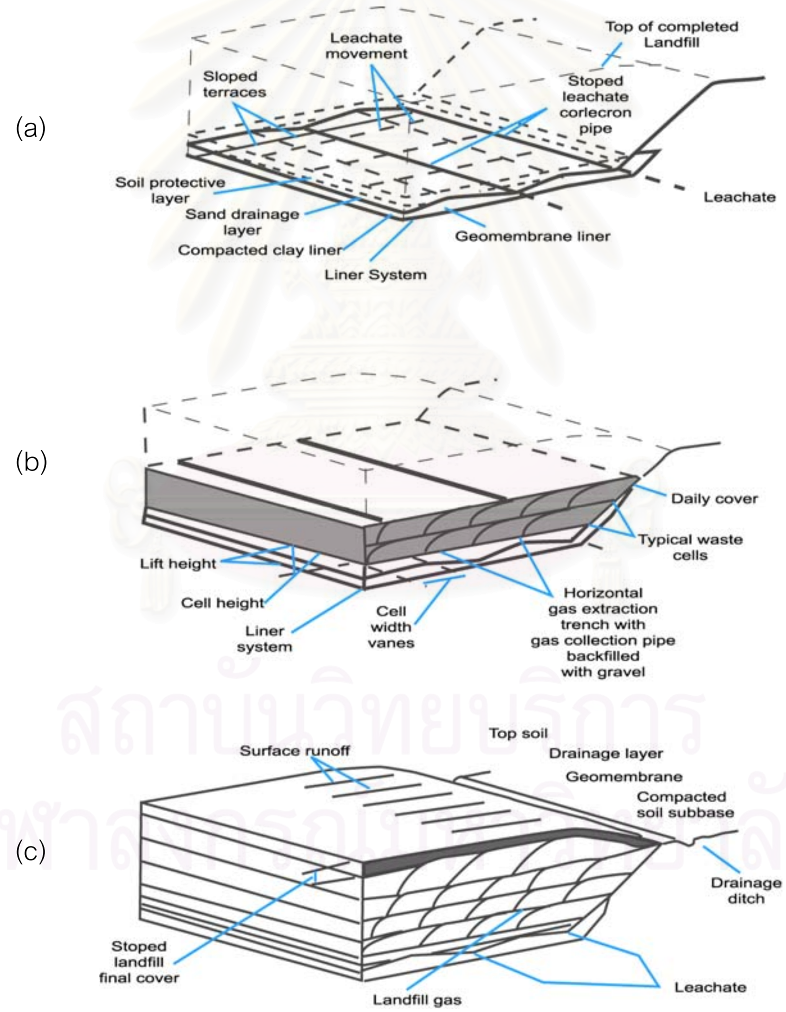


Figure 2.1 The general feature of a sanitary landfill. (after Kreith, 1994)

Table 2.4 Comparison three different kinds of waste disposal.

(Pollution Control Department,1993)

Item	Incineration	Composting	Sanitary Landfill
1.Operation & maintenance	- almost high technology - need skillful staff	- medium technology - need semi-skillful staff	- low technology - need normal skillful staff
2.Effective disposing	- 80-90% volume reduction - eradicate infection 100%	- 30-35% volume reduction - eradicate infection 70%	- 0%volume reduction - eradicate a little of infection
3. System flexibility	- low	- low	- high
4.Environmental effects on - surface water - ground water - air -odors, insects and carrier of disease germs	 - none - none - some - none	 - possible - possible - none - may be have	 - most possible - most possible - none - have
5.Characteristics of wastes	- Combustible, heat value not less than 800 kcaL/kg and moisture less than 40%	- able to be compost organics, moisture 50-60%	- every kind of waste except infection and hazardous wastes.
6.Land size	- small	- moderate	- large
7.Capital cost	- very high	- rather high	- rather low
8.Cost for operation & maintenance	- high	- rather high	- low
9.By products	- heat energy substance and separated metal	- soil treatment	- final area can be used as park, etc. - methane gas for fuel

2.2.3.1 Landfill Method

According to Pavoni and other (1975), there are two variations in refuse placement; the trench method, and the area method, which are described as below.

In the trench method of sanitary landfilling, a long narrow excavation is made in the earth and the soil removed from this excavation to stockpile. Waste is then deposited at the end of the excavation on a sloped end of the trench. The refuse is spread on a rather shallow inclination (usually about 3 horizontal to 1 vertical) and is then compacted by the placement/compaction equipment used at the site. At the end of the day's operation, the compacted layers of refuse are covered with a layer of soil taken from the stockpile of material removed in the original excavation. When the entire trench has been filled with refuse, a thicker final cover layer is placed over the completed deposit of refuse.

The trench method is most suitable for sites where the groundwater table is at significant depth and where there is a deep layer of suitable cover soil. Generally, the trench method of landfilling is also most suitable where the site topography is rather regular (see Figure 2.2):

In the area method of sanitary landfilling, in contrast to the trench method, refuse is dumped on an undisturbed existing ground surface; the only prior operation in the area method landfill may be surface removal of the top soil and highly organic material (humus) suitable for final cover. After refuse is dumped from collection and transportation vehicles, it is spread over the ground surface in a uniform layer and then compacted to a higher density. The compacted layer of refuse is covered with soil at the end of an operational day or when the deposition area is filled, a final cover layer of greater thickness is placed over the completed fill.

Generally, in area-method landfills, the cover soil is transported onto the site from another location. The area method is used where the groundwater table is at or near the surface and on sites where the terrain is rough and irregular (see Figure 2.3).

In addition for the above method, the ramp method is a hybrid technique combining features of both trench and area methods of landfilling. Before refuse deposition is begun, a small excavation is made in front of the proposed face on an existing slope. The soil removed in this excavation is stockpiled nearby. Refuse is then deposited on the face of the slope, spread and compacted by standard landfilling equipment, and then covered with the soil which had been stockpiled from the preceding excavation (see Figure 2.4).

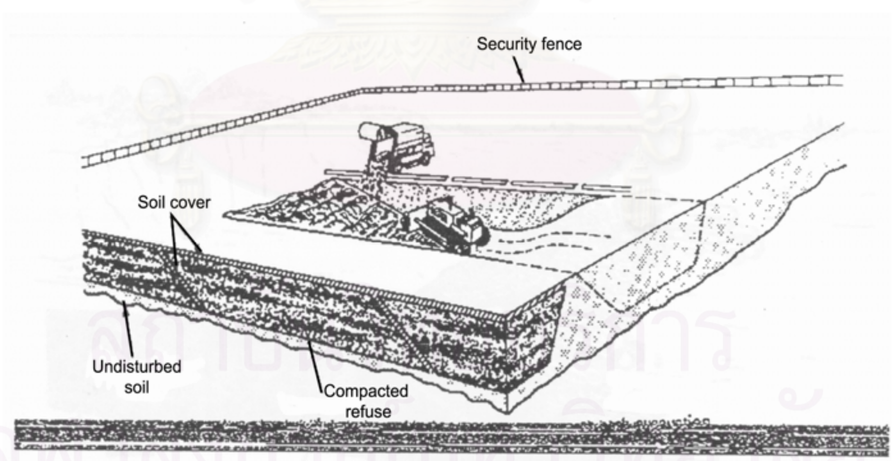


Figure 2.2 Trench method (after Pavoni and other,1975)

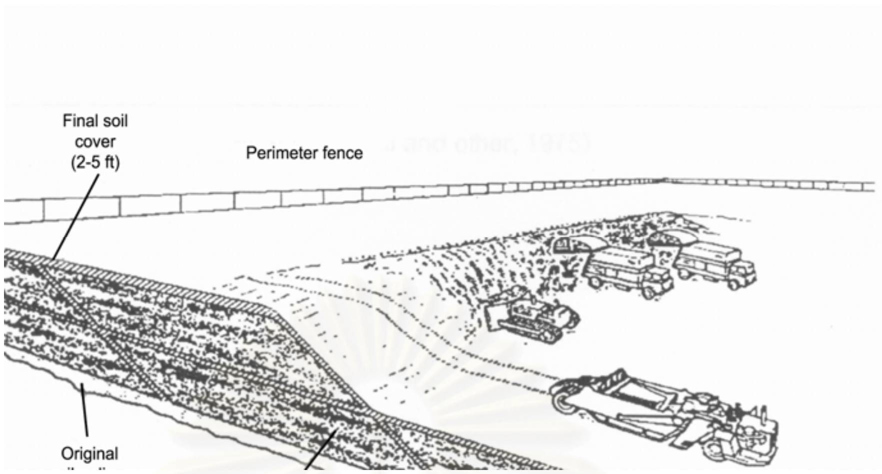


Figure 2.3 Area method (after Pavoni and other,1975)

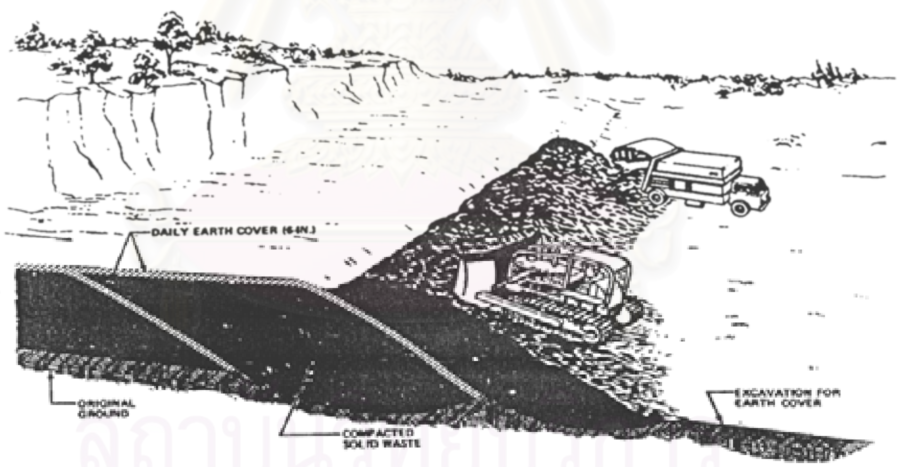


Figure 2.4 Ramp method (after Pavoni and other,1975)

2.2.3.2 Cover Material and Landfill Base Liners

The presence of suitable cover material at a particular site is much to create an efficient landfilling operation; if it is necessary to import cover soil from a source area outside the close environs of the landfill site, high transportation costs will be incurred. However, the quality of the available cover soil is just as important as is its quantity. The characteristics of a desirable cover material are easy workability, moderate cohesion, and significant strength. To fulfill these requirements, the most suitable cover soil is mixture of sand, silt, and clay. Generally, a sandy loam is a very desirable cover material. Clean sands are somewhat unsuitable for cover material since they are readily permeable and allow large quantities of water to invade the deposited refuse. Fine-grained soils such as clays and silts are not ideal cover materials because of their difficulties in working on. Noble (1976) proposed the ternary diagram to shows the soils suitable for cover material as shown in figure 2.5. Cover soil for sanitary landfill to control surface infiltration, discharge of the leachate through seepage and groundwater.

For the landfill base liner: The United Nations Environment Programme (UNEP) and other organizations (1993) suggested that a composite liner consists of a clay liner with an additional synthetic membrane liner (thickness > 2.5 mm). The synthetic liner should be installed in an overlapping manner. Figure 2.6 shows basement layer system as specified in Germany.

Three main types of barriers must be considered: (1) the waste itself, (2) man-made barriers (liner and drainage system), and (3) the geological barrier (Stief and Dörhöfer, 1992). It is agreed that none of these elements can be dispensed with, since one barrier alone cannot guarantee the necessary high degree of safety.

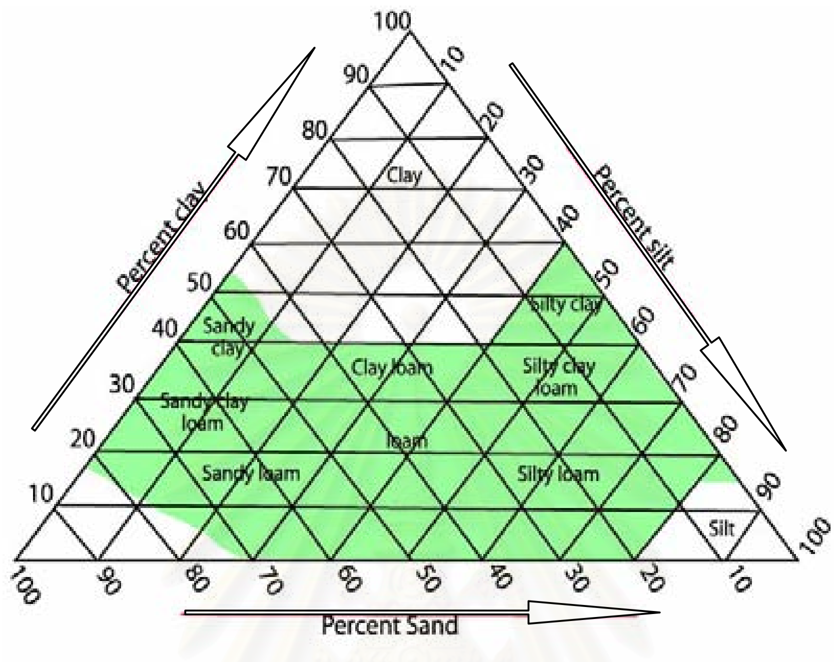


Figure 2.5 Ternary Diagram showing soil suitable for cover material (the high light color). (after Noble, 1976)

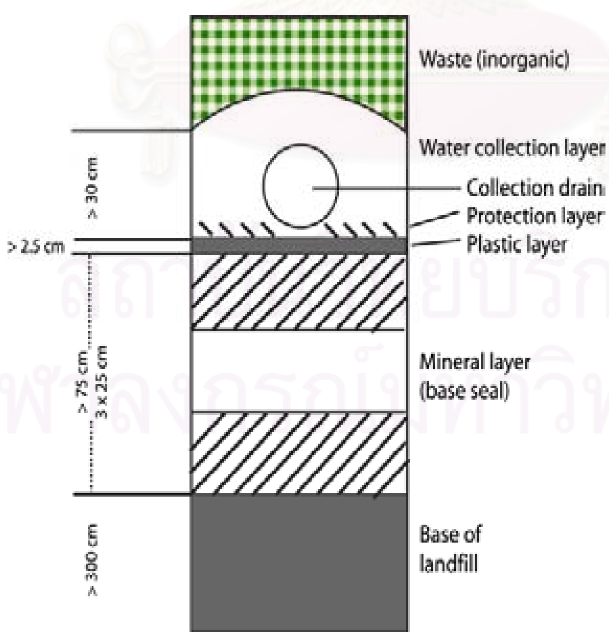


Figure 2.6 Basement layer system as specified in Germany. (after UNEP, 1993)

2.2.3.4 Landfill Barriers

The landfill barriers can be classified into 3 types as waste barrier, man-made barrier, and geological barrier. They were classified from material and underlained the landfill for protected landfill leachate to soil and groundwater.

(a) The waste “barrier”

Landfills are constructed for permanent disposal, for example, the waste is dumped with the objective of leaving it there indefinitely. Thus, the problem is not ours alone, but also that of future generations. When waste is disposed of responsibly in a landfill, it must be non-toxic and nearly insoluble at the time of disposal or within a reasonable period of time, it must not react with other substances, it must impede the passage of water and must be stable. Wastes disposed of in landfills today do not meet these high standards. By thorough pre-sorting and treatment the situation can be considerably improved, but this will not yield more or less inert and homogeneous waste (suitable for long-term disposal). Considerable problems arise when a “gate inspection” is made. The increasing role of chemicals in our daily life makes it extremely difficult to assess the toxicity of the wastes. A special problem is the lack of means to influence chemical production. The only sure way to solve the problems of disposing of persistent organic compounds is to give up the production of such materials. In the near future, however, it will not be possible to completely eliminate the disposal of toxic wastes in landfills. Hence it follows that waste disposal as practiced at present must, at least for a rather long transition period, be regarded as dangerous. Even if avoidance strategies are successful soon, the cleanup of older landfills will remain a problem, at least in the foreseeable future. (Döhöfer and Siebert, 1998)

(b) The man-made barrier

During the last several years, discussions on standards for landfills have initiated development of increasingly “perfect” liner systems. Because simple liner systems have often failed, liner systems combining mineral and plastic liners have now become the generally accepted standard for new landfills. Another reason why perfection of liner techniques is sought is a lack of confidence in the retention properties of natural systems; “perfect” man-made barriers would also make the selection of a site for a landfill independent of the geology of the site.

To assess the efficiency of man-made barrier systems, it is necessary to ask whether they meet the requirements placed on a landfill (see Figure 2.7). Thus, the long-term stability of the material of the liner system is of interest. Studies of the rates of permeation of plastic sheets and the liner properties of argillaceous rock show that persistent organic substances, but also large amounts of salt in leachate may be a problem in the long term (more than 30 years). If the waste as a barrier fails, and assuming unfavorable site conditions, the safety of landfills would depend exclusively on the functioning of liner system, the failure of the man-made barrier would immediately cause serious ecological problems. Often failure of this barrier is already “built in” at the time of its installation. The lack of technical standards and requirements has disastrous effects on the quality of these installations.

Nevertheless, it is apparently not always possible to fulfill all of these requirements when the manmade barrier is installed. As an answer to the dilemma, the catchwords “repairability” and “monitorability” were introduced into the general discussion. Additionally, landfills are now designated as “constructions.” This terminology attempts to express that landfills, like other construction objects (e.g., bridges) require constant maintenance and monitoring.

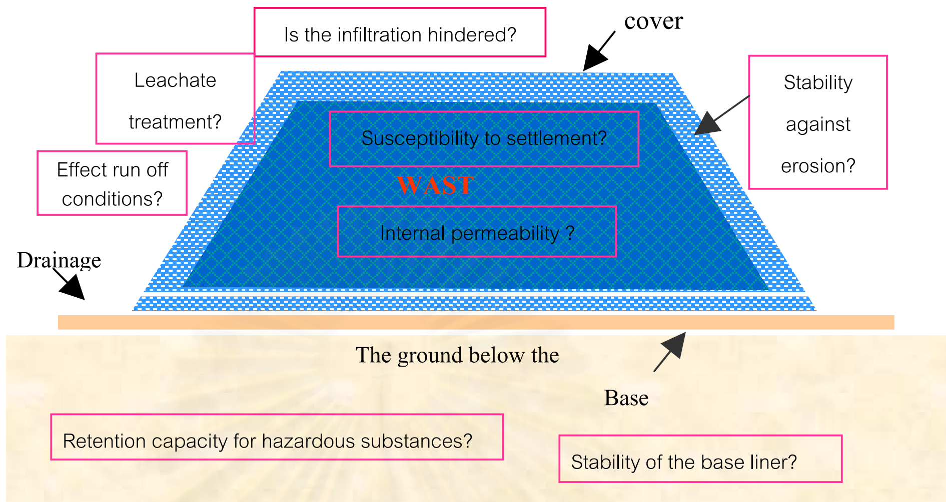


Figure 2.7 Weak point the landfill concept above ground.

(Döhöfer and Siebert, 1998)

However, the idea of monitoring and repair is illusionary to some degree and in contradiction to the objective of permanent disposal. Landfills are required to remain stable over long periods of time without constant repair. Landfills on the surface are exposed to the climate and will, therefore, not remain intact over the long term. Any attempt to repair a liner beneath high heaps of waste is doomed a priori. In the case of a landfill built above the highest groundwater level, the long-term functioning of the drainage system above the liner system is of great importance. If this system fails, leachate will back up in the waste, water will seep out uncontrolled at the sides of the landfill, and the hydraulic pressure on the liner system at the base will increase. Studies have shown that drainage systems in landfills with a high amount of organic input, as is true for our large landfills for domestic wastes, become very ineffective due to incrustation after a very short period of time of several weeks to months (Ramke and Brune 1990).

There is a positive correlation between rate of incrustation and the rate of waste disposal. Therefore, the worst-case scenario for currently operating landfills is complete failure of the drainage at the base of the landfill.

To avoid generation of leachate by infiltration of precipitation, the landfill must be covered with a material that requirements placed on a landfill hinders infiltration. Systems that combine mineral and plastic liners promise to be the most effective. Long-term stability of such systems is not guaranteed, however, considering that a landfill has steep slopes and is highly susceptible to differential setting.

Moreover, landfills above the water table with their special microclimatic conditions (high wind velocities, heavy rain, desiccation of the soil cover) are especially susceptible to erosion. These disadvantages are of minor relevance for landfills in pits, but these have the added disadvantage that the base of the landfill is usually below the groundwater table.

(c) The geological barrier

Considering the failure scenario for engineered barriers in landfills as described above, it is quite clear that particularly high standards must be required for the longterm functioning of the geological barrier. The main requirements are: (see Figure 2.8)

1. low permeability,
2. low (effective) porosity,
3. large thickness, and
4. high natural retention capacity for hazardous substances (Döhöfer and Siebert, 1998)

If these conditions are met, little groundwater will flow through the barrier and if the technical barriers fail, which should of course be constructed as efficiently as possible, groundwater contamination can be kept to a minimum.

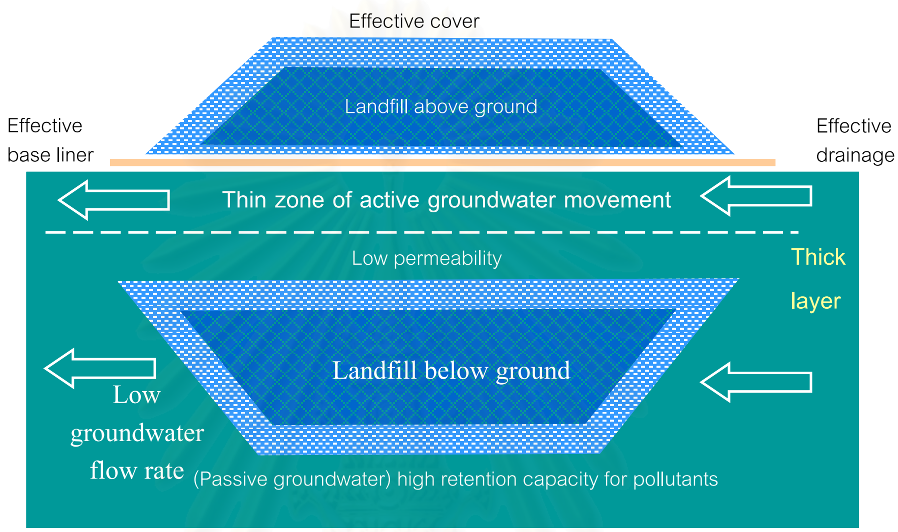


Figure 2.8 Requirement place on a landfill.

(Döhöfer and Siebert, 1998)

Of the rocks that might be suitable as a geological barrier, only cohesive, argillaceous rocks have these favorable properties (Dörhöfer 1988). Aquifers, whether sand or gravel layers or heavily fractured rocks like sandstone or limestone, can not be regarded as barrier rocks. Regrettably, however, these rocks are in high demand as raw materials and, when worked quarries, and gravel and sand pits are produced which have always attracted disposal of wastes. Even the few secondary biotopes for endangered species have been filled with waste under the pretext of landscape esthetics. In spite of the experience gathered with abandoned hazardous waste sites, many quarry and gravel-pit operators are much interested in using their sites for waste disposal. (Döhöfer and Siebert, 1998)

Most landfill hydrogeologists agree that waste must be disposed of only on thick, highly impermeable rocks. It is a matter of dispute with the operators of landfills how high the requirements should be set with respect to the quantifiable properties "permeability" and "thickness". The adsorptive capacity of a barrier whose thickness is not sufficient will be quickly exhausted and thus only slightly impede the entry of hazardous substances into the groundwater. Thus, a large barrier volume is decisive for minimization of contamination of the groundwater below a landfill. Such volumes are available, however, only if the barriers are thick. Thickness is a more important factor than permeability, which leads to an efficient reduction of the infiltration rate only if it is less than $k_f > 10^{-7}$ m/s (Döhöfer and Siebert, 1998). It is clear from the formulation of these requirements that the term "**geological barrier**" does not refer to individual quantifiable parameters, but to a complex system as a whole: (see Figure 2.9)

In conclusion, *"The **geological barrier** is the naturally occurring rock immediately below a landfill, extending some distance into the surrounding area, which, due to its properties and extent, substantially hinders the spread of contaminants. A geological barrier consists of naturally occurring, low permeability, consolidated or unconsolidated rock several meters thick which has a high potential for the retention of contaminants and extends beyond the area of the landfill proper. The geological barrier immediately below the landfill should be as homogenous as possible..."*

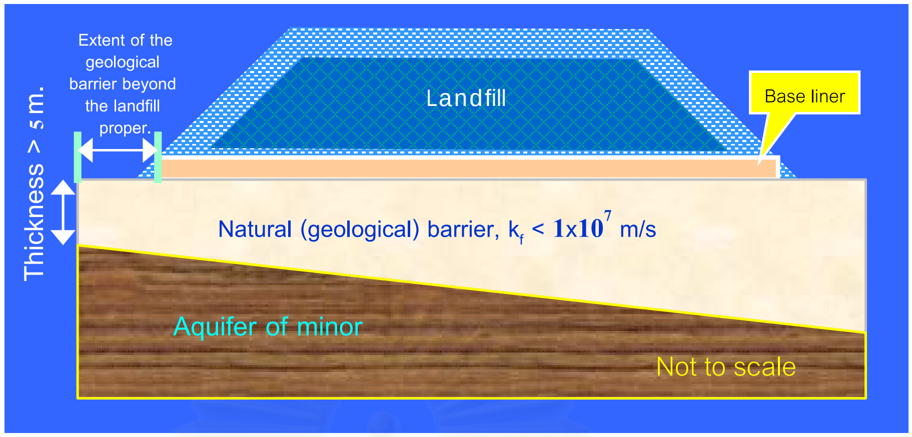


Figure 2.9 Standards for the geological barrier for domestic landfills. (Döhöfer and Siebert, 1998)

2.2.3.2 Environmental Impacts of Sanitary Landfill

Decomposing is a natural process after filling and covering solid wastes in each landfill site. The aerobic and anaerobic decomposition of solid wastes occur, m the first year, temperature and the amount of generated gas are normally very high. Later, decomposing rate reduces as a result of rather constant temperature. If the total solid wastes consist of 15% garbage, the decomposition occurs slowly but the decomposition of rubbish occurs quickly. In general, decomposing should completely finish in 12 months.

For the gas generation, the principle gases produced from the anaerobic decomposition of organic components are methane and carbon-dioxide. Peavy, Rowe and Tchobanoglous (1988) described the first step of decomposition in which carbondioxide reaches a peak and then is slowly tapped off. While the volume of methane is increasing, its density is more than carbondioxide and thus it moves toward the bottom of the landfill site. Carbondioxide will also move downward through the underlying formation until it reaches the groundwater and is rapidly soluble water.

The gas-movement in-landfill can -be controlled, by designing and constructing vents and barrier of materials that are more impermeable than the soil. Nevertheless, the use of compacted clays is most common. The thickness varies, depending on the types of clay and the degree of control required. Generally, the thickness of clay is from 0.15-1.25 meter.

For the leachate generation; water may enter the landfill site from external sources, such as, surface drainage, rainfall, and groundwater. The leachate causes deterioration of groundwater and surface water quality. The occurrence of leachate-movement occurs depends on the characteristics of the waste materials. The leachate discharge rate per unit area is equal to the value of the coefficient of permeability expressed in meters per day.

The control of the movement of leachate is equally important to the elimination of surface water infiltration. Ultimately, it may be necessary to collect and treat the leachate to percolate to the groundwater. The best practice is to cell for its elimination containment. The use of clay has been a favored method of reducing or eliminating the percolation of leachate. With the use of the geological barrier, appropriate surface slope (1-2%) and adequate drainage surface, infiltration can be controlled effectively.

The settlement of landfill site depends on characteristics of wastes and compaction density which affect the consolidation, the leachate and gases formed in the landfill site. Particularly, the height of completed fill influences the compaction ratio and the degree of consolidation.

The selection of proper landfill site is important. It is possible to select sites which are not suitable for agriculture, and other development activities, or abandoned mining.

Kertput (1999) suggests that 3 kinds of waste disposal method, namely, incineration, composting, and sanitary landfill, the incineration have more than 10% ash. These ashes must be disposed by landfill. In addition, the composting is the process that use more time, generate many residual wastes which must take for landfilling. So the sanitary landfill should be a final disposal of both the incineration and the composting.

2.3 Land Resource Evaluation for Waste Disposal

2.3.1 Criteria of Land Resources for Area Selection of the Sanitary Landfill

There are many of criteria which selected to evaluated the landfill suitability site, such as distance to municipality area, distance to groundwater well location, surface runoff, forest conservation areas, geology, soil type, hazard zone, etc. Table 2.5 is summarized the criteria for selecting the landfill area from large amount of papers both inside and outside the country.

2.3.2 The Role of GIS in Land Resource Inventory

Geographic Information System (GIS) is a rapidly advancing computer based technology, where information is organized, analyzed and presented with reference to location (Aronoff, 1989). Frequently described as a spatial process because location exist within space, GIS has revolutionized the way geographical information such as maps, airphotograhps, satellite image and geographical statistics are use in evaluation and decision making. The GIS covers the integrated technology that links the field of computer to any fields of study that concern with spatial information. These fields are, for example geology, soil science, environment, urban and regional planning, etc.

Table 4.6 Summarized the criteria, which used for selecting the solid waste disposal.

	Criteria	Buntharaksa (1992)	Disathien (1992)	Jeapatranon (1992)	Van der Wall and other (1992)
1	Conservation area: forest, watershed areas				
2	Topography and landform				non rough-morphology
3	Slope		< 20%	< 36 %	
4	groundwater table	> 1m.			> 2 m.
5	distance from municipality area			> 300 m.	> 300 m.
6	distance from village				
7	distance from historical site and airport site				
8	distance from groundwater well				
9	Surface water runoff	> 150 m.	slow surface runoff	>100 m.	> 100 m.
10	rock type/ lithology				non-kast or subrosion
11	geological structure				non-faults, volcanoes, landslides
12	Suitability soil - low permeability and thick layer				kf < 10 -7 m/s thickness > 5 m. (sediments) thickness > 20 m. (hardrock)
13	Transportation	> 500 m.			
14	non-flooding				

Table 4.6 (Cont.)

	Basagaoglu (1997)	PCD (1998)	Nuanchawi (1998)	Boonlue (1998)	Kerdput (1999)	Boonraung (2001)
1						
2			contour > 100 m.	non-swamp and highland		
3	5 - 10 degree			< 35 %		
4				deep groundwater table		
5	> 2 km.		> 300 m.	> 500 m.	> 15 km.	> 5 km
6		> 1 km.		> 1 km.		
7		> 5 km.				
8	> 365 m.	> 700m.		> 700 m.	> 700 m.	> 700 m.
9	100-300 m.	> 300 m.		> 300 m.	> 60 m.	> 300 m.
10				non-shalow bedrock		
11	non-faults			> 500 m. active faults	> 500 m	> 500 m. active faults
12				low permeability in lower soil		low permeability in lower soil
13	100-300 m				> 300 m	> 300 m
14						

GIS techniques allow the compilation and organization of information and facilitated their integration with environmental geology conditions, such as geology, geomorphology, natural resources, soil and land use. Any spatial or geo-referenced information from this study can be input into computer systems by conversion conventional data in hard copy from digital form data and allows computer analysis and output. This knowledge can be use to plan future land use planning programs.

2.3.2.1 GIS components

GIS is considered as a powerful tool used to handle the spatial information. Its main components involve hardware, software, data and people who also use it. These components can vary upon different applications and aims of organization.

GIS software should be basically composed of mapping software and database management system software. Mapping software has ability to organize geo-reference, geographic data while the database management system is use to organize their non-spatial attribute. This makes GIS to be different from other information system because it has an ability in spatial analysis with allow graphic an attribute data to be analyses simultaneously. It means that the output obtained from the analysis can answer questions, regarding resource management, in term of quality, quantity, and location of the resource and its potential uses. "ArcGIS" the GIS software is used in this study.

Data: In GIS, the graphic data are composed of not only a set of geographic elements or entities i.e. point, line, and polygon but also the spatial relationships among these element which are technically called topology (Korte, 1992). The distribution of these elements on a map is referenced by designated coordinate systems such as latitude/longitude, UTM, user-defined systems, etc.

Topology is the mathematical method used to defined spatial relationships in GIS (Aronoff, 1989). The topological model is basically applied to vector data structure. For example, the spatial relationships of a live can be expressed as, node of which line status and ends. Topology of a polygon is expressed as sries of lines that composing the polygon. and a certain polygon is composed of which arcs.

Data input and edit: Data input is how to encode data in various types into GIS. The input data types which cover graphic, attribute, and textual data can be in forms of hard copy (printed) and digital files. In case they are presented as printed format, the graphic data can be encoded to be digital using digitization or scanning to which attribute data are linked later.

Data storage and retrieval: The GIS data should be able to manage efficiently. Not only high efficiently in data storage and retrieval required in GIS but also data update and security should be provided. This depends on the facilities and capabilities of hardware and software. Redundancy of data should be avoided too because of great time consumption and the storage space wasting of the system.

Data manipulation and analysis: By nature, GIS data are generated as map layers. Therefore, GIS analysis function is capable for new layer derivation. This function can be used to replace conventional manual methods. Further, due to the automation capability used, GIS function can work for what never been done or never been able to do before by using manual methods. The GIS functions cover from simple analyses to the ones that use the facilities of mathematics and statistics.

Data display and query: Data display and query are functions used to show results to users. The system should be able to produce the results in hard copy form through printing media. It would also allow querying, which is on-line questioning of the database such as attribute, statistics, measurements, etc.

Metadata: the data about data. Metadata consists of data and document that are designed to help a prospective user find GIS data, determine whether it will serve a particular purpose, andhow to obtain and use obtaine the data. (Vienneau, 2001)

2.3.2.2 GIS Database Development

GIS database development is considered to be the most tedious and time-consuming activity. But this leads to an achievement of a database, which is very useful. A database is invaluable and meaningful in itself and also for further applications. Practically, the uses of a high quality database can results in fruitful outputs of GIS analysis.

The database collecting in GIS, the basic information for land use planning is the subject covering the environmental geology, socio-economic and lands information. In the study of Pokaew (1999), all of information used in evaluation for land use planning is presented in map form (Table 2.6 and Figure 2.10). The subjects are recorded relating to position, being known as spatial data. These information are created in the processes of input data and the development data base system for land use planning using the GIS.

2.3.3 Different Methods for Area Selecting

In general, a GIS need model representing reality. Due to the inherent complexity of the world and the interactions in it, the models are created as a simplified, manageable view of reality. The models help to understand, describe, or predict how things work in the real world. There are three main types of GIS models as follows;

2.3.3.1 Representative models

Representative models try to describe the objects in a landscape, such a stream, land use, or forest. The way representative models are created in a GIS is through a set of data layers. For example, is spatial analyst, an extension in Arc GIS, the data layers can be either raster or feature data. Raster layers are represented by a rectangular mesh or grid, and each location in each layer is

Table 2.6 Typical components of a GIS database of environmental geology (example of Pokaew, 1999)

Theme	Spatial and attribute data base
1.	Land tenure: administrative of Amphoe, Tambon, Municipal and sanitary districts
2.	Topography: elevation, slope classification and aspect.
3.	Water resources: water basin, watershed class, stream, water bodies, aquifer, and groundwater quality
4.	Mineral resources: mineral resources location, mining
5.	Geology: geological boundary, unit and landforms, fault and jount.
6.	Geomorphology: geomorphology boundary, unit and landforms
7.	Construction material: surfacial and rock material
8.	Soil type: soil boundary, soil type, soil characteristic
9.	Forest: forest land, forest use
10.	Land use: land use type
11.	Tourism: cultural and amenity tourism location
12.	Infrastructure: facilities, place and public facilities, transportation.

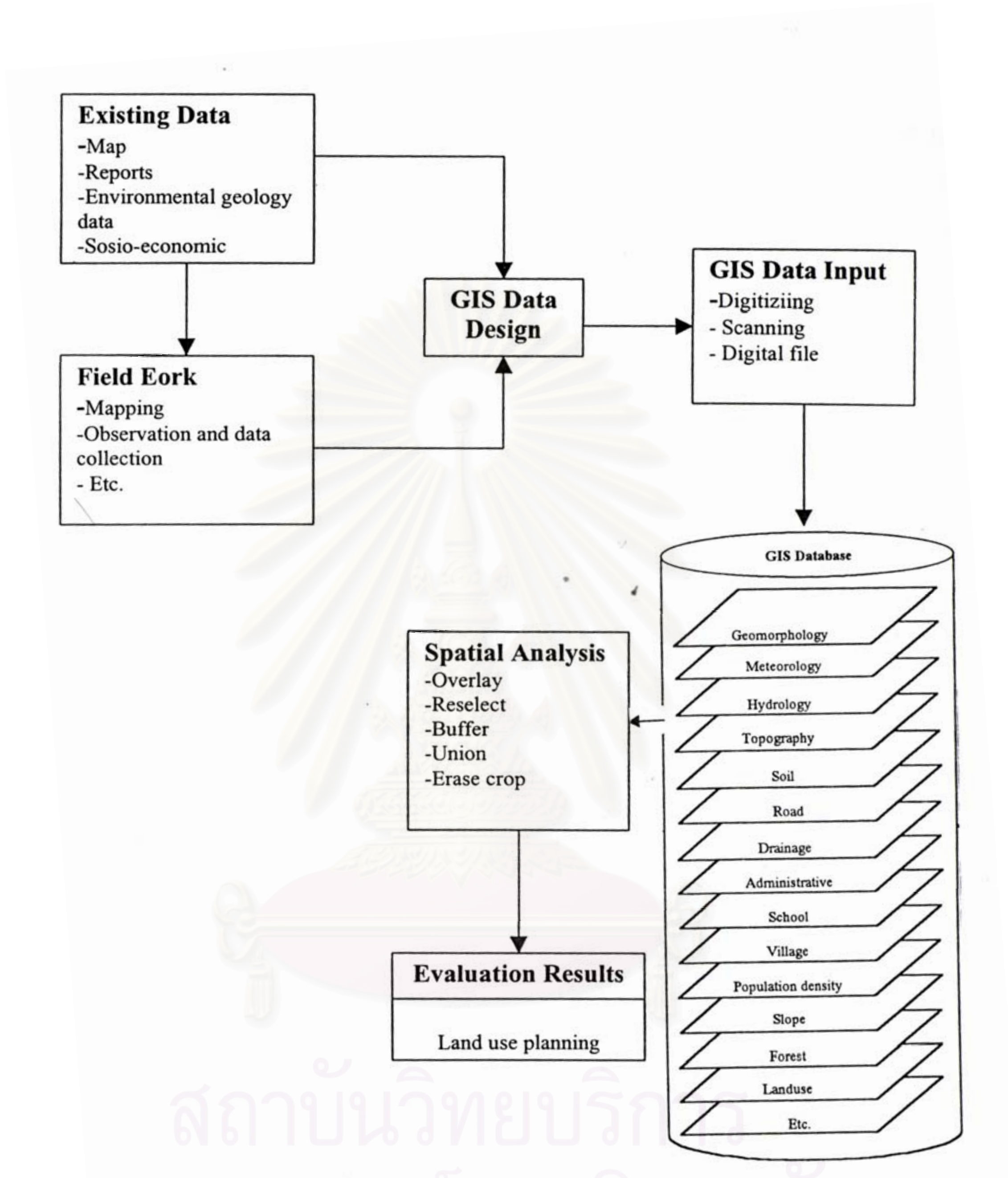


Figure 2.10 A typical flow chart of database development.
(example of Pokaew, 1999)

represented by grid cell, which has a value. Cells from various layers stack on top of each other, describing many attributes of each location. The model works by mathematically and/or logically operating values of the stacking cells.

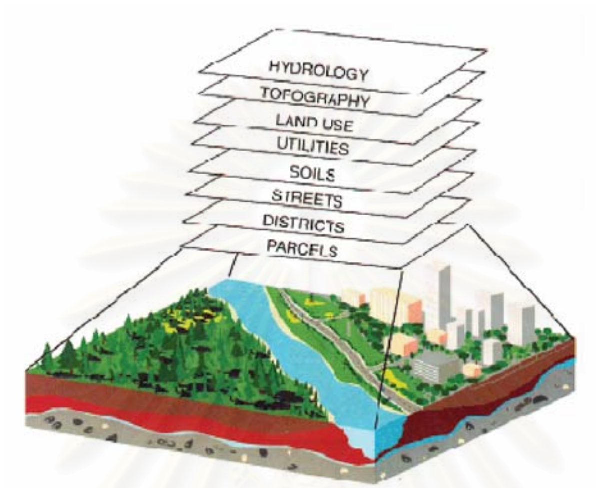


Figure 2.11 Representative models (after ESRI, 2000)

2.3.3.2 Process models

Process models attempt to describe the interaction between the geographic objects that are defined in the representation models through a defined set of algorithms. The algorithms are generally based on scientific understanding of the concerning process. Some examples are predicting the area of inundation behind a proposed dam, prediction where an oil slack will hit the coast, or the spread of a forest fire. These types of models are often difficult to design and implement, and there is no set methodology to follow. The GIS tools must be known and applied them creatively.

Table 2.7 The example of GIS process model integration.

(Bregt and Bulens, nodate)

Reference	Application	Process	Model type	GIS-package	Data of int. stored in GIS data structure
Vieux, 1991	Hydrology	AgNPS	Dynamic, 2D	ARC/INFO	TIN
Roo et al., 1989	Soil erosion	ANSWERS	Dynamic, 2D	Deltamap	cell grids
Lal et al., 1993	Crop growth	BEANGRO	Dynamic, 1D	ARC/INFO	.
Zack & Minnich, 1991	Fire management	KRISSY	Dynamic	ARC/INFO	polygon
Stuebe & Johnston, 1990	Hydrology	RCN	Static, 1D	GRASS	cell grids
Stuart & Stocks, 1993	Hydrology	TOPMODEL	Dynamic, 2D	SPANS	cell grids
Van Deursen & Kwadijk, 1993	Hydrology	RHINEFLOW	Dynamic, 2D	PC-raster	cell grids
Van Lanen, 1992	Crop growth	WOFOST	Dynamic, 1D	ARC/INFO	polygon
Grunblatt et al., 1991	Desertification		Static, 1D	?	polygon
Shea, et al. 1993 Burke et al, 1990	Hydrology Ecology	HEC-1/HEC-2 Century	Dynamic,2D Static, 1D	ARC/INFO Arc/Info	Polygon polygon

M L = Model implemented in GIS macro language

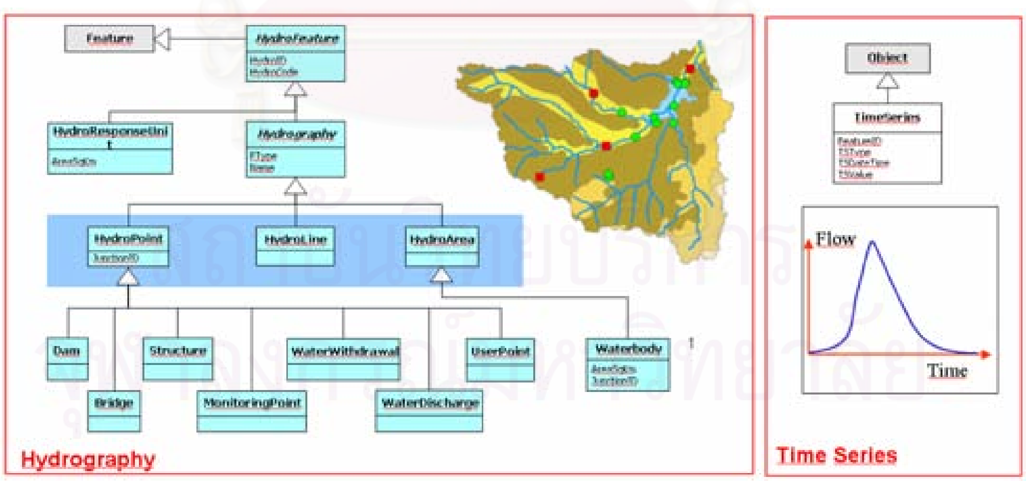


Figure 2.12 Process models: the example of the process model as HEC-GeoRAS

(after Maidment, 1998)

2.3.2.3 Suitability models

GIS is often used to find the best location for some purposes: new businesses, schools, sanitary landfills, and emergency evaluation sites are some examples. The models apply a set of criteria to the GIS layers to find places that are acceptable locations for the activity. Suitability modeling is fairly easy at least, there is a standard methodology to follow, and the GIS processing is trivial. The hard part is defining the criteria for selecting the site. The suitability models can be described to 2 types, as Binary suitability models and Weighted suitability models.

(a) Binary suitability models: this is perhaps the easiest approach to spatial coincidence modeling (ESRI Thailand, 2002). The layers was classified into "good" or "bad" and combine the reclassified layers with Map algebra using a logical "AND" and "OR". Any non-zero output cells meet the criteria. Figure 2.13a showing the example of the binary suitability models.

(b) Weighted suitability models: these models are more complex than binary suitability model because they have ranking value on each data as a value on layer and layer themselves. The values in the layer have relative importance, called "Score" or "Rating number" (R), and the layers themselves have relative importance, called "Importance number" or "Weighted number" (W). as shown in figure 2.13b. There are many of formulas used in this model but the famous formula to solve the area selection for landfill in the following form:

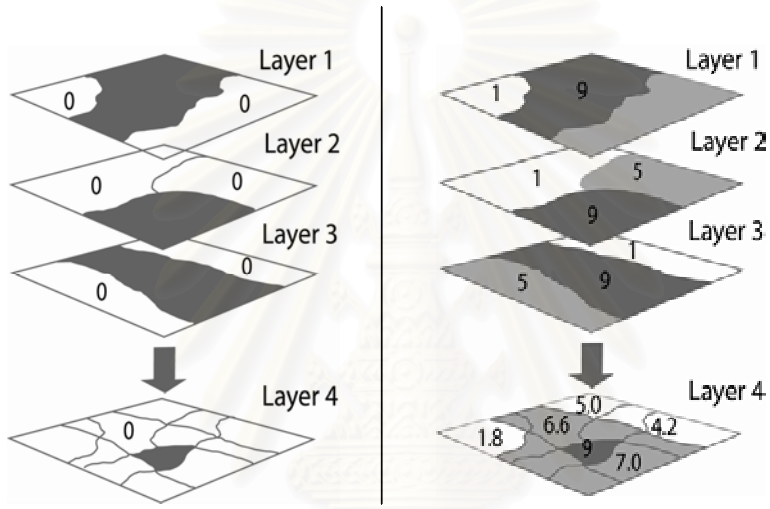
$$A = R_1W_1 + R_2W_2 + R_3+W_3 + \ldots.. + R_nW_n$$

While; A = suitability area

R(i) = Rating number of value (i) in layer (j)

W(j) = Weighted number of layer (j)

n = number of layer



(a) Binary suitability model

(b) Weighted suitability model:

By Layer4 = (Layer1 * 0.5) + (Layer2 * 0.3)

+ (Layer3 * 0.2)

Figure 2.13 Suitability models which is included Binary suitability model and weighted suitability model (applied from ESRI Thailand, 2002).

CHAPTER III

SONGKHLA: THE STUDY AREA

3.1 Socio-economic Background

3.1.1 Social Conditions

3.1.1.1 Administration

The administration of Songkhla can be divided into 3 levels, including;

Central administration consists of government agencies from various ministries that have arrigned duties to be set up in the provincial area.

Provincial administration consists of 2 sub-levels namely,

Provincial level: consisting of 33 permanent offices.

District level: consisting of altogether 16 Amphoes, 124 tambons, and 958 village.

Local administration consists of 1 administrative council, 4 municipality councils, 15 sanitary councils, and 121 tambons administrative councils.

3.1.1.2 Population

The total number of population of Songkhla area is 1,249,402 in December 2001. Among these, 615,043 are male, and 634,359 are female. Therefore, the ratio of male:female is about 1:1.

The total area of Songkhla area is approximately 7,400 km^2. This makes the average population density to be about 169 person/km^2. There are altogether 321,264 families (Dec, 2001) with an average of 4.04 persons/family.

In 2001, Songkhla municipality has the maximum population density about 11,900 persons /km. sq. Hat Yai municipality is the second of about 7,300 persons /km. sq. And the minimum is Saba Yoi municipals of about 60 persons / km^2.

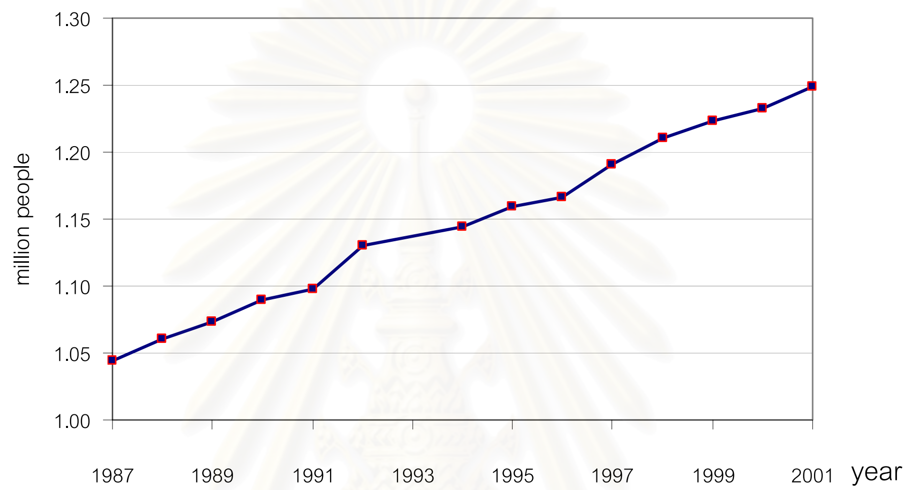


Figure 3.1 Population-year curve of Songkhla in 1987 to 2001.

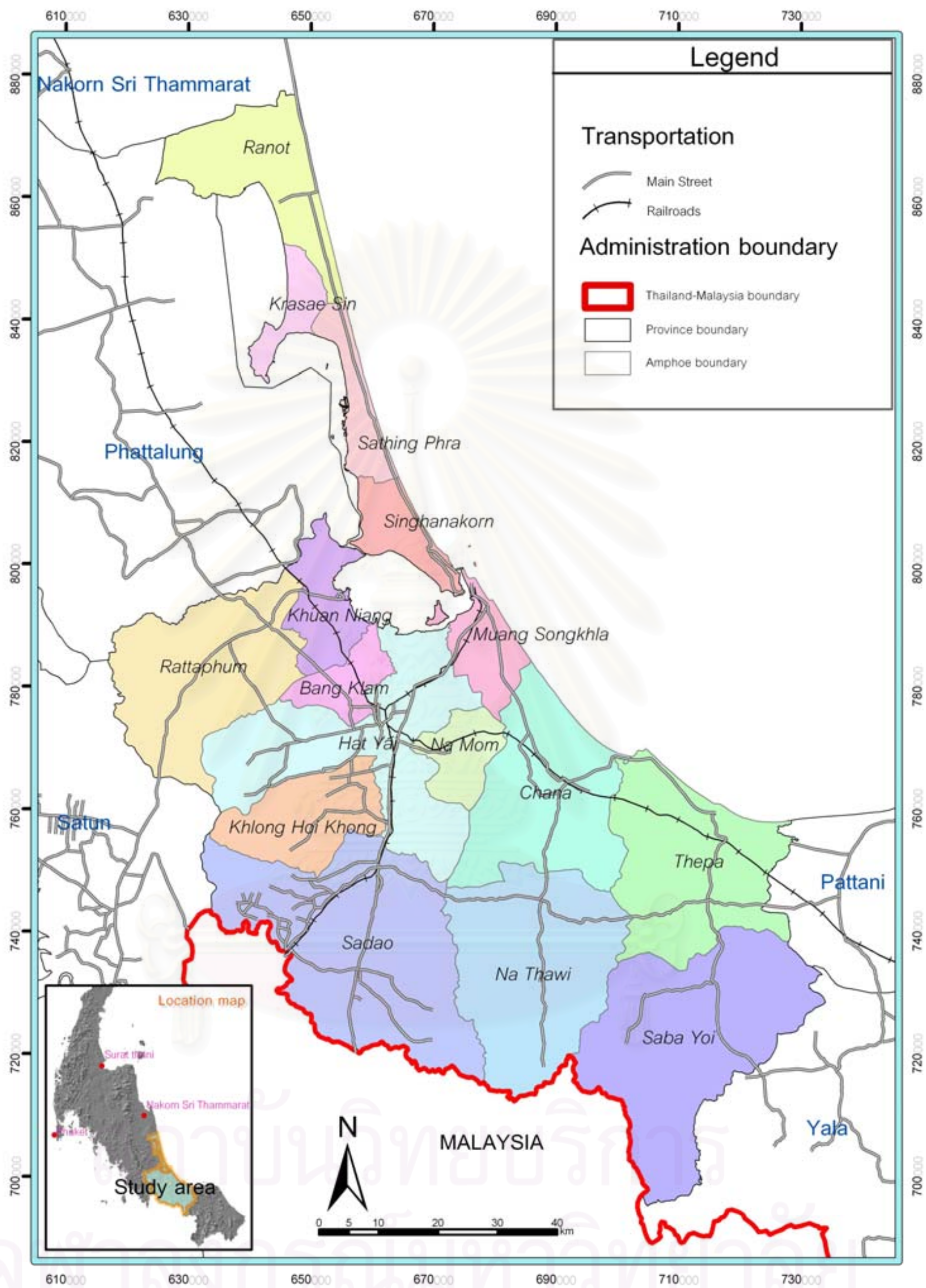


Figure 3.2 Administration boundary map of Songkhla

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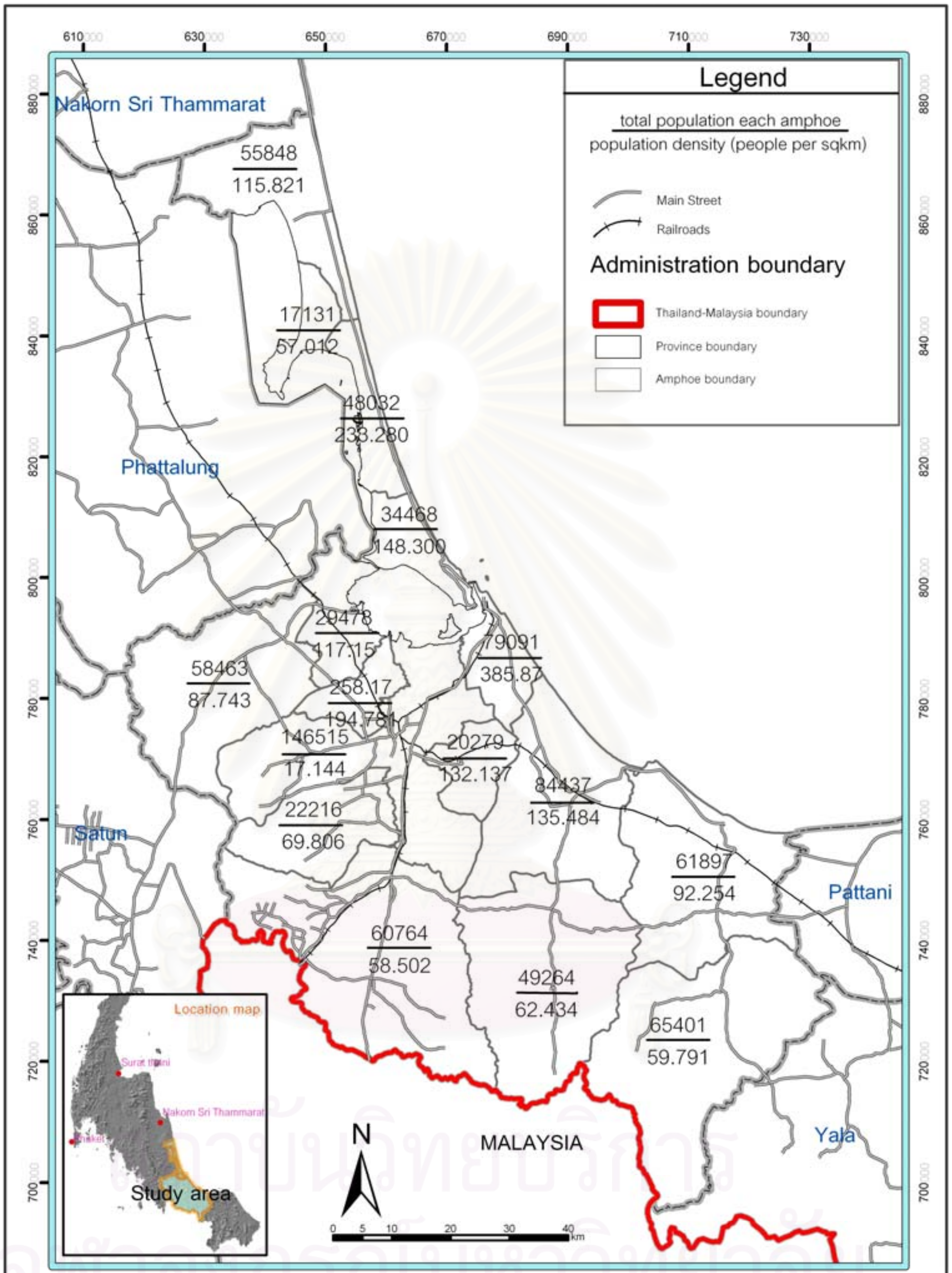

Figure 3.3 Population map of Songkhla

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3.1.1.4 Water Supply:

Within Songkhla area, there are five provincial water supply centers as follows:

Songkhla area Water Supply: water production capacity 1,978,812 m^3/year, number of customers 41,463.

Sadao Water Supply: water production capacity 165,220 m^3/yr., number of customers 4,274.

Patong-Pangla Water Supply: water production capacity 34,142 m^3/yr., number of customers 838.

Ranot Water Supply: water production capacity 28,200 m^3/yr., number of customers 1,434.

Nathawee Water Supply: water production capacity 1,978,812 m^3/yr., number of customers 41,463.

In addition, there are other local water supply centers under the responsibilities of the Department of Public Works, Office of Rural Department, Department of Public Health, Department of Mineral Resources.

3.1.1.5 Transportation and Communication

The transportation to, from, and within Songkhla area can be most conveniently done by means of very good road network systems. The main road, which runs from Bangkok to Songkhla area, is the Petchakaseam road or Highway no. 4 of about 950 km. It extends further to Malaysia at Ban Dan Nok, Amphoe Sadao, with distance from Amphoe Hat Yai of about 35 km. Altogether, there are 7 national Highways passing through Songkhla area, namely, nos. 4, 42, 43, 406, 407, 408, 414. Besides, there are 202 local roads under the responsibility of the Department of Public Works. In addition, Songkhla area can be reached by railroads; namely, the Southern railroad extends from Bangkok.

There is one deep-sea port located at Tambon Hua Khao, Amphoe Singha Nakorn with total delivery capacity of 1,000,000 metric-tons per annum (Ministry of Interia, 1999). Altogether, there are 3 fishing ports located at Amphoe Muang. There is also navy port located at Amphoe Muang for coastal defense purpose. Besides, there is one refined oil unloading facility and oil depots in the vicinity of Amphoe Singha Nakorn.

In Songkhla area, there are two airports, namely, the international airport at Amphoe Hat Yai, and navy airport at Amphoe Muang.

3.1.2 Economics

3.1.2.1 Provincial Product

The gross provincial product (GPP) of Songkhla is highest in southern Thailand. The GPP of Songkhla in 1994 was 58,720,905 baht with the per capita income of 48,171 baht. The agriculture contributes approximately one-third of the total GPP, or 20,631,787 baht. There are 72.74 percent of the workforces in agricultural sector. The important economic crops are para rubber, rice, coconut, etc. The para rubber plantation occupies totally 1,601,402 rais which is the highest in Thailand. However, during the past years the increases in agricultural production have been relatively low due to the problems of prices and marketing.

The industrial structure of Songkhla area is mainly agro-industries, namely, para rubber industry, Sea-food industry. During 1993-1998 the industrial outputs of Songkhla area is slowly increase due to the lack of financial liquidity, increasing labor cost ,limited fuel supply. In addition, the agricultural produces have been substantially high during the same period and consequently cause the over supply, and price decrease.

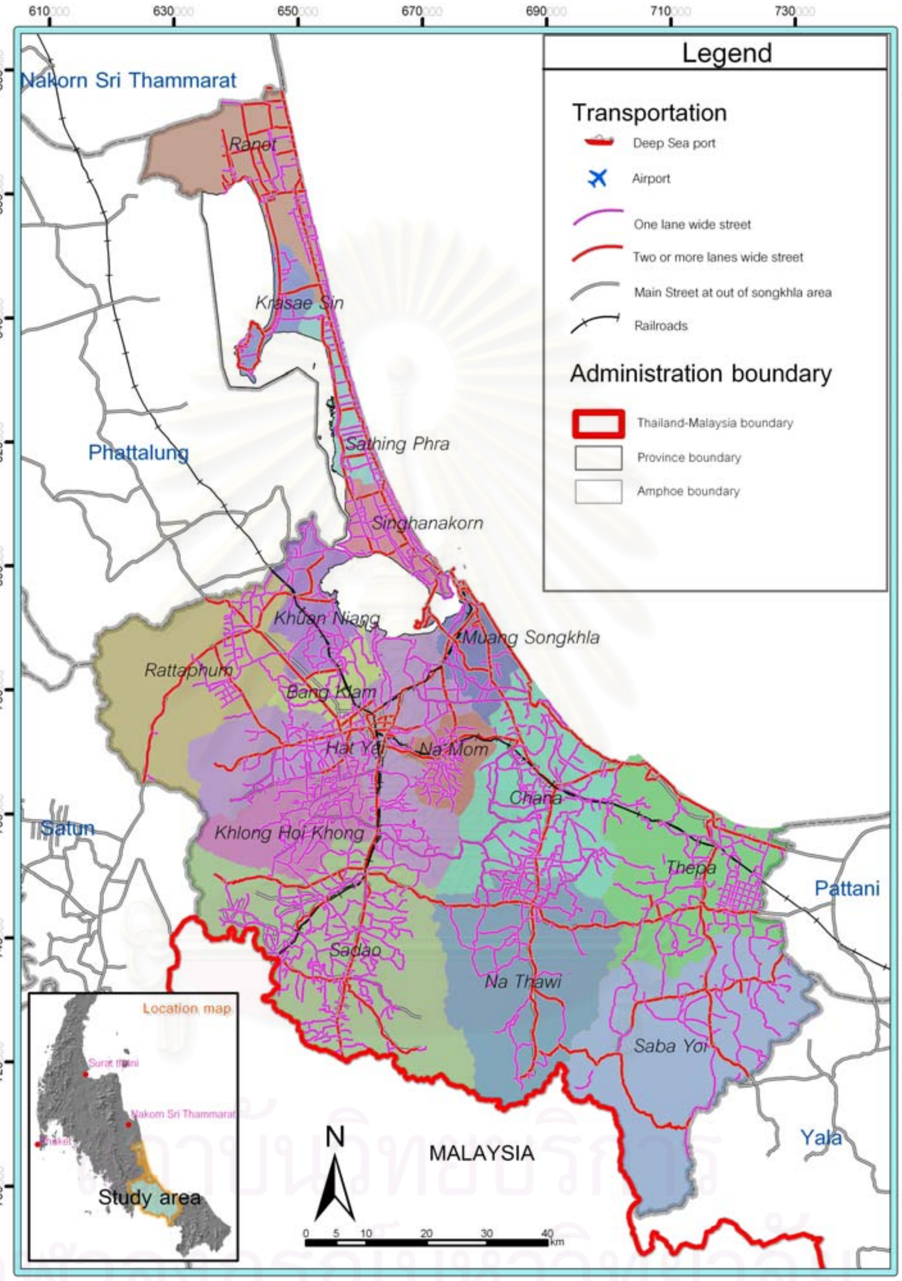

Figure 3.4 Transportation map of Songkhla

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It is noted that the government has promoted the setting up of the industrial estate under the sub-regional development known as Indonesia-Malaysia-Thailand Growth Triangle (IMT-GT).

The service industry related to tourism is among one of the most promising and expanding rapidly of Songkhla area. Most of the tourists are from Malaysia and Singapore. All supporting facilities and services have been substantially developed to promote tourism. In 1994, there are altogether 2,074,348 for foreign tourists coming to this area, an increase of approximately 8.5 per cent from those of the 1993. It is estimated that each foreign tourist spends approximately 2,600 baht per day during the visit to Songkhla area. The overall incomes of this area from tourism are 14,297 million baht in 1994.

Table 3.1 Gross provincial product of Songkhla year 1996 to 1998

	Current market prices (million baht)	Per capita (Baht)
1996	76483	60,991
1997	78947	62,163
1998	84,498	65,706

3.1.2.2 Land Use and Land Use Changes

The land use pattern of Songkhla is determined on a basis of data and information obtained 1982, 1992, and 2000, they are classified as Follows:

Agriculture land, which is a further subdivided into paddy field, Para rubber plantation, coconut plantation, oil palm plantation, mixed orchard, and coastal aquacultural area.

Forest, which is further, subdivided into beach forest, mangrove forest and tropical rain forest.

Urban and build-up area

Mining and abandon mine

Water body and wet land

The proportion of various types and the comparison of land use change in 1982, 1992, and 2000 are summarized in figure 3.5, 3.6, and 3.7.

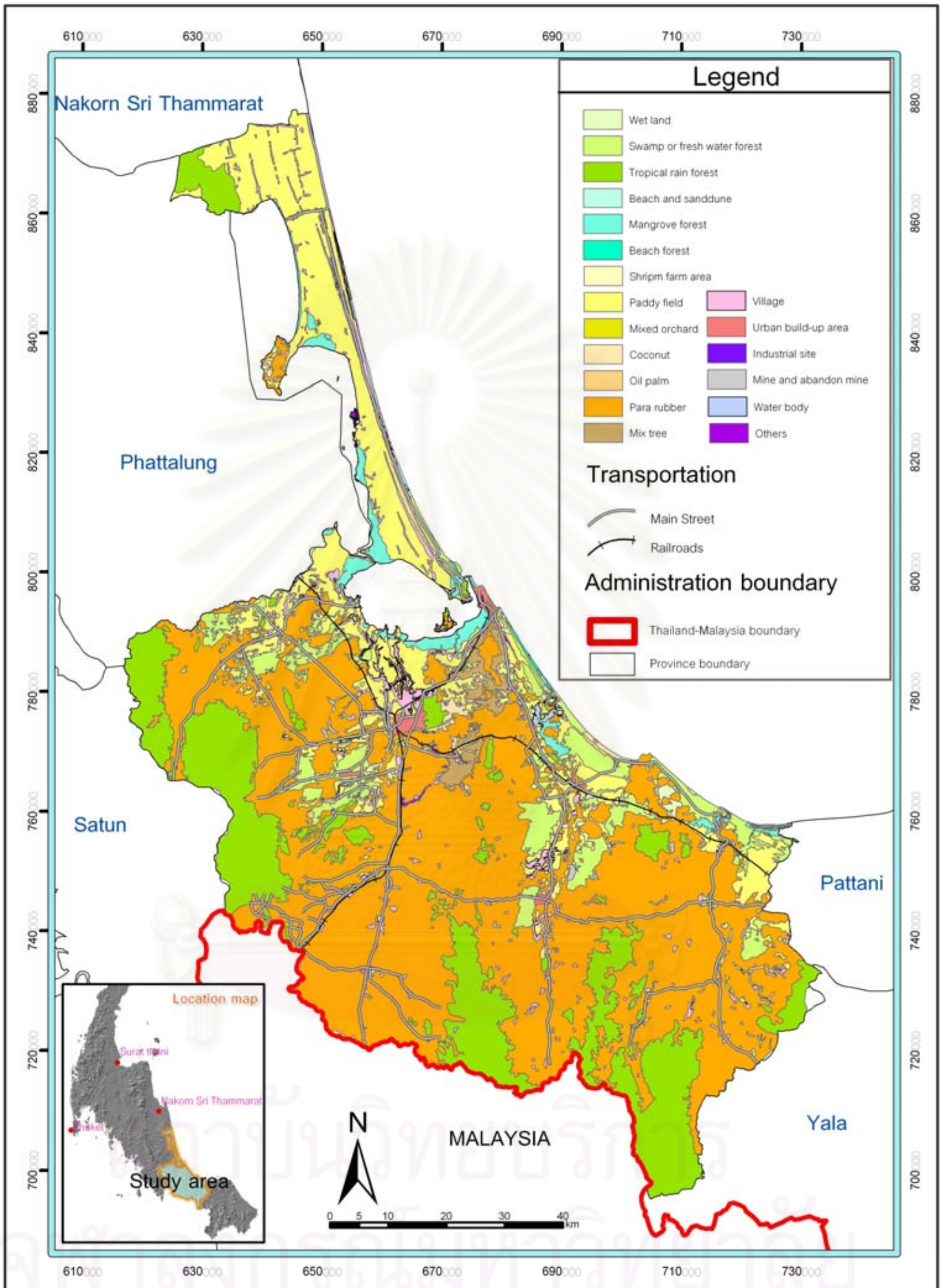

Figure 3.5 Land use map year 1982 of Songkhla

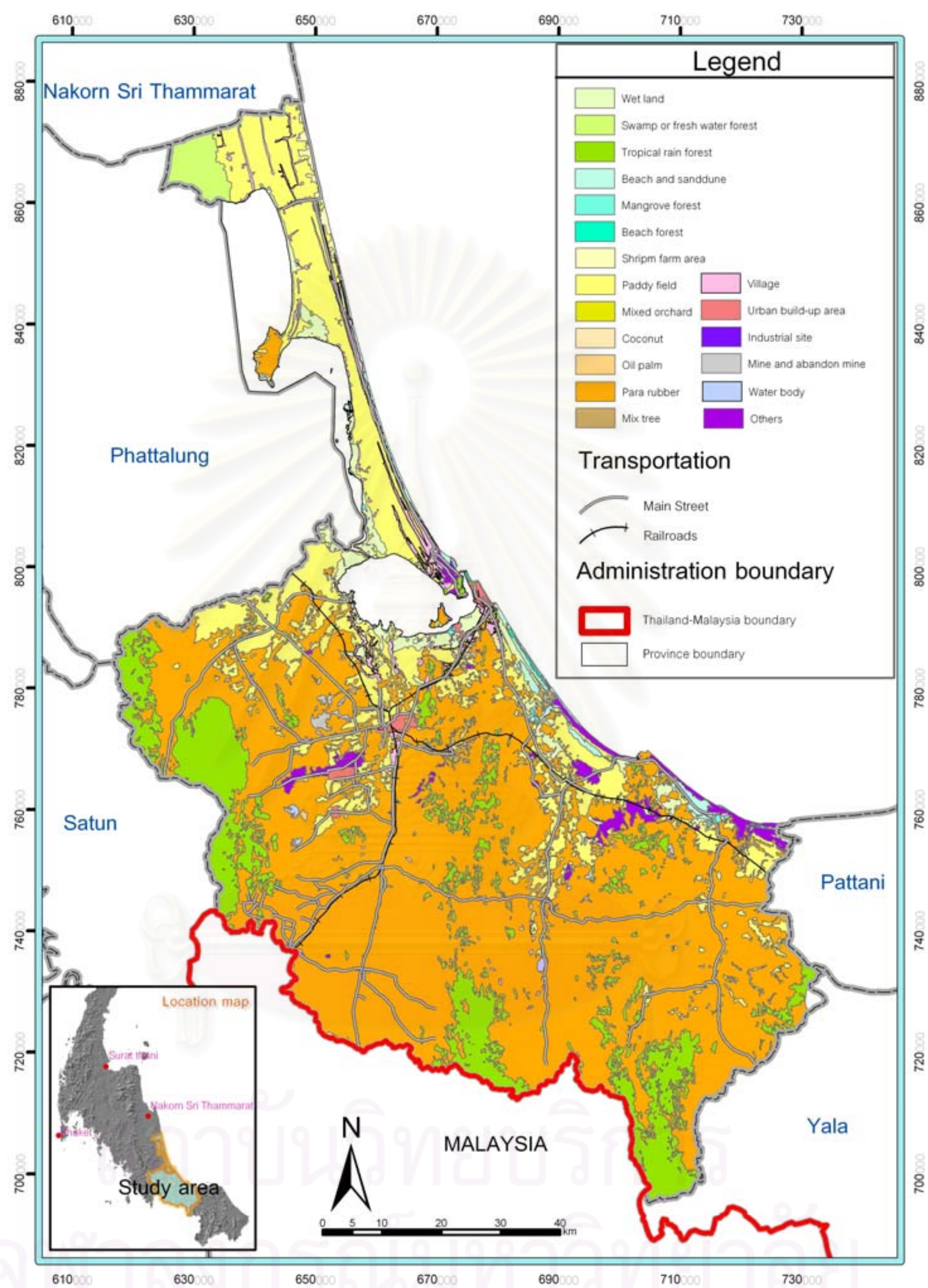

Figure 3.6 Land use map year 1992 of Songkhla

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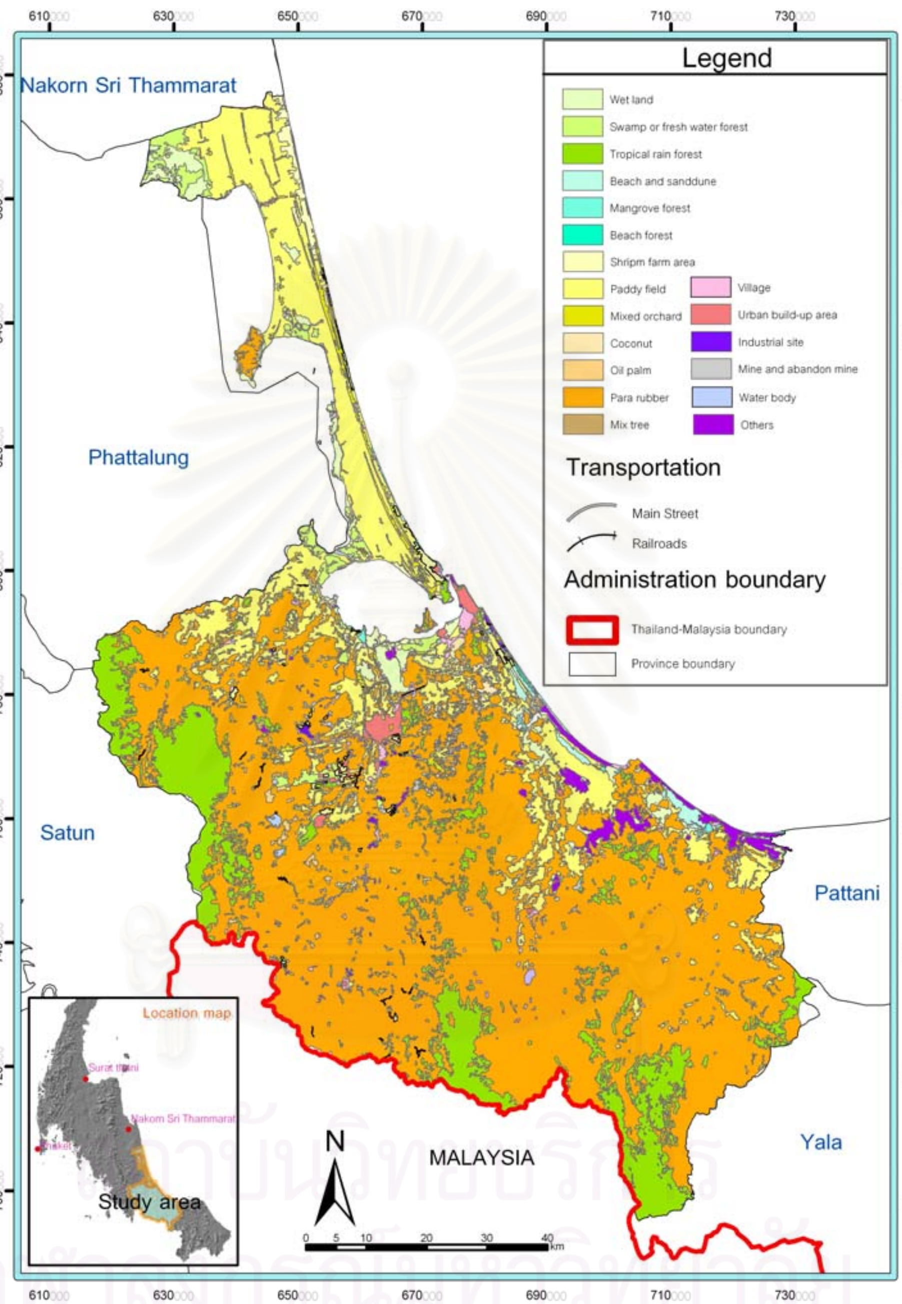

Figure 3.7 Land use map year 2000 of Songkhla

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3.2 Physical Environment of Songkhla

3.2.1 Climate

The general climatic condition of Songkhla area is considered to be the monsoon climate type with distinctive wet and dry seasons. The wet season lasts for nine months between May to January. The area is under the influence of SW monsoon during may to September, and under the NE monsoon during October to January. This season is characterized by heave rainfall under these two monsoons.

The dry season begins in February until April, and is characterized by the high temperature with little rainfall under the influence of the SE monsoon.

The average annual rainfall of the Songkhla area is 2,018.5 mm. with the maximum rainfall in November.

The average annual maximum temperature is 31.4^{o}C, whereas, the average annual minimum temperature is 24.3^{o}C. The maximum average annual temperature in May is 32.9^{o}C, and the minimum average annual temperature in October is 23.9^{o}C. In all year round, the difference in temperature is approximately 10^{o}C.

The relationship between average monthly temperature and average monthly rainfall of Songkhla area represented as the hypther graph (Figure 3.8).

The maximum relative humidity of the Songkhla area in November is 83 %, whereas the minimum relative humidity in February, August, and September is 75 % and the average annual humidity is 77%.

The average annual wind speed in the Songkhla area is between 3.9-8.6 knots with the maximum speed in November of 7.6 knots, eastwardly. The easterly wind is during November to April. Whereas, the southwesterly wind during May to October.

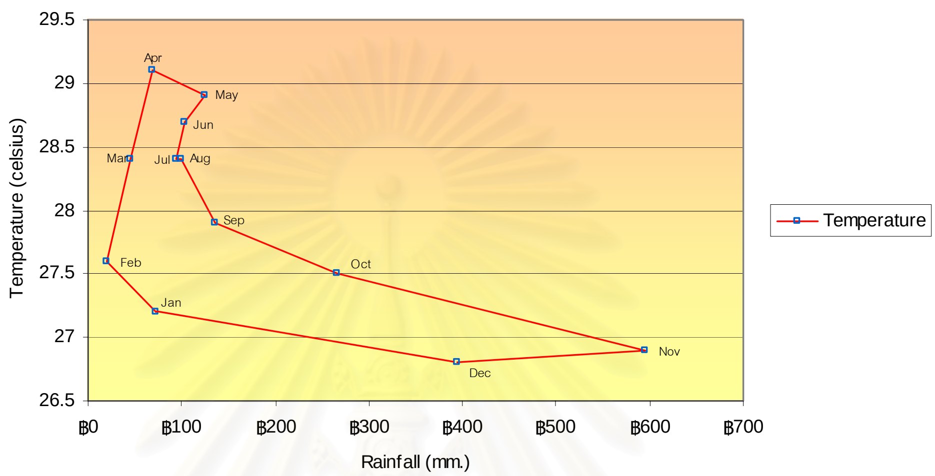

Figure3.8 Hypthergraph of Songkhla at Hat Yai Airport Station

3.2.2 Topography

Songkhla area is situated in the Thai-Malay peninsula facing the Gulf of Thailand. The general landforms of the area can be categorized as mountainous areas, unduratory terrains, and flat coastal plain. The mountainous area consists of N-S oriented mountain ranges, namely; part of Ban Thad range in the most western part, central range and most eastern range of northern of Sankala Kiri range. For the most western mountain range, there are Khoa Khaew with the peak of 742 meters MSL, and Khao Soi Dao are the main mountain locating from north to south, respectively. The central mountain range consists of Khao Ok Kai in the north and Khao Nam Khang with peak of 748 meters MSL locating from north to south, respectively. The eastern mountain range consists of Khao Sung with peak 316 in the north and Khao Plai Than with peak 642 in the south.

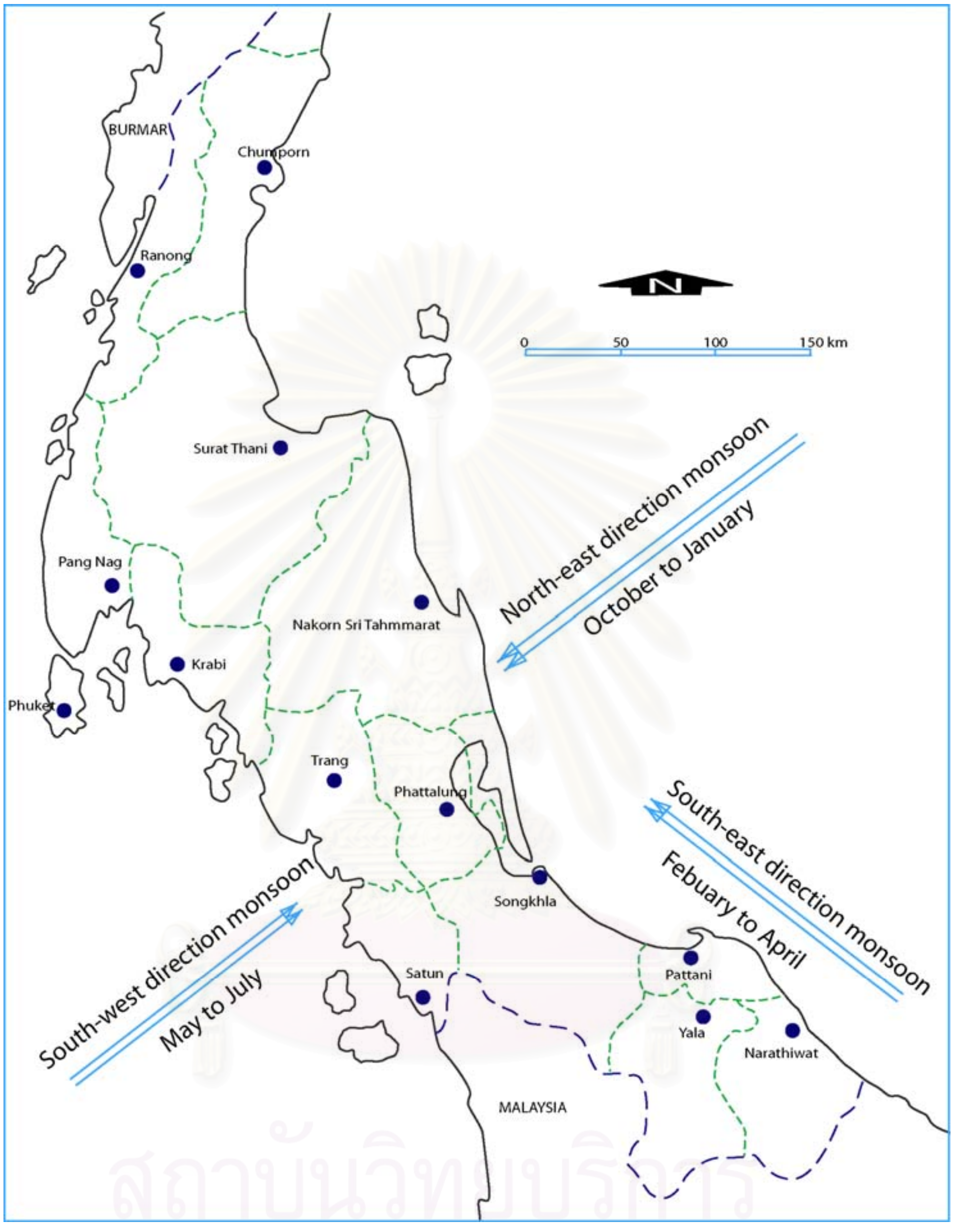

Figure 3.9 The main monsoon in Southern Thailand

Between the western and central mountain range, there is an unduratory terrain of approximately 30-km wide, and 70 km. long. Between the central and eastern mountain ranges, there is another smaller unduratory terrain of approximately 20-km wide, and 30 km long.

The most eastern boundary of Songkhla area is bounded by the narrows, flat sandy coastal plain of approximately 155 km. long extending from Nakorn Si Thammarat in the north to Pattani in the South.

The area in the northern part behide the flat coastal plain is a large fresh/brackish water body or lake extending north-south parallel to the flat coastal plain. The small lake in the most northern part is known as Tale Noi, and the relatively large lake in the central part is Tale Luang connected with the Tale Saab Songkhla area in the South by Khlong Pak Khad. The Songkhla Lake has a small opening to the Gulf of Thailand, therefore the water in the Tale Saab Songkhla area and Tale Luang is salty and blackish, respectively, whereas the water in Tale Noi is fresh water. Within Tale Luang, there are three islands close to the western margin of the lake called Ko Si and Ko Ha locating in Tale Luang, and Ko Yor locating in Tale Saab Songkhla area.

There are 3 off-shore island in Songkhla area, namely, Ko Hnoo wth an area of 94 rai and distance 2.5 km. off Samila beach; Ko Maw, north of Ko Hnoo, with an area of 25 rai and distance of 3.5 km. of Samila beach; and Ko Kham, south-eastern part of Amphoe Chana with an area of 25 rai and distance of 2 km. from Paknam Sakom.

The topography and slope of Songkhla area is presented in Figure 3.10 and 3.11, respectively.

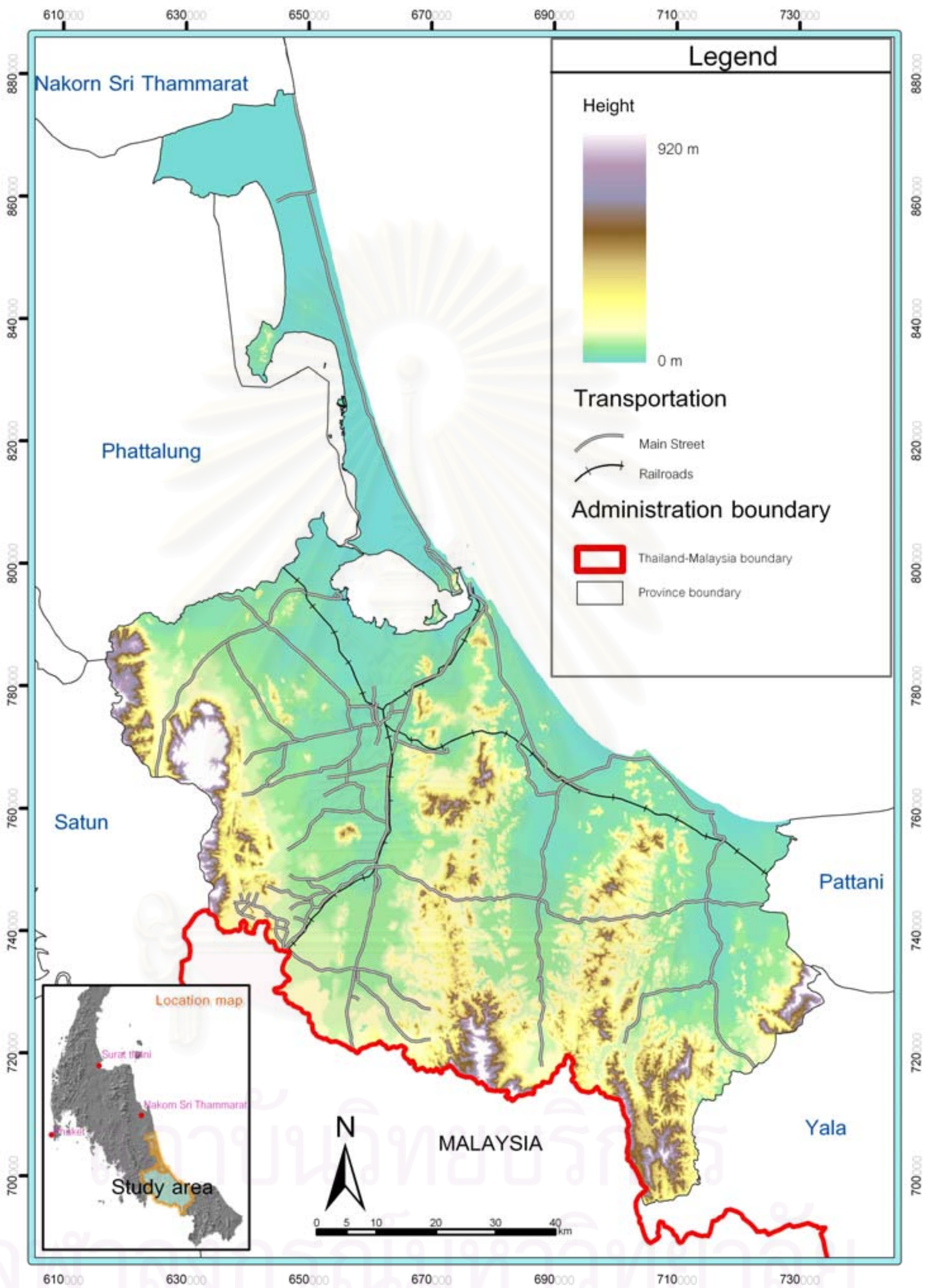

Figure 3.10 Topographic map of Songkhla

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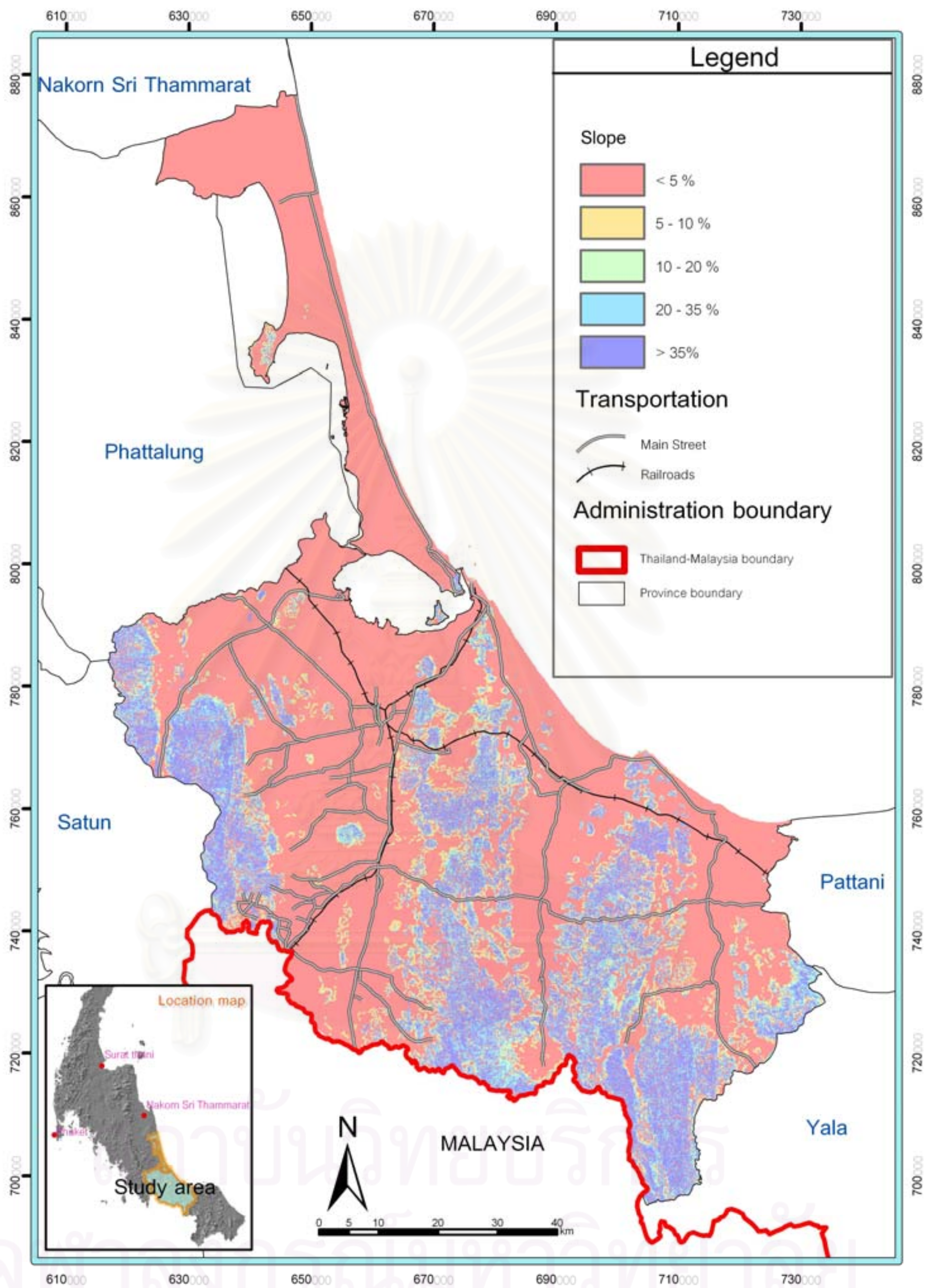

Figure 3.11 Slope map of Songkhla

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3.2.3 Surface Drainage

The important surface water system can be categorized to 2 types as follows:

Songkhla area Lake Basin: the largest surface water covering area approximately 1,045 km. sq. are lakes, namely, Tale Noi Lake, Tale Luang Lake, and Tale Saab Songkhla area Lake details are early discussed in figure 3.12

Surface Drainage System: Songkhla area is covered by 4 main catchment area, namely, Khlong Rattaphum, Khlong U Tapao catchment area, Khlong Nathawee catchment area, and Khlong Thepa catchment area.

The Khlong Rattaphum catchment area covered approximantely 700 km^2 with the main channel Khlong Rattaphum of totally 45 km. long originated from the Ban Thad and Khao Luang ranges, passing through Amphoe Rattaphum, Kuanniang, and finally drain in to the Songkhla area Lake at Ban Hua Hat.

The Khlong U Tapao catchment area covered approximately 4,000 km^2 with the main channel Khlong U Tapao of totally 68 km. long originated from the Sankala Kiri ranges, passing through Amphoe Hat Yai, King Amphoe Bang Klam, and finally drain in to the Songkhla area Lake at Ban Khlong Bang Klam.

The Khlong Na Thawee catchment area covered approximately 1,700 km^2 with the main channel Khlong Na Thawee of totally 70 km. long originated from the Khao Nam Khang, Sankala Kiri ranges, passing through Amphoe Na Thawee, Chana, and finally drains in to the Gulf of Thailand at Ban Pak Bang.

The Khlong Thepa catchment area covered approximately 1,600 km^2 with the main channel Khlong Thepa of totally 135 km. long originated from the

Sankala Kiri ranges, passing through Amphoe Thepa, and finally drains in to the Gulf of Thailand at Ban Khlong Pradue.

3.2.4 Soil and Landform

3.2.4.1 Soil

The soil unit is Songkhla area can be categorized into 26 units as see in figure 3.13. The description is explained as follows;

Soil unit 2: Upper soil is grey to dark grey clay in colour, lower soil is grey clay with yellow and brown mottles. Usually found in central plain, water confined 20-50 cm about 3-5 months. There is yellow jarosite in the area that influenced by saline water, low permeability, extremely to strongly acid (pH 4.5-5.5).

Soil unit 3: Upper soil is dark grey and dark greyish brown clay, lower soil is grey and light brown clay with dark brown, yellowish brown, and yellowish red mottles. Physiography is flood plain and plain, low permeability. In rainy season, water confined 20-50 cm about 4-5 months long. There is mud crack in dry season. In coastal area, usually found shell in lower soil. There is slightly acid (pH 5.5-6.5), and lower soil with shell is slightly alkaline (pH 7.5-8.0).

Soil unit 5: Upper soil is dark grey, greyish brown clay, lower soil is light grey to grey clay with dark brown and yellowish brown mottles. Usually found iron and manganese concretion. It occurs from alluvium. Physiography is plain of recent terrace and low terrace. Water confined less than 30 cm about 3-5 months, slightly acid (pH 5.5-6.5), in lower soil with calcareous concretion is slightly alkaline (pH 7.5-8.0).

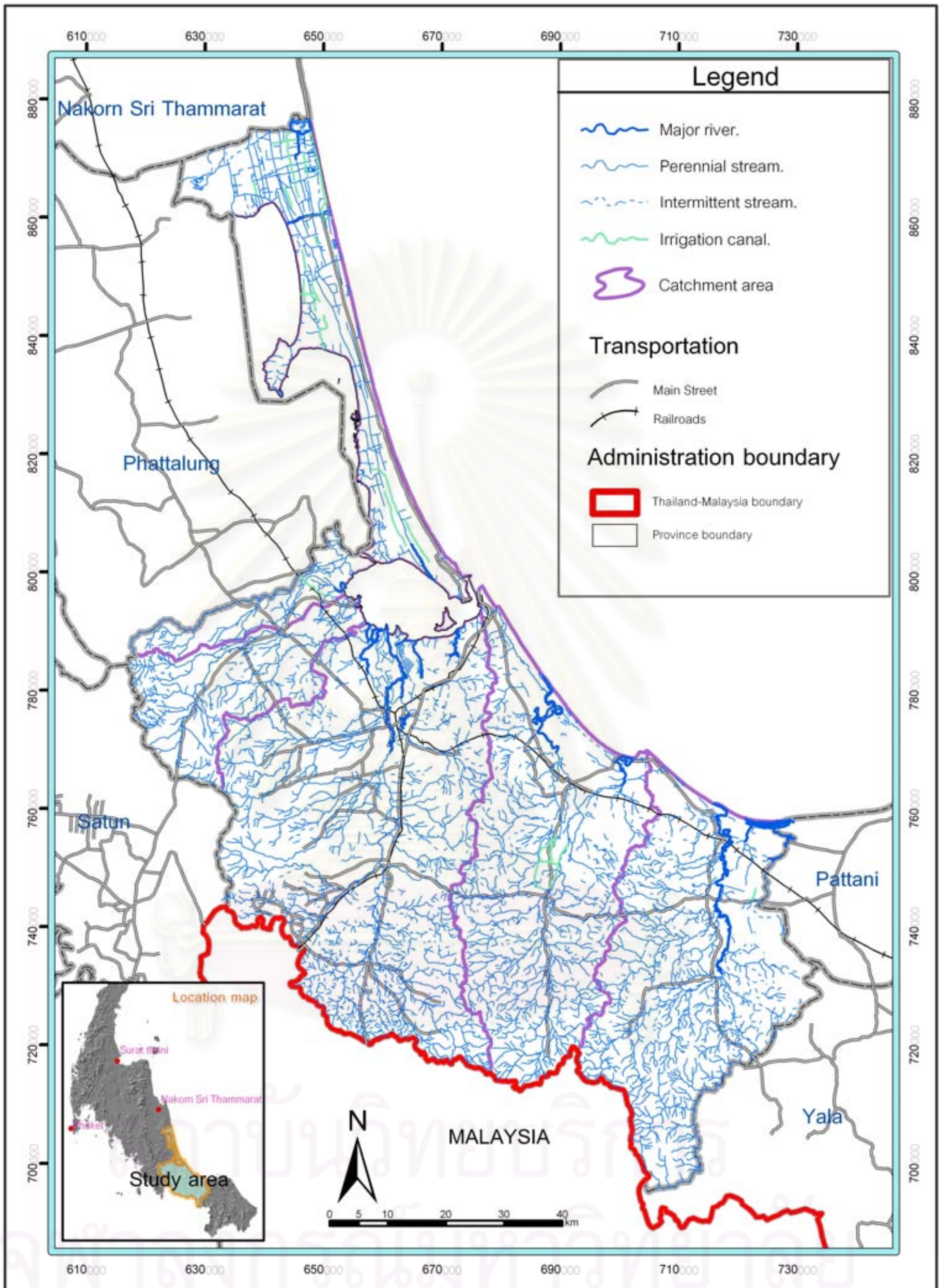

Figure 3.12 Surface drainage system and catchment area map of Songkhla

Area Selection for Solid Waste Disposal in Changwat Songkhla

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Soil unit 6: Upper soil is dark grey clay and lower soil is greyish brown or grey clay with brown and red mottles. Some area is lateritic soil, iron or manganese concretion. It occurs in alluvium, low permeability. Physiography is plain, flood plain, and low terrace. There is water confined 30-50 cm about 3-5 months long, extremely to strongly acid (pH 4.5-5.5).

Soil unit 10: Uppter soil is black or dark grey clay and grey clay in the lower soil with jarosite mottle in 100 cm depth. Physiography is coastal plain, water confined 100 cm about 6-7 months, low permeability, extreme to very strong acid (pH 4.5).

Soil unit 11: Upper soil is dark grey to black clay. Lower soil is grey clay with brown, yellow, red mottles in upper part, and light yellow mottles of jarosite at 50-100 cm depth. Physiography is coastal plain, water confined 50-100 cm about 3-5 months, and 6-7 months in some area, low permeability, extremely to very strongly acid (pH 4.5-5.0)

Soil unit 13: There is high sulfide content soil. Wet soil is neutral to slightly alkaline, dry soil is extremely acid.

Soil unit 14: Upper soil is dark grey to black clay with high organic matter. Lower soil is grey clay with yellow and brown mottles. There is greenish grey clay with high sulfide content in lower soil at deeper than 80 cm depth, low permeability, extremely acid (pH less than 4.5).

Soil unit 16: There is light brown or greyish brown silty loam with dark brown, yellow, red mottles. Iron and manganese could be found in lower soil. It occurs in alluvium. Physiography is plain, lower terrace, water confined less than 30 cm about 4-5 months, low permeability.

Soil unit 17: Upper soil is brown, greyish brown loam, sandy loam. Lower soil is light brown, light grey, pinkish grey clayey loam, sandy-clayey loam with yellowish brown, yellowish red, and red mottles. It occurs in alluvium. Physiography is plain, lower terrace, water confined 30-50 cm about 2-4 months. It could be found soft laterite in lower soil, low permeability, extremely to strongly acid (pH 4.5-5.5).

Soil unit 22: There is grey, and greyey brown sandy loam, loamy sand with yellowish brown or light greyish yellow mottles. It could be found soft laterite in lower soil, low permeability, extremely to strongly acid (pH 4.5-5.5).

Soil unit 23: Upper soil is grey sand, lower soil is sand with shell and brown or yellow mottles. It occurs in saline sediment. Physiography is plain inter sand dune, water confined 30-50 cm about 4-5 months, low to very low permeability, moderately acid to neutral (pH 6.0-7.0), and slightly to strongly alkaline (pH 7.5-8.5) in sand with shell.

Soil unit 25: Upper soil is sandy loam, lower soil is clay, clayey loam with lateritic soil and yellowish brown, light grey, and greyish brown mottles. It occurs in alluvium over weathered rock. Physiography is plain, and low to moderately terrace, water confined 30 cm depth about 3-4 months, low permeability, extremely to moderately acid (pH 4.5-6.0).

Soil unit 26: There is brown, yellow, red loam, clayey loam, and sandy loam. It occurs from weathered igneous, sedimentary, and metamorphic rock. Physiography is hill, well permeability, extremely to strongly acid (pH 4.5-5.5).

Soil unit 32: There is brown,brownish yellow loam, silty-clayey loam with fined sand intercalated in some area. It occurs in alluvium. Physiography is plain, well permeability, extremely to strongly acid (pH 4.5-5.5).

Soil unit 34: There is brown, yellow, red sandy loam, lower soil is sandy-clayey loam. It occurs in alluvium, well to moderately permeability, extremely to strongly acid (pH 4.5-5.5).

Soil unit 39: There is brown, yellow, and red sandy loam. It occurs in alluvium. Physiography is plain to apron, well permeability, extremely to strongly acid (pH 4.5-5.5).

Soil unit 35: There is brown, yellow, red sandy loam, lower soil is sandy-clayey loam. It occurs in alluvium. Physiography is plain to apron, 3-20% of slope and 20-35% of slope in some area, well permeability, extremely to strongly acid (pH 4.5-5.5).

Soil unit 41: There is sand and loamy sand at 50 cm depth. Lower soil is dark brown sandy-clayey loam. It occurs in alluvium. Physiography is plain, middle alluvial terrace, 2-12% of slope, moderately to well permeability. Groundwater level is deeper than 3.0 m, moderately acid to moderately alkaline (pH 6.0-8.0).

Soil unit 42: Upper soil is dark grey and white sand, lower soil is brown or red organic soil. It occurs in old beach and sand ridge. Physiography is plain, moderately permeability, very strongly to medium acid (pH 5.0-6.0).

Soil unit 43: There is grey, light grey, greyish brown, and yellow sand with shell in some area. Physiography is beach, sand ridge, low hill 2-4% of slope, very well permeability. Groundwater level is below 1.5 m, strongly to slightly acid (pH 5.5-6.5), and moderately alkaline in sand with shell area.

Soil unit 45: There is brown, yellow, or red clay and loam with lateritic soil and pebble. Physiography is hill, well permeability, extremely to strongly acid (pH 4.5-5.5).

Soil Unit 50: Upper soil is sandy loam or sandy-clayey loam at 50 cm depth. At 50-100 cm depth, there is brown, yellow, and red lateritic soil. Physiography is hill, well permeability, very strongly to strongly acid (pH 5.0-5.5).

Soil Unit 51: There is brown, yellow or red loam with rock fragment. Rock fragment is sandstone, quartz, and shale fragment. Physiography is hill, shallow soil, well permeability, very strongly to strongly acid (pH 5.0-5.5).

Soil Unit 53: Upper soil is loam or clayey loam, lower soil is lateritic soil or weathered shale soil at 50-100 cm depth, very strongly to strongly acid (pH 5.0-5.5). Physiography is hill.

Soil Unit 58: It occurs in bog. There is organic soil over 100 cm thick with organic fragment. Now, there is still being bog.

Soil Unit 62: Physiography is mountain area, > 35% of slope. There are shallow and deep soil. Usually found rock fragment or outcrop.

For the other soil units, which have "/" ,are complex soil unit of both one in the example, the soil unit 2/10 is a complex soil unit between soil unit 2 and soil unit 10.

3.2.4.2 Landform

The geomorphologic units of the study area were provided by Landsat image interpretation, compile with soil units grouping from soil map. Landform of Songkhla were describes into 9 landform units as swamp, beach and beach ridge, tidal flat, former tidal flat, flood plain, low terrace, middle terrace, high terrace or alluvial fan, Hill slope, and Hill or mountain.

Table 3.2 shows the summary of technically of landform mapping and figure 3.14 shows the landform map of Songkhla.

Table 3.2 Technically landform mapping in Songkhla

Landform	Soil unit
Swamp	5, 8
Beach and beach ridge	3, 42, 43
Tidal flat	11, 10
Former tidal flat	2, 10
Flood plain	2, 3, 6, 14, 32
Low terrace	5, 16, 22, 25, 45, 50
Middle terrace	22, 26, 34, 35, 29, 41
High terrace or alluvial fan	17
Hill slope or hill	39, 45
Hill or mountain	51, 53, 62

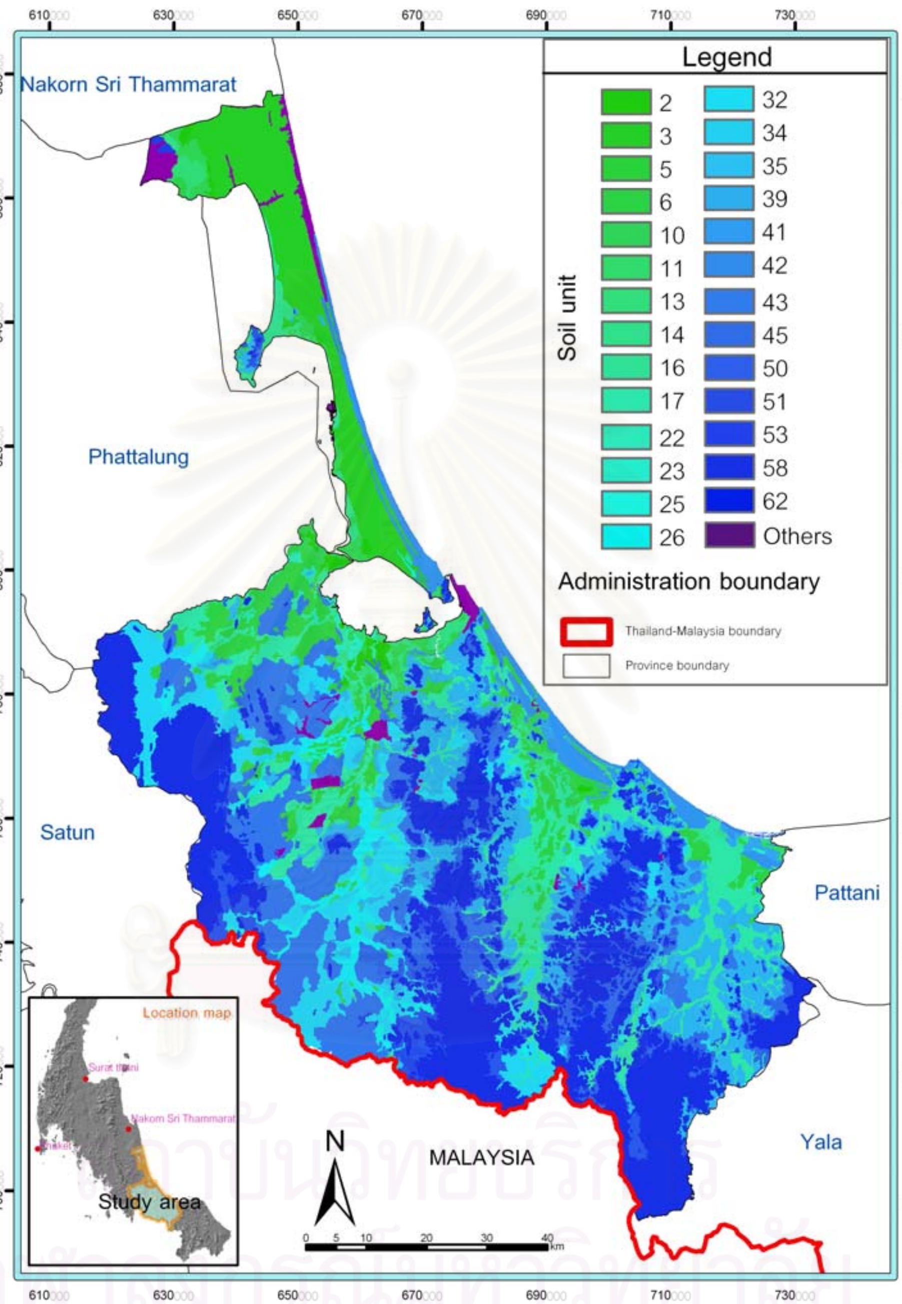

Figure 3.13 Soil unit map of Songkhla

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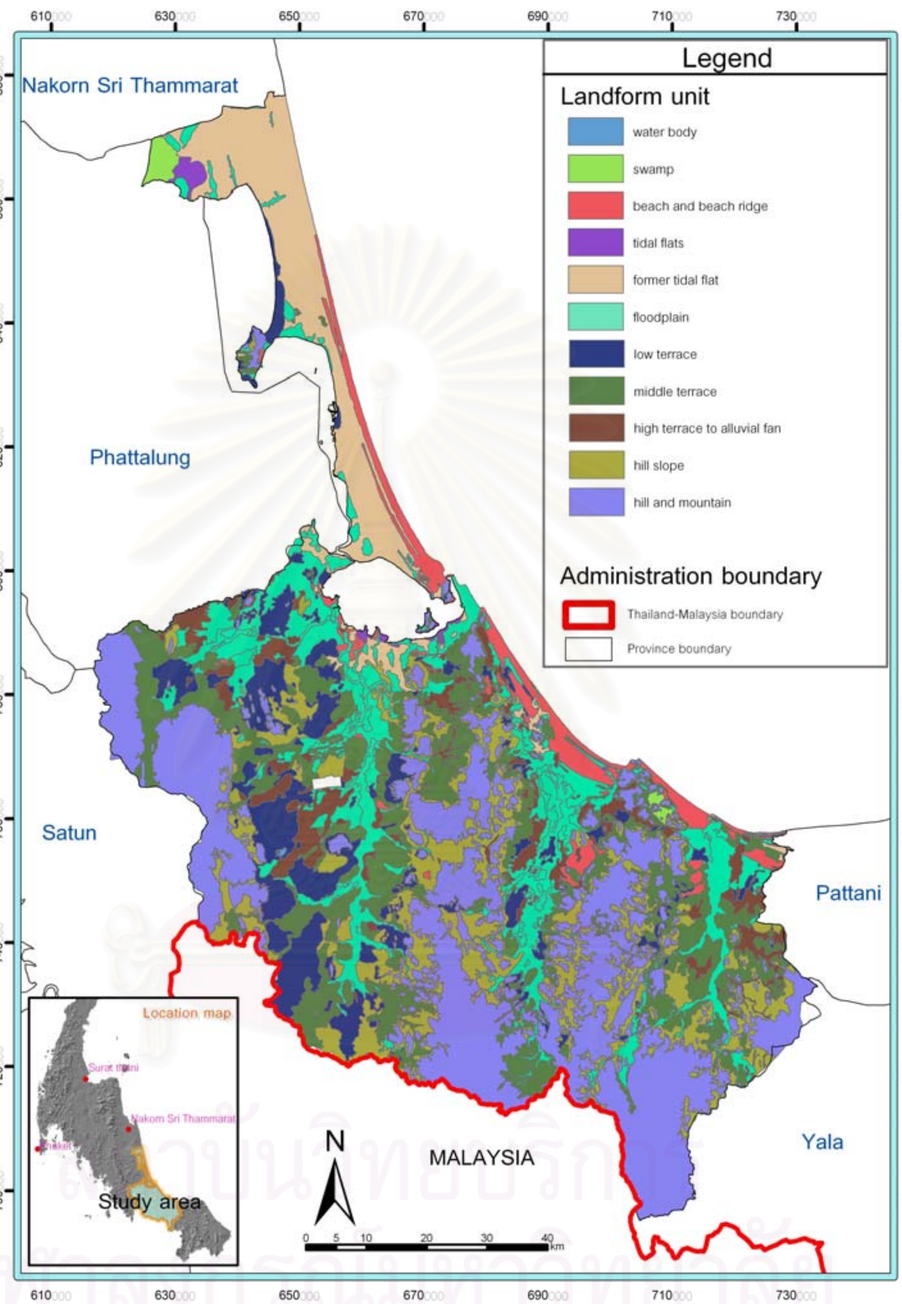

Figure 3.14 Landform map of Songkhla

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3.2.5 Geology and Mineral Resources

Songkhla area is underlain stratigraphically, by a variety of rocks ranging in age from the oldest rock of Cambrian, to the youngest Quaternary beach/alluvial deposits. (Figure 3.9)

3.2.5.1 Stratigraphy

Songkhla area is underlain by altogether 9 chronostratigraphic units. In addition, the area is also underlain by another two igneous rock units and their associates.

Cambrian rocks are composed predominantly of brownish gray, brown, yellowish brown sandstone, shale, quartzite, and phyllite, locally red sandstone, siltstone, and shale. The sequence is exposed in the western part of area in contact granitic hill called Khao Kieo of Ban Thad range. This rock is also lithostratigraphically designated as the Tarutao Group.

Ordovician rocks comprise predominantly of light to dark gray, bluish-gray, massive to thin bedded limestone and argillaceous layers. The sequences are commonly designated as the Thung Song Group. The group overlies conformably contacts with the Cambrian rocks and underlies with conformably contact the Silurian-Devonian sequences. Usually, the sequences expose in the southwestern of Amphoe Rattaphum.

Silurian-Devonian rocks are currently classified under the lithostratigraphic system as the Thong Pha Phum Group. This rock unit is exposed around Khuan Yo, in the western part of the Amphoe Rattaphum. The rocks consist mainly of sandstone, shale, chert, metatuff, schist, quartzite, black shale and mudstone with limestone lenses. Some fossils of i.e. graptolites and brachiopods are preserved in some beds.

Carboniferous rocks are characterized by mudstone, sandstone, shale, bedded chert, and cross-bedded quartz sandstone with fossils of brachiopods, pelecypods, trilobites and conodonts. Most of these rocks are exposed in the western part of the area, contact granitic rocks at Khuan Liap. In addition, the rocks are also distributed around Amphoes Hat Yai, Khuanniang, and Muang Songkhla area.

Permian rocks comprise predominantly of bedded to massive limestone with partly dolomitic limestones, chert nodules, as lenticular beds are common, and occasionally intercalated with shale and siltstone. Abundant fossils are fusulinids, brachiopods, corals, foraminiferas, crinoids, and algaes. The rock sequences are only limited in the western part of Songkhla area, and are currently classified as Ratburi Group.

Triassic rocks are mainly marine deposits of red-bed sequences. The sequences comprise of thick-bedded to massive cross-bedded sandstones, siltstones, and locally dolomitic limestone. Significant fossil contents Daonella, Posidonia, and ammonite trace. The sequences are exposed continuously in the eastern of the Songkhla area area with the regional trend in the N-S direction.

Jurassic-Cretaceous rocks are characterized as non-marine deposits, consisting mainly of deep red, red brown, cross- bedded sandstone, siltstone, shale, conglomeratic sandstone, and basal conglomerate; intercalated with gray shale, limestone, dolomitic limestone and dolomite. Fossil plants are present in some beds. The sequences expose at Ko Yai, King Amphoe Krasaesin.

Quaternary deposits comprise all of the younger unconsolidated deposits, terrace/colluvial and beach/alluvial deposits. Terraces, alluvial fans, colluvials of unconsolidated gravels, sands, silts and clays characterize the former sequence. The latter sequence is composed mainly of unconsolidated beach deposits, consisting of beach sands, silts, and clays. However, eluvial gavels, clayey estuarine, and tidal flat deposits are also common. The distributions are extensive, especially in the intermountain basins, undulated terrains, as well as along the minor and major stream courses in the area. The upper units are governed in both the coastal range zones.

Igneous and associated rocks are classified as central belt's granitic rocks, are comprised two ages, namely, Cretaceous-Tertiary granitic rocks and Jurassic-Triassic rocks.

Cretaceous-Tertiary granitic rocks are characterized as consists of porphyritic biotite granite, granodiorite, hornblend adamellitte and fine-grain muscovite-tourmaline granite. These rocks expose at central to the western of the area, Khao Nam Khang, Khao Ok Kai, and at the western of Amphoe Saba Yoi.

A Jurassic-Triassic granitic rock is mainly medium- to course-grained porphyritic biotite granite, adamellite, and granodiorite. Their distributions are mainly in Nakorn Si Thammarat range from Pattalung. And at the south of Muang Songkhla area, the rock is exposed along Khoa Koa Seng to Khuan Luk Phun Si.

3.2.5.2 Geological Structure

The general geological structure of Songkhla area is characterized by the folding of Carboniferous rocks with fold axes oriented in the NW-SE and NE-SW in the SE part of Songkhla area as both anticlines and synclines.

Regarding the major fault, it is believed that there is a buried major fault oriented in the NE-SW direction extending from Satoon to Amphoe Rattaphum of Songkhla area. Other minor faults in rocks of almost all geological age are in the NE-SW and NW-SE direction.

The other major geological structures of a series of horsts ad grabens with N-S trending in the Gulf of Thailand are believed to extend into the study area, known as “Hat Yai graben” and “Songkhla area Host” passing through the vicinity of the lake areas.

3.2.5.3 Mineral Resources

Casseterite: Most of the tin produced in Songkhla area is from placer deposits especially the alluvial placer. However, disseminated tin in granite, tin-bearing quartz vein, pegmatite and aplite dike are also noted. The resources of tin are from both western granite belt, known as “Wang Pha Pluton” of Cretaceous age and eastern granite belt known as “Songkhla area Pluton” of late Triassic to Early Jurassic age. The economic tin deposits are located in numerous Amphoes, namely, Hat Yai, Chana, Na Thawee, Thepa, Sadao, and King Amphoe Namom. The mining activity of tin has been stopped for several due to the decreasing demand and price of the world market.

Wolframite: The wolframite in Songkhla area is mainly associated with the cassiterite-wolframite bearing quartz-vein in the eastern margin of the Wang

Ha Platoon. Besides, the wolframite is also associated with casseterite derived from the eastern granite belt of Songkhla area Pluton in vicinity of Amphoe Hat Yai and Sadao. The economic production of this mineral has been stopped from many years under the similar condition as tin.

Barite: The only barite deposit is in Amphoe Rattaphum where it occurs as veins in Cambrian sandstone and shale. The are had been produced and used in drilling muds for petroleum exploration for several years. At present, there is no production.

Silica Sand: Songkhla area has been known as the silica sand producing area for the glass industry for along time. Silica sand occurs along the NW coastal plain extending from Amphoe Muang to Amphoe Chana. The total reserve is estimated up to 7 million metric ton.

Coal: The coal has been discovered into localities in Songkhla area, namely, the Sadao basin in Amphoe Sadao and the Saba Yoi basin in Ampheo Saba Yoi. The reserve of coal deposits in Saba Yoi basin is estimated to be 600 million tons.

Construction Materials;

Heavy clay: This low-cost heavy clay is used for bricks, roof-tiles, and earthen wares. There are several deposits in Amphoe Chana and Amphoe Hat Yai.

Crushed stone; The limestone deposits in Amphoe Rattaphum, Hat Yai, and Saba Yin have been quarried for crushed stone in many localities. In addition, the granite is also available as crushed stone for concrete aggregate and road base material.

Dimension stone; The only granite quarry for dimension stone is located in Amphoe Chana.

Gravel and sand; both gravel and sand are used as concrete aggregate. Besides, the sand is also use in the production of sand-lime bricks and as filling material in the land reclamation.

3.2.6 Hydrogeology

The information of hydrogeology in this passage is referred to the hydrogeological map of Southern Thailand by Groundwater Division, Department of Mineral Resources as follows:

3.2.6.1 Extensive and Productive Quaternary Aquifers

These aquifers consist of unconsolidated gravel, sand, and clay of fluvial origins, occur in narrow to broad floodplains or meander belts. At least two-aquifers each of which is formed by alternating layers of sand, gravel and clay, are recognized in the coastal plain region. The aquifer is generally less than 500 feet in thickness and normally yields more than 500 gpm. The water quality is generally good excepting in some areas where brackish to salty water or water with high iron concentration exist. These aquifers are presented in the area of along of Khlong Thepa, Khlong Nam Khem, Khlong Na Thawee, Khlong U Tapao, and flat area of Amphoe Ranot.

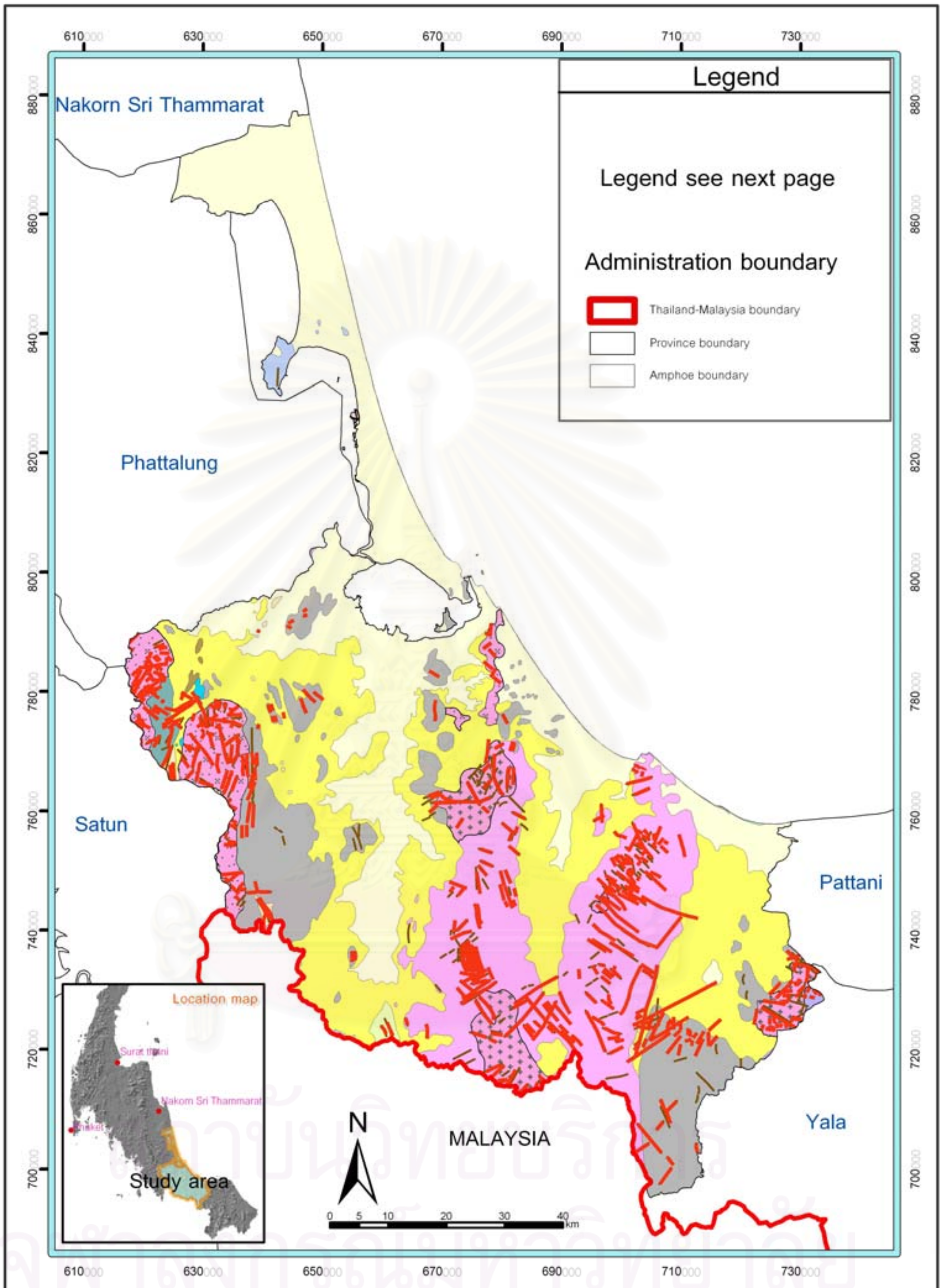

Figure 3.16 Geologic map of Songkhla

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Rottana Ladachart

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Explanation

Geologic Time		Sediment and Metamorphic rocks
Cenozoic	Quaternary	Alluvial deposits: Gravel, sand, silt, clay, and beach sand
		Terraces deposits: gravel, sand, silt, clay, and lateritic soil
	Tertiary	Conglomerate, sandstone; sand, silt; and gravel, semi-consolidated to well cement
Mesozoic	Triassic	Conglomerate, sandstone, siltstone, mudstone and shale, greenish-gray to brown
	Jurassic-Cretaceous	Thick-bedded to massive cross-bedded sandstones, siltstones, and locally dolomitic limestone
Paleozoic	Permian	Crystalline limestone, light gray to white, massive and well-bedded; and marble
	Carboniferous	Mudstone, sandstone, shale, bedded-chert, and cross-bedded quartz sandstone
	Silurian-Devonian	Sandstone, shale, chert, metatuff, schist, quartzite, black shale, and mudstone with limestone lenses.
	Ordivician	Light to dark gray, bluish-gray, massive to thin bedded limestone and argillaceous layers
	Cambrian	Brownish gray, brown, yellowish brown sandstone, shale, quartzite, and phyllite
		Igneous rocks
	Triassic Granite	Medium- to course-grained porphyritic biotite granite, adamellite, and granodiorite
	Cretaceous Granite	Porphyritic biotite granite, granodiorite, hornblend adamellitte and fine-grain muscovite-tourmaline granite

Fault and lineament

3.2.6.2 Extensive but Less Productive Quaternary Aquifers

These aquifers consist of thin layers of unconsolidated gravel, and clay of fluvial origins occurs in narrow to broad flood plains or meander belts. Due to the poor assortment and thin permeable beds, these alluvial deposits form relatively poor aquifers with the thickness less than 200 feet. The yield varies between 100 – 500 gpm. of relatively good quality water. These aquifers are presented in the area of both side of Khlong Thepa, Khlong Na Thawee, Khlong Na Thawee, Khlong U Tapao, and the northern area of Amphoe Ranot.

3.2.6.3 Local and Less Productive Quaternary Aquifers

Alluvial aquifers: these aquifers consist of unconsolidated clay, sand, and gravel of alluvial deposits occurs in narrow flood plains and small valleys. The thickness of the aquifer is generally less than 200 feet, with the yield of 20 – 100 gpm. with good quality water. These aquifers are presented in the area of the western of Amphoe Sathing Phra, Amphoe Hat Yai, and the eastern of King Amphoe Kuanniang.

Beach sand aquifers: these aquifers consist of beach and dune sand deposited along old and recent shorelines, generally less than 20 feet in thickness. These aquifers yield 5-10 gpm. of brackish water from most shallow well. These aquifers are presented in the area of the eastern of Amphoe Ranot, Sathing Phra, Muang Songkhla area, and Thepa

Colluvial aquifers: these aquifers consist of poorly sorted valley filled talus and granite wash deposits. The thickness of aquifers is generally less than 300 feet and generally yield 50 gpm. of good water quality with high iron contact in some places. These aquifers are presented in the area of origin of Khlong Thepa and Khlong Nathawee.

3.2.6.4 Extensive and Productive Aquifers

The Carbonate aquifer (Permian/Ordovician) comprises the Permian limestone of Ratburi Group and the Ordovician limestone of the Thung Song Group. The groundwater occurs mainly in solution cavities bedding place, contact zones. The yield generally varies between 50-100 gpm. with maximum yield up to 500 gpm and can be expected from the highly cavernous Permian limestone.

3.2.6.5 Extensive but Less Productive Aquifers

Marine sedimentary aquifers (Triassic) consistes friable marine shale and thin-bedded fine-grained sandstone with layers of conglomerates in the lower parts. The yield varies from very few to 30 gpm. of good quality water. These aquifers presents in the area of Amphoe Na Thawee, and the western part of Amphoe Thepa.

Metasediment aquifers (Permian to Carboniferous) consist of clastic sedimentary rocks of the Ratburi and Kaeng Krachan Group. The main rock types are quartzitic sandstone, feldspathic sandstone, phyllitic to slaty shale and graywacke. The groundwater occurs only in complex joints and fractures, which is not well interconnected. The yield ranges from meager to about 30 gpm. with occasional yield of slightly over 50 gpm. of good quality water. These aquifers are in the area of the western part of Songkhla area, the eastern part of Amphoe Hat Yai, and Southern part of Amphoe Thepa.

3.2.6.6 Local and Less Productive Aquifer

Metamorphic aquifers (Cambrian to Devonian) consist of poorly to well-bedded quartzite, phyllite, slate, and schist. The rocks are complexly folded, contorted or crumbled and subjected to various degrees of faulting or fracturing, but the fissure system is generally not well interconnected. The groundwater is devoid in many places or in some places the yield is sufficient only for domestic purposes. These aquifers are in the area of the western part of Amphoe Rattaphum.

Granitic aquifers consist of massive granite with localized granite gneiss. The groundwater is available in joint or fissure system and decomposed zones with an average yield of 10 gpm., with maximum yields up to 30 gpm. The water quality is generally good but locally inferior due to high iron content. These aquifers are present in the area of the granitic hill of the western and central of Songkhla area area.

The groundwater system of Songkhla area can be summarized and presented in figures 3.18, 3.19, and 3.20.

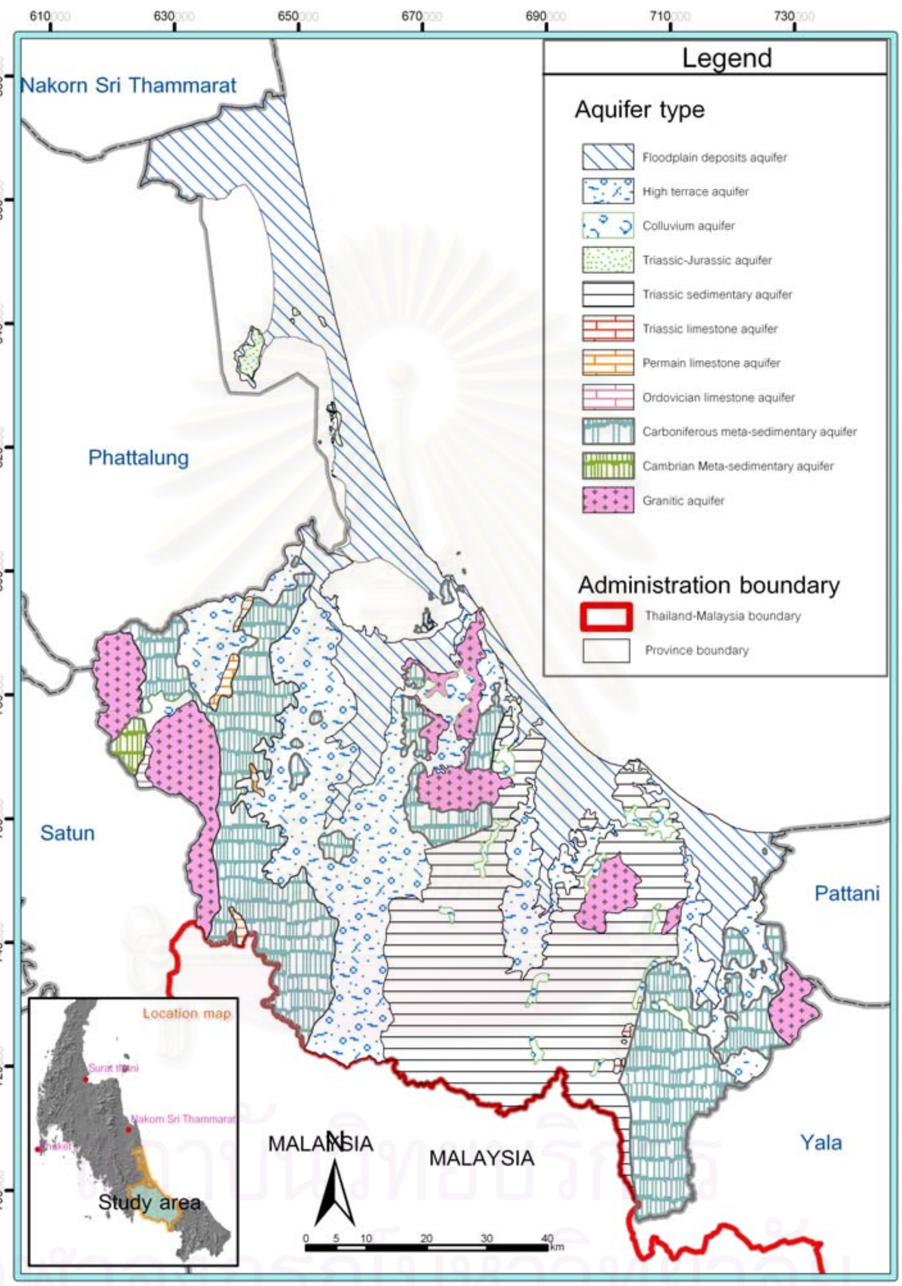

Figure 3.2 Administration boundary map of Songkhla

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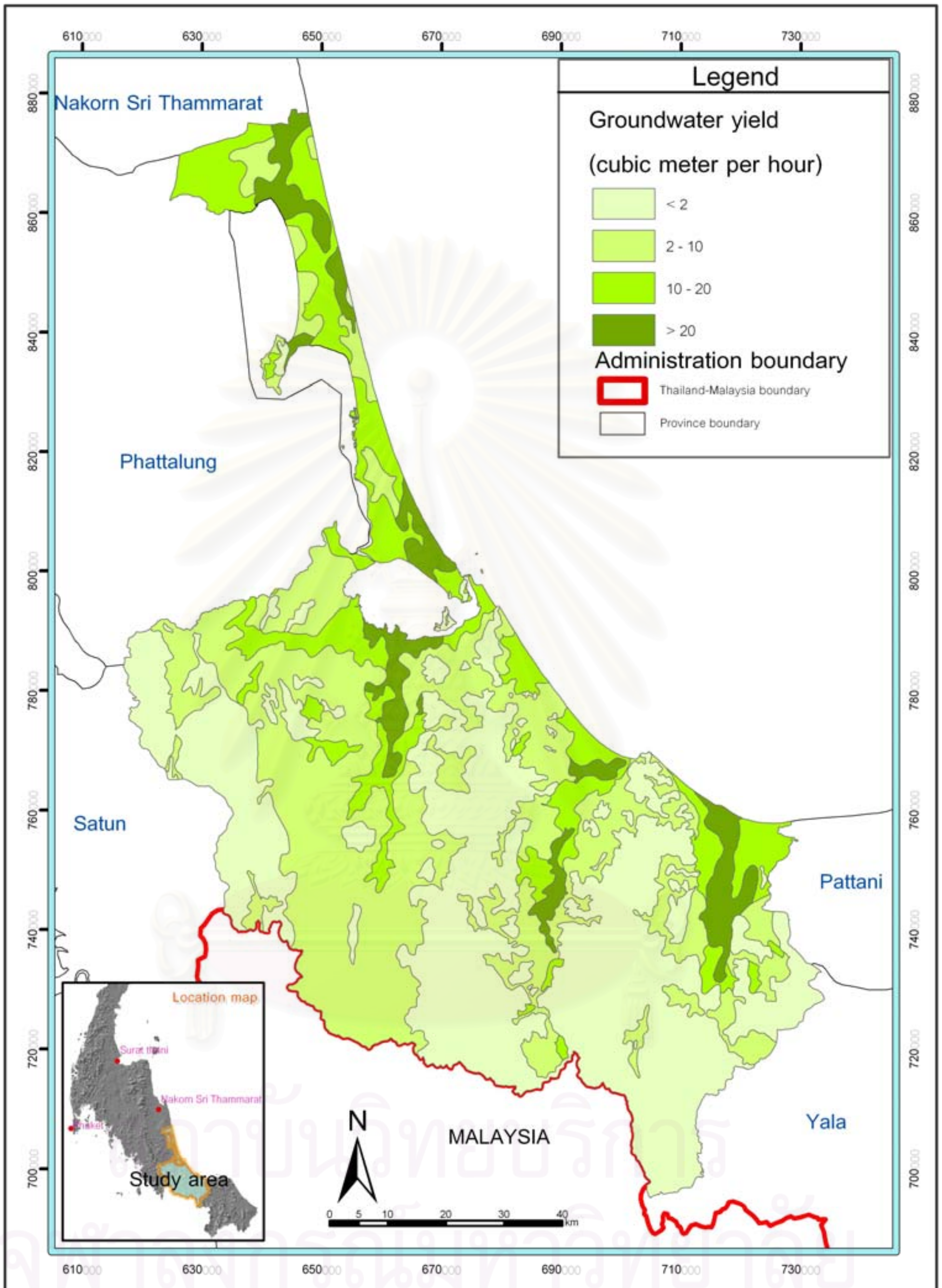

Figure 3.19 Groundwater yield map of Songkhla

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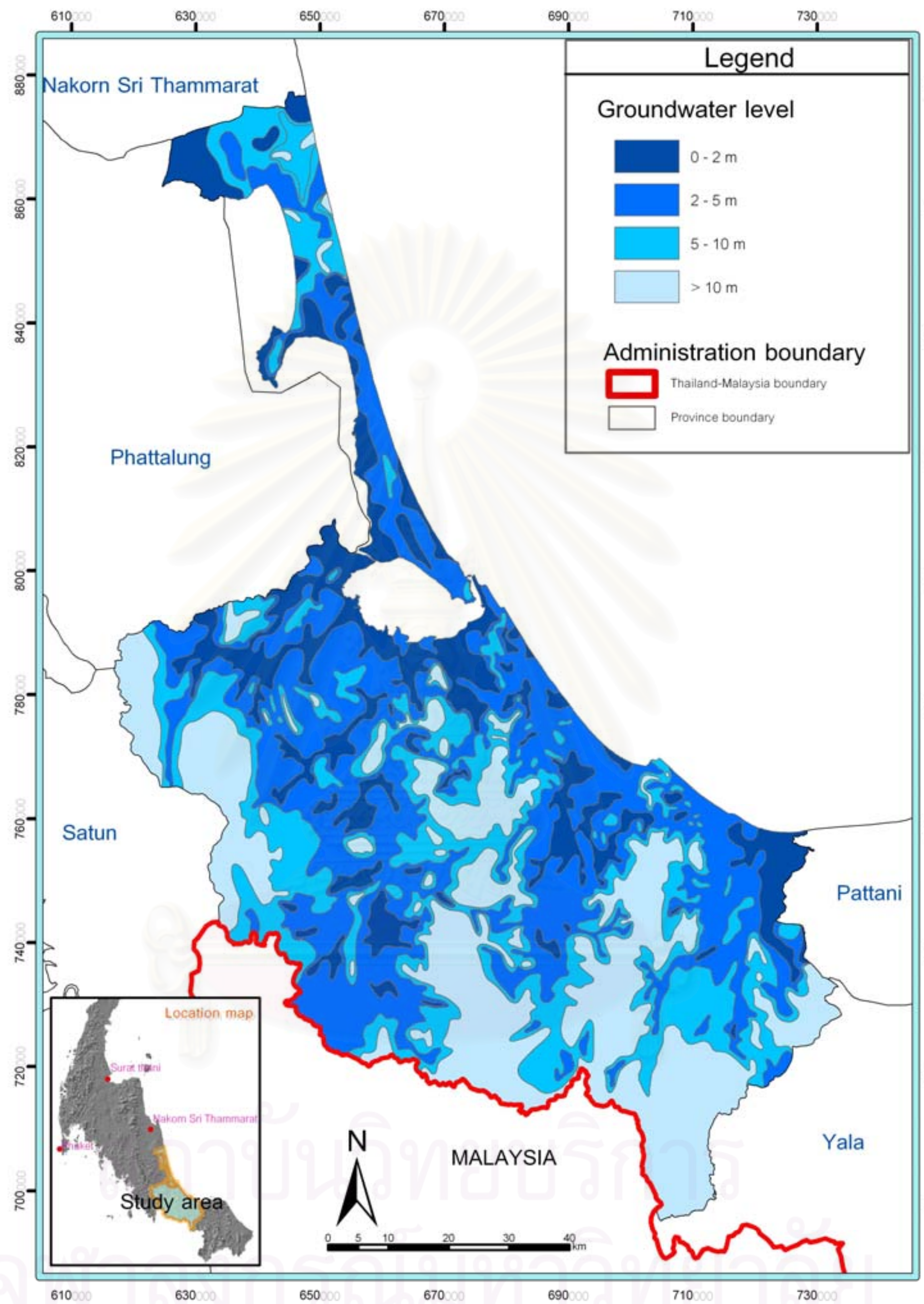

Figure 3.20 Groundwater table map of Songkhla

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3.2.7 Flood Hazard

Amphoe Hat Yai, the most populated area of Songkhla area, appears to be damaged by frequent floods in the past and consequently brought about serious economic lost on properties and lives. During the past 72-years period (1916-1997), Amphoe Hat Yai had been flooded altogether 14 times. The records of historical flood are summarized and presented in table 3.4

Table 3.4 Summary of past flooding in Amphoe Hat Yai.

Year	Flood condition (flood level (m.) above ground surface)	Damage (baht)
1916	2.0 m. during November to December.	n.a.
1942	0.6 m. during November to December.	n.a.
1959	n.a.	200,000
1961	n.a.	1,200,000 with lose of live.
1962	0.7 m. during November to December.	n.a.
1966	0.7 m. during 5-7 December.	1,200,000
1967	0.7 m. at 6 January.	2,700,000
1972	n.a.	n.a.
1973	0.76 m.	6,700,000 with lose of live.
1975	0.7 m. during November to December.	n.a.
1981	0.5 m. covered 10 sq. km.	n.a.
1983	0.6 m. at 14 December.	n.a.
1987	0.4 m. at 8 December.	n.a.
1988	1.43 m. covered 20 sq. km.	1,000,000,000
2000	2 m.	n.a.

n.a. = Not available.

Lather on the study on flood protection and drainage in the area of Amphoe Hat Yai was came out by the survey and design for the hat Yai municipality by WDC CO., LTD. At present, the project is under construction and the problem of flood as well as drainage will be eliminated in the near future.

Flood prone area of Songkhla was analyzed from landform map and Landsat TM5 interpretation, which was presented in figure 3.21. Table 3.5 is summarized the technically flood prone area mapping in Songkhla.

Table 3.5 Technically flood prone area mapping in this study.

Unit	Criteria	Landform unit
Very high	- submerged in flood time. Depth of stagnation is deepest, swampy in dry season. - Influence by daily/seasonal high tide of the daily ebb and flow	Swamp Tidal flat
High	- submerged in flood time	Former tidal flat Alluvial plain
Medium	- submerged in flood time but the water drain of well and the period stagnation is short	Alluvial plain Lower terrace Alluvial fan
Low	- submerge by sheet flood in extraordinary flood time but the water drain of well	Middle terrace Alluvial fan
Very rare	- in general the area never submerged in flood time but in locally can be get sheet flood and/or forest flowing but the water drain of well	Hill slope Hill and mountain

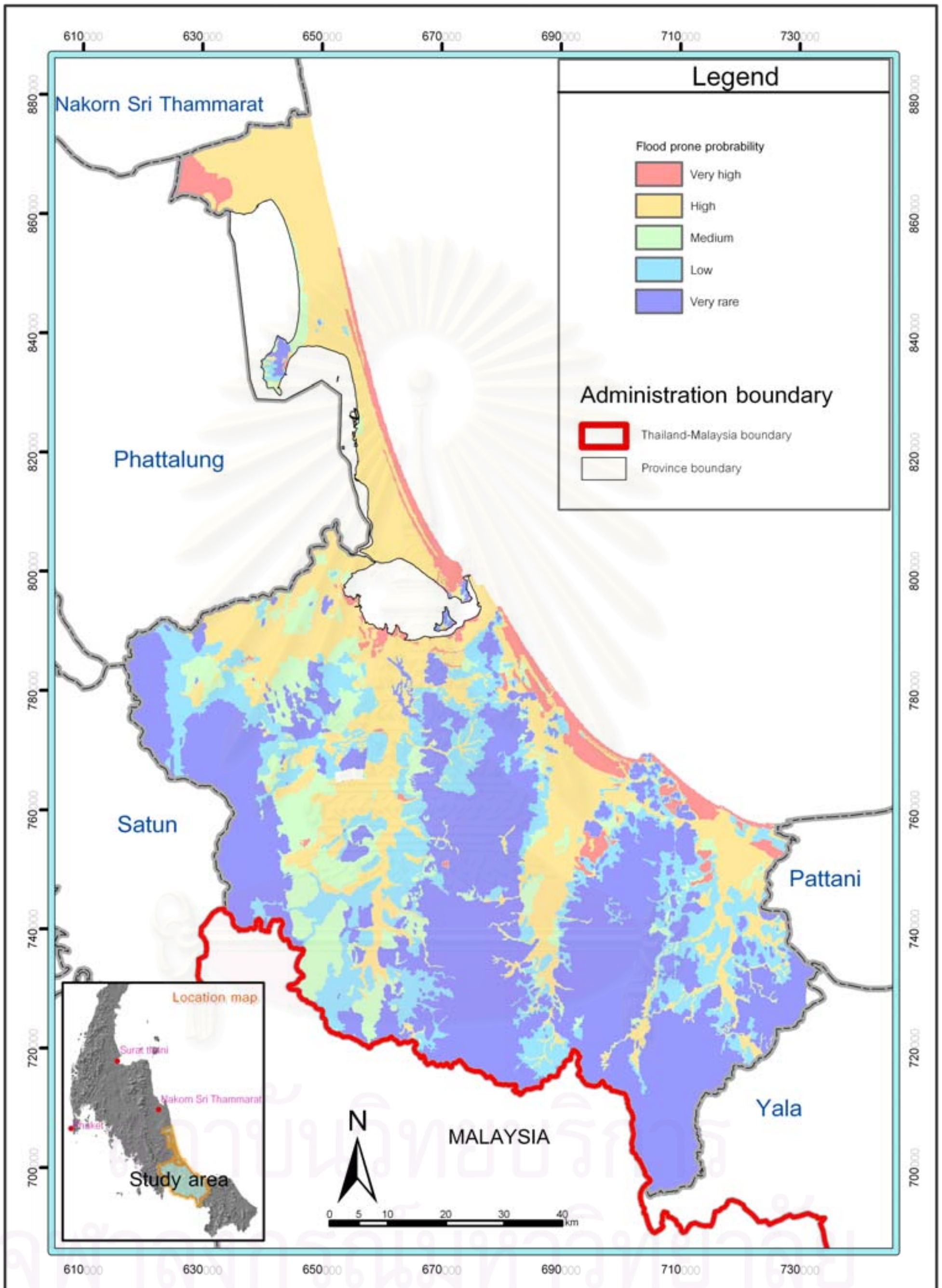

Figure 3.21 Flood prone area map of Songkhla

Area Selection for Solid Waste Disposal in Changwat Songkhla

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Department of Geology, Faculty of Science, Chulalongkorn University, 2002

CHAPTER IV

PROPOSED AREAS FOR SOLID WASTE DISPOSAL OF SONGKHLA

4.1 Land Requirement for Solid Waste Disposal Areas Calculation

The calculations for land requirement of sanitary landfill area that can be divided into 2 major steps; i.e., solid waste estimation and area calculation for the lifespan of the project. Details of calculations for this study are described as following the schematic diagram in figure 4.1.

4.1.1 Projection of Solid Waste Quantities

There are 3 variables required for calculating the quantities of solid waste. They include number of population of the next 20 years, the solid waste generating rate, and the physical characteristic of solid waste.

4.1.1.1 The existing Solid Waste Generation in Songkhla

There are many sources of waste generation in Songkhla such as municipality areas, industrial sites, agricultural areas, etc. In the study, the consideration was focused to solve the solid waste problem generated from municipality areas. In 2001, there are 16 municipality areas in Songkhla (Pollution Control Department, 2001) (Figure 4.2). The quantity and quality of solid waste in each municipality were concluded in Table 4.1.

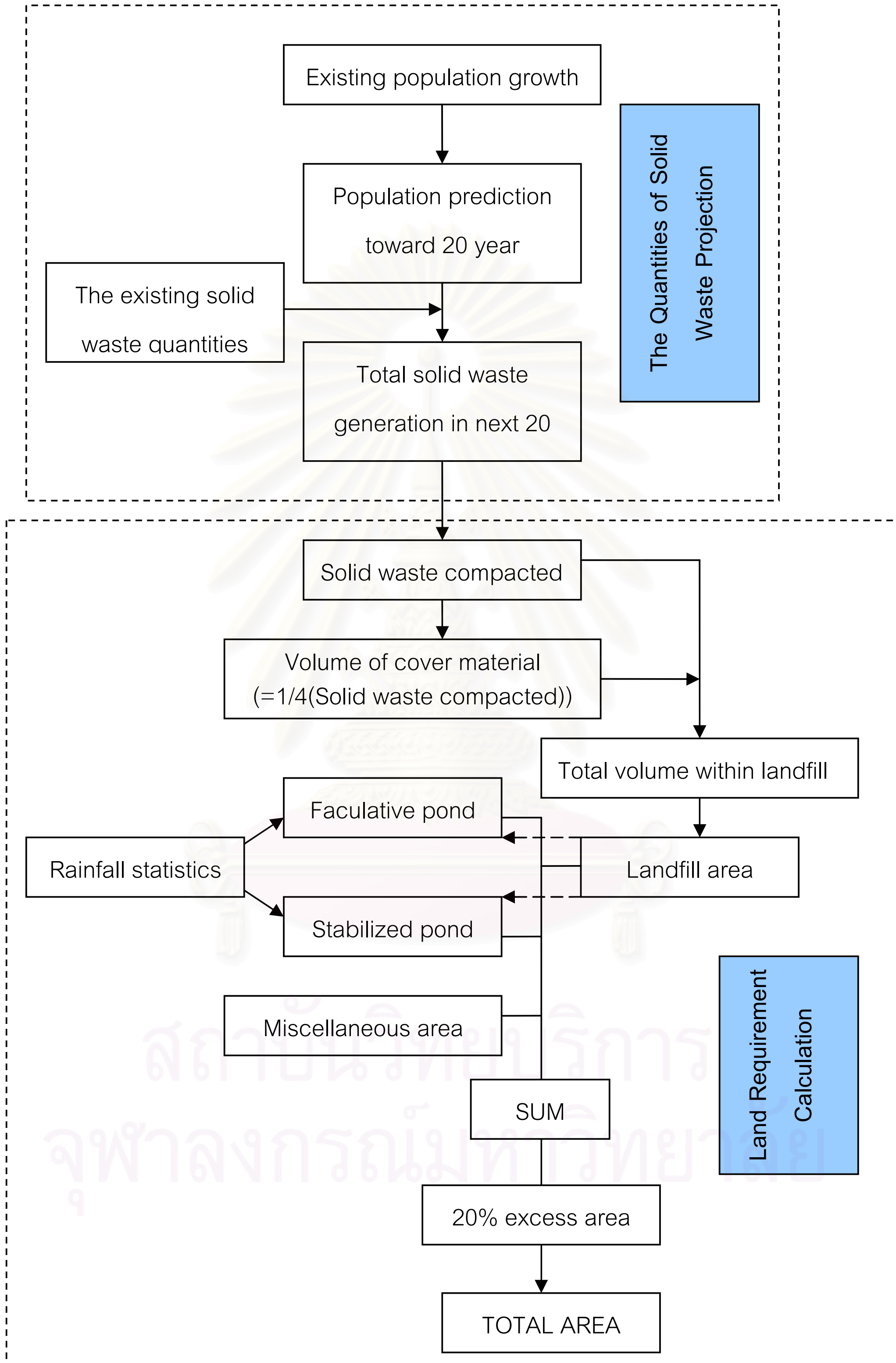

Figure 4.1 Schematic diagram of landfill area calculation.

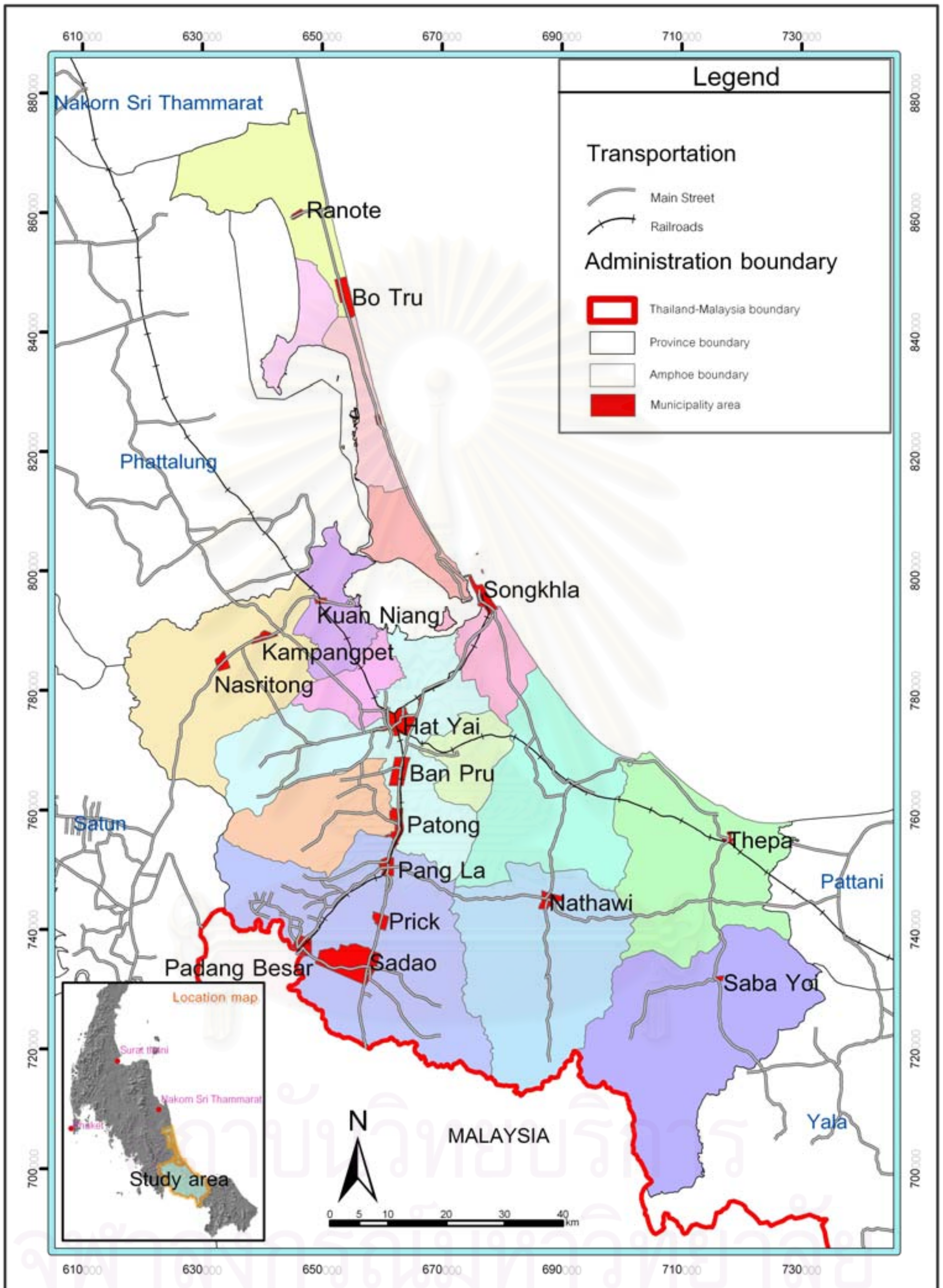

Figure 4.1 Solid waste generation sources map of Songkhla

Area Selection for Solid Waste Disposal in Changwat Songkhla

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Table 4.1 The composition of solid waste in each municipality area in Songkhla (Pollution Control Department, 2002)

Municipality	The physical Characteristics of Solid Wastes in Municipalities of Songkhla by percent										Population	Waste Quantity	Waste generation rate
	Food	Paper	Plastic	Glass	Metal	Rubber	Cloth	Wood	Block	Other	(people)	(kg/day)	(kg/capita/day)
Songkhla	22.3	14.7	10.6	16	8.4	4.2	4.5	12	-	7.2	82,003	70,523	0.86
Hat Yai	37.94	11.13	16.08	10.68	11.54	2.53	2.8	2	0.07	5.23	155,763	109,034	0.7
Sadao	52.37	15.78	13.6	4.88	3.28	-	-	2.92	2.58	4.59	17,338	15,800	0.91
Ban Pru	24	15.87	10.63	13.83	6.5	8.3	3.8	8.53	-	8.5	16,198	34,200	2.11
Kampangpret	-	-	-	-	-	-	-	-	-	-	5,571	3,340	0.6
Kuan Niang	-	-	-	-	-	-	-	-	-	-	4,034	2,420	0.6
Chana	-	-	-	-	-	-	-	-	-	-	6,743	4,050	0.6
Thepa	-	-	-	-	-	-	-	-	-	-	2,683	1,610	0.6
Nathawi	-	-	-	-	-	-	-	-	-	-	6,984	4,190	0.6
Nasrithong	-	-	-	-	-	-	-	-	-	-	2,627	1,580	0.6
Bo Tru	-	-	-	-	-	-	-	-	-	-	12,019	7,210	0.6
Prick	-	-	-	-	-	-	-	-	-	-	5,748	3,450	0.6
Padang Besa	-	-	-	-	-	-	-	-	-	-	12,620	7,570	0.6
Patong	-	-	-	-	-	-	-	-	-	-	7,429	4,460	0.6
Pangla	-	-	-	-	-	-	-	-	-	-	8,414	5,050	0.6
Ranote	-	-	-	-	-	-	-	-	-	-	6,269	3,760	0.6
Total	**34.16**	**14.38**	**12.73**	**11.35**	**7.43**	**3.76**	**2.78**	**6.36**	**0.66**	**6.38**	**352,443**	**278,247**	**0.79**

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4.1.1.2 Number of Population During 2002 to 2022

Field and Mac Gregor (1992) proposed several forecasting techniques for population projection. However, this study used only geometric/exponential trend for determining the growth rate. Generally, the formula for geometric growth is expressed as:

$$P_{(t+n)} = (1+r)^n \times P_{(t)} \text{......................................} (4.1)$$

where $P_{(t)}$ is the population at time t – the base year (person).

$P_{(t+n)}$ is the population to be forecast at time t+n (person).

n is the number of years between t and t+n (year).

r is the annual population growth rate.

From equation (4.1), P(t) and P(t+n) were replaced by number of population of the whole of Songkhla area during 1987 to 2000 and 1988 to 2001, year by year, respectively. As a result, growth rate (r) of each year in Songkhla was calculated (table 4.2), which shows growth rates (r) during 1987 to 2000 ranges from 0.005904 to 0.029985 with a mean of 0.013916.

The prediction of population for 2002 to 2022 in each municipality were calculated by the maximum, minimum, and mean growth rates as shown as the example in figure 4.3.

4.1.1.3 The Solid Waste Generated Rate and Quantities Calculation

According to Pollution Control Department (2001), the existing solid waste generation rate in 2001 of each municipality in Songkhla ranged from 0.6 to 2.11 kg per person per day. These generation rates were used for calculating quantities of solid waste.

Table 4.2 population growth rates in Changwat Songkhla.

year	P(t)	P(t+1)	Population growth rate	
1987	1044200	1060000	0.015131201	
1988	1060000	1073500	0.012735849	
1989	1073500	1090000	0.015370284	
1990	1090000	1097200	0.006605505	
1991	1097200	1130100	0.029985417	Maximum
1992	1130100	1144300	0.01256526	
1994	1144300	1159672	0.01343354	
1995	1159672	1166519	0.005904256	Minimum
1996	1166519	1191233	0.02118611	
1997	1191233	1210921	0.016527413	
1998	1210921	1223833	0.010662958	
1999	1223833	1232600	0.007163559	
2000	1232600	1249402	0.013631348	

Knowing population and rates of waste generation per person, the quantities of solid waste in a year can be estimated as:

$$Qw = P \times Rw \qquad (4.2)$$

where Qw is the quantities of solid waste time t+n (kg).

P is the population to be forecast at time t+n (person).

Rw is the solid waste generated rate (kg/capita/day).

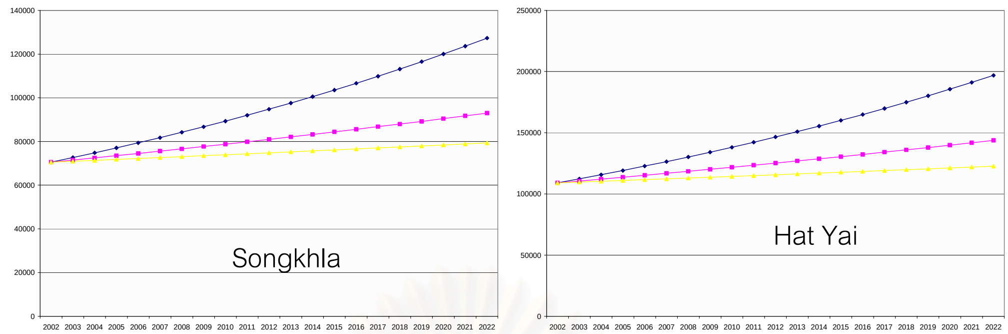


Figure 4.3 The population projection from 2002 to 2022 for Songkhla and Hat Yai municipalities.

Blue line: maximum projection

Pink line: mean projection

Yellow line: minimum projection

From equation (4.2), P and Rw were replaced by population, which had been forecasted for each municipality during 2002 to 2022, and the solid generation rate of each municipality in 2001. Results of the calculation were presented in table 4.3. Figure 4.4 shows typical results of quantities of solid waste calculation with maximum, mean, and minimum growth rate of forecasted population.

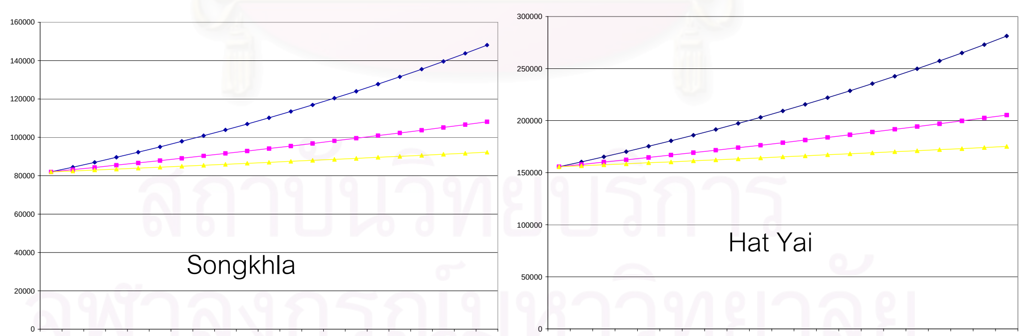


Figure 4.4 The graph shows solid waste generation in Songkhla and Hat Yai municipalities

Blue line: maximum projection

Pink line: mean projection

Yellow line: minimum projectio

Table 4.3 Waste generation predicted in each municipality in Songkhla (predicted by max, mean, and min of population growth rate)

Municipality	Waste generation in 20 years (tons)		
	Maximum	Mean	Minimum
Songkhla	738,035	622,844	573,696
Hat Yai	1,141,067	962,972	886,984
Sadao	165,116	139,345	128,349
Ban Pru	357,678	301,853	278,034
Kampangpret	34,981	29,521	27,192
Kuan Niang	25,330	21,377	19,690
Chana	42,340	35,732	32,912
Thepa	16,847	14,217	13,096
Nathawi	43,853	37,009	34,089
Nasrithong	16,495	13,921	12,822
Bo Tru	75,469	63,690	58,664
Prick	36,092	30,459	28,056
Padang Besa	79,243	66,875	61,598
Patong	46,648	39,367	36,261
Pangla	52,833	44,587	41,068
Ranote	39,364	33,220	30,599
TOTAL	2,911,391	2,456,989	2,263,110

4.1.2 Area Requirement Calculation

The total quantities of solid waste that are produced during 2002 to 2020 had been conducted for area requirement calculation. Four parameters were considered in present study, which include the quantities of solid waste, compacted density of solid waste, sanitary landfill design, and volume of cover material. Details of the parameter are described as follows:

4.1.2.1 The Quantities of Solid Waste

According to section 4.1.1, the quantities of solid waste were calculated and presented in table 4.3. The total waste in Songkhla had been predicted as 2,265 to 2,914 thousand metric-tons for the next 20 years.

4.1.2.2 Compacted Density of Solid Waste in Sanitary Landfill.

Loawatcharin (1998) showed that compacted density of solid waste in municipality are range between 530 to 710 kg/m^3. He also suggested that 550 kg/m^3 is a good representation of compacted solid waste density for the condition of Thai municipality. Therefore, total volume of compacted solid waste was computed, and the result was displayed in table 4.6 with the suggested density.

4.1.2.3 Volume of Daily Cover

Noble (1976) suggested that a sufficient amount of cover soil should be available to insure that there is 1 part of cover soil for 4 parts of refuse in the completed landfill. In addition, daily and interim cover needs are expressed as a waste/soil ratio, defined as the volume of waste deposited per unit volume of cover provided. Typically, waste/soil ratios range from 4:1 to 10:1(Kreith, 1994). Thus, waste/soil ratio 4:1 was employed in the present study. The result is displayed in Table 4.4

4.1.2.4 Sanitary Landfill Design

Boonrueng (2001) suggested that the sanitary landfill in her report composed of 3 layers of compacted solid (2 layers for area method, 1 layer for trench method), 2 meters of the height of each lift, 30° of side slope, liners (synthetic and clay liners), and geological barrier as presented in figure 4.5. In this study, it was assumed that landfill will have 2.5 m of base of compacted solid waste, 1 m of both liners, and 5 m of geological barrier, the depth of the groundwater level should be detected at least 8.5 m from ground surface.

Net volume of compacted solid waste (including volume of cover material) was computed for area of compacted solid waste. The calculation method for compacted solid waste area was concluded and presented in table 4.5. As a result, area for compacted solid waste in each municipality were concluded and presented in table 4.6

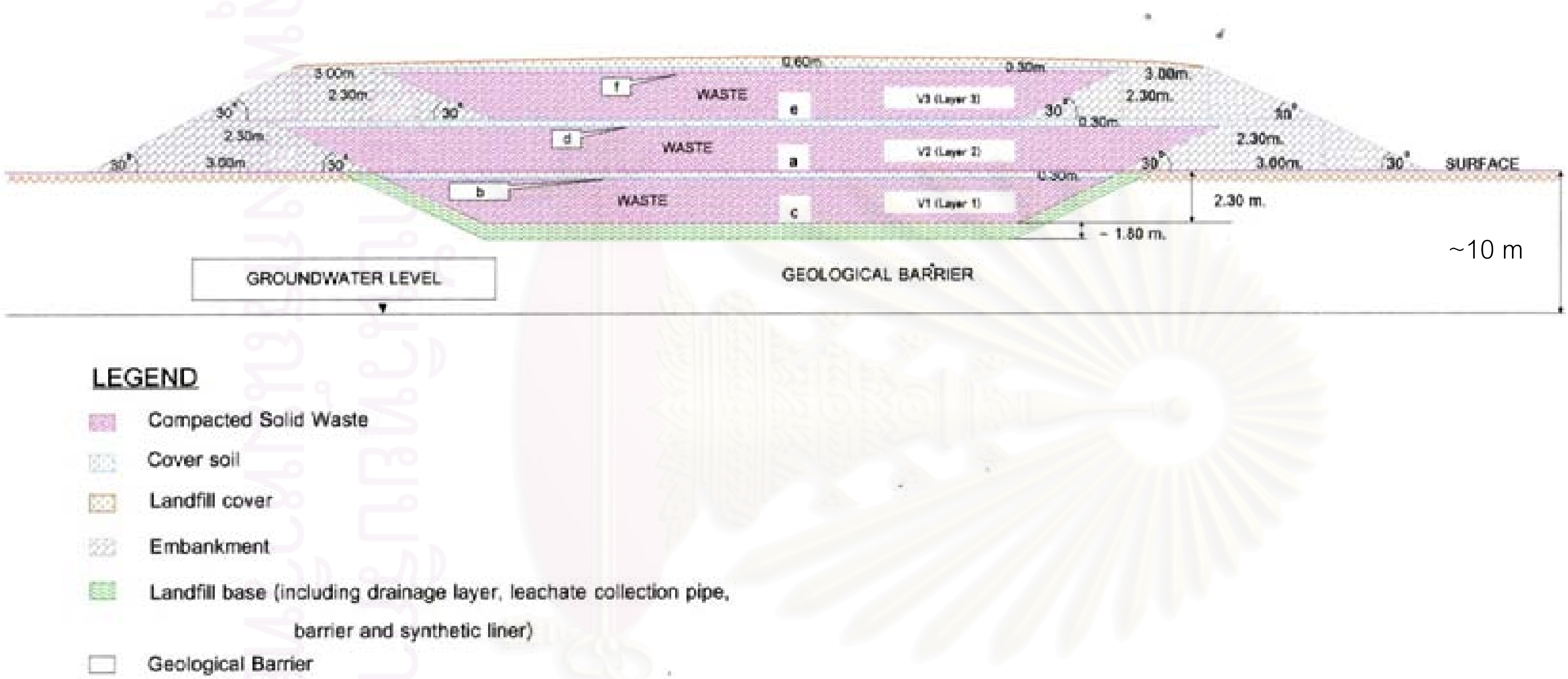


Figure 4.5 The conceptual model of sanitary landfill design

Table 4.4 Calculation to compacted solid waste area for Songkhla municipality.

From figure 4.5	
Where;	V is totally volume
	V_1 is volume of compacted solid waste layer 1
	V_2 is volume of compacted solid waste layer 2
	V_3 is volume of compacted solid waste layer 3
Equation	$V_1 = ½(b+c) \times h_1 \times l_1$
	$V_2 = ½(a+d) \times h_2 \times l_2$
	$V_3 = ½(e+f) \times h_3 \times l_3$
Where;	a, b, c, d, e, f = width of each layer
	b = a-2x(0.30/tan30°) = a-1.03923
	c = a-2x(2.30/ tan30°) = a-7.967434
	d = a+2x(2.30/ tan30°) = a+6.928203
	e = a-2x(2.30/ tan30°) = a-7.967434
	f = a-2x(0.30/ tan30°) = a-1.03923
Design	h_1, h_2, h_3 = height of each layer = 2.00 m
	Height cover material of each lift = 0.30 m
Assumption	l_1, l_2, l_2 = length of layer = 700 m
Replace b, c, d, e, f	V_1 = 1400a-6304.66494
	V_2 = 1400a+4849.74226
	V_3 = 1400a-6304.66494
So;	V = 4200a-7759.58762
For the example use Volume of compact waste of Songkhla municipality is 1,132,444 m^3	
Thus;	a = 339
From	l = 700 m
So	Area for compact waste is 339x700 = 237,220 m^2

Table 4.5 Total volume of compacted solid waste.

	Rate of population growth	volume of solid waste year 2002 to 2022 (metric-tons)	volume of compacted solid waste (cubic meter)	volume of daily cover (cubic meter)	total volume (cubic meter)
Songkhla	maximum	738,035	1341,881	335,470	1,677,352
	mean	622,844	1132,444	283,110	1,415,554
	minimum	573,696	1043,083	260,770	1,303,853
Hat Yai	maximum	1,141,067	2,074,666	518,666	2,593,333
	mean	962,972	1,750,857	437,714	2,188,571
	minimum	886,984	1,612,697	403,174	2,015,872
Sadao	maximum	165,116	300,210	75,052	375,263
	mean	139,345	253,354	63,338	316,693
	minimum	128,349	233,362	58,340	291,703
Ban Pru	maximum	357,678	650,324	162,581	812,905
	mean	301,853	548,823	137,205	686,028
	minimum	278,033	505,515	126,378	631,894
Kampangpret	maximum	34,981	63,602	15,900	79,502
	mean	29,521	53,675	13,418	67,093
	minimum	27,191	49,439	12,359	61,799
Kuan Niang	maximum	25,330	46,054	11,513	57,568
	mean	21,376.	38,866	9,716	48,583
	minimum	19,689	35,799	8,949	44,749
Chana	maximum	42,340	76,982	19,245	96,228
	mean	35,732	64,967	16,241	81,209
	minimum	32,912	59,840	14,960	74,801

Table 4.5 (cont.)

	Rate of population growth	volume of solid waste year 2002 to 2022 (metric-tons)	volume of compacted solid waste (cubic meter)	volume of daily cover (cubic meter)	total volume (cubic meter)
Thepa	maximum	16,847	30,630	7,657	38,288
	mean	14,217	25,849	6,462	32,312
	minimum	13,095	23,810	5,952	29,762
Nathawi	maximum	43,853	79,733	19,933	99,667
	mean	37,009	67,288	16,822	84,111
	minimum	34,088	61,979	15,494	77,474
Nasrithong	maximum	16,495	29,991	7,497	37,489
	mean	13,921	25,310	6,327	31,638
	minimum	12,822	23,313	5,828	29,141
Bo Tru	maximum	75,469	137,216	34,304	171,520
	mean	63,690	115,799	28,949	144,749
	minimum	58,664	106,662	26,665	133,327
Prick	maximum	36,092	65,622	16,405	82,028
	mean	30,459	55,380	13,845	69,225
	minimum	28,056	51,010	12,752	63,762
Padang Besa	maximum	79,243	144,077	36,019	180,097
	mean	66,875	121,590	30,397	151,987
	minimum	61,598	111,995	27,998	139,994
Patong	maximum	46,648	84,814	21,203	106,017
	mean	39,367	71,576	17,894	89,470
	minimum	36,261	65,928	16,482	82,410
Pangla	maximum	52,833	96,059	24,014	120,074
	mean	44,587	81,066	20,266	101,333
	minimum	41,068	74,669	18,667	93,337
Ranote	maximum	39,363	71,570	17,892	89,463
	mean	33,220	60,400	15,100	75,500
	minimum	30,598	55,633	13,908	69,542

4.1.2.5 The Required Area for Leachate Treatment.

Each landfill site should have area for leachate treatment plant. Loawatcharin (1998) mentioned that 20% of leachate is produced from the amount of rainfall. The formula of amount of rainfall determination on sanitary landfill is expressed as:

Q_{rf} = Q_{rd} X A_w.. ……………(4.3)

Where; Q_{rf} = the amount of rainfall falling on the sanitary landfill (m^3)

Q_{rd} = the amount of rainfall for a day (m)

A_w = area of compacted solid waste (m^2)

Generally, leachate is a result of the percolation of precipitation, uncontrolled runoff, and irrigation water into the sanitary landfill (Pfeffer, 1992). For the present study, percolation of precipitation into the sanitary landfill was used to calculate area for leachate treatment plant.

The maximum of mean monthly rainfall and average rain-day of Songkhla during 1966 to 1995 were measured at Station number 48568 that were 594.3 mm of mean rainfall and 22.3 days of rain-day in November. Area for compacted solid waste, a maximum of mean monthly rainfall, and average rain-day were replaced in equation (4.3).

Loawatcharin (1998) suggested that leachate treatment plant, including faculative pond, and stabilization pond. The former should be 2.00-3.00 m of depth and 10 day of detentional time while the latter should be 1.2-1.5 m of depth and 20 day of detentional time. The formulas for faculative pond and stabilization pond calculation are expressed as follows:

<u>Faculative pond:</u>

$$Afp = \frac{Vfp}{Dfp} \qquad \text{...(4.4)}$$

Where; $Vfp = \left\{ Qrf \times \frac{20}{100} \right\} \times 10$;

Qrf = the amount of rainfall falling on a sanitary landfill (m^3);

Vfp = capacity or volume of facultative pond (m^3);

Dfp = depth of facultative pond (m); and

Afp = area of facultative pond (m^2).

<u>Stabilization pond:</u>

$$Asp = \frac{Vsp}{Dsp} \qquad \text{...(4.5)}$$

Where; $Vsp = \left\{ Qrf \times \frac{20}{100} \right\} \times 20$;

Qrf = the amount of rainfall falling on a sanitary landfill (m^3);

Vsp = capacity or volume of stabilization pond (m^3);

Asp = area of stabilization pond (m^2).

The calculation was done by replacing the amount of rainfall falling on a sanitary landfill, 2 m of depth of faculative pond, and 1.5 m of depth of stabilization pond in equations (4.4) and (4.5), respectively. As a result, area of faculative pond and area of stabilization pond were computed and presented in table 4.7. (see calculation method in Table 4.6).

4.1.2.6 Miscellaneous Area

Loawatcharin (1998) suggested that the sanitary landfill area should include miscellaneous area (i.e., internal road system, plant zone, drainage lane, equipment storage, house of laborer). In this study, there are 10 m of width for internal road system. 10 m of width for plant zone, 150 m^2 for equipment storage, and 100 m^2 for house of laborer. As a result, area for miscellaneous area was estimated to be 60,750 m^2.

Total area required for a landfill site must include for compacted municipal solid waste, daily cover, leachate treatment plants, and miscellaneous areas. As a result, total areas in Songkhla were presented in table 4.7. For contingency events area for sanitary landfill, 20% of excess area was also computed. Consequently, total land requirements for sanitary landfill in Songkhla area were calculated and summarized in Table 4.7

Table 4.6 Calculation method for area requirement for solid waste disposal in Songkhla. The example is at Songkhla municipality.

1. Calculation method for compacted solid waste area (see table 4.5)			
From	Area = Width x Length		
Where	Width = a	399	m
	Length	700	m
Thus	Area for compacted solid waste	237,220	m^2
2. calculation method for leachate treatment plant area			
Calculation method for amount of leachate			
From section 3.2.1; Maximum rainfall at station kiskdjalfd		594.3	mm(rain/day)
So	Rainfall	26.65	mm/day
	Or	0.02665	m/day
	Area for compacted solid waste	280,852	m^2
So	Amount of rainfall	7,484.7	m^3/day
From	Amount of leachate = 20% of rainfall		
So	Amount of Leachate	1,496.94	m^3/day
2.1 calculation method for faculative pond			
	Amount of leachate for 10 day	1,496.94x10	m^3/dayxday
So	Capacity of pond	14,969.2	m^3
	Depth of pond	2.5	m
So	Area of faculative pond	5,987	m^2
2.2Calculation method for Stabilization pond			
	Amount of leachate for 20 day	1,496.94x20	m^3/dayxday
So	Capacity of pond	29,938.4	m^3
	Depth of pond	1.5	m
So	Area of stabilization pond	19,958.9	m^2
3. Miscellaneous areas		60,750	m^2
4. 20 % excess areas		64,783.2	m^2
	Total	388699.2	m^2

Table 4.7 Land Requirement for Sanitary Landfill in Songkhla

	Population prediction	Disposal area	Faculative pond	Stabilized pond	Miscel-laneous area	SUM
Songkhla	maximum	280851.9573	598.7763729	1995.921243	60750	344196.6549
	mean	237219.0543	505.7510239	1685.836746	60750	300160.6421
	minimum	218602.2311	466.0599567	1553.533189	60750	281371.8242
Hat Yai	maximum	433515.5465	924.2551452	3080.850484	60750	498270.6521
	mean	366055.248	780.4297886	2601.432629	60750	430187.1104
	minimum	337272.0048	719.0639142	2396.879714	60750	401137.9484
Sadao	maximum	63837.1993	136.1009089	453.6696964	60750	125176.9699
	mean	54075.4802	115.2889238	384.2964126	60750	115325.0655
	minimum	49910.45364	106.4090872	354.6969572	60750	111121.5597
Ban Pru	maximum	136777.4669	291.6095594	972.0318648	60750	198791.1083
	mean	115631.392	246.5261278	821.7537593	60750	177449.6719
	minimum	106609.0096	227.2904084	757.6346945	60750	168343.9347
Kampangpret	maximum	14543.67158	31.00710781	103.357026	60750	75428.03572
	mean	12475.57734	26.5979309	88.65976965	60750	73340.83504
	minimum	11593.18487	24.71667015	82.38890051	60750	72450.29045
Kuan Niang	maximum	10887.97682	23.21316658	77.37722192	60750	71738.56721
	mean	9390.45534	20.02045078	66.73483595	60750	70227.21063
	minimum	8751.508792	18.65821674	62.19405582	60750	69582.36106
Chana	maximum	17331.22803	36.95017816	123.1672605	60750	78241.34547
	mean	14828.05814	31.61341996	105.3780665	60750	75715.04963
	minimum	13760.03222	29.33638869	97.78796231	60750	74637.15657
Thepa	maximum	7674.675826	16.36240886	54.54136287	60750	68495.5796
	mean	6678.679265	14.23894419	47.46314731	60750	67490.38136
	minimum	6253.718039	13.33292686	44.44308953	60750	67061.49406
Nathawi	maximum	17904.43716	38.17226003	127.2408668	60750	78819.85029
	mean	15311.80206	32.64476199	108.8158733	60750	76203.2627
	minimum	14205.60407	30.28634788	100.9544929	60750	75086.84491
Nasrithong	maximum	7541.482003	16.07843963	53.59479877	60750	68361.15524
	mean	6566.274039	13.99929625	46.66432084	60750	67376.93766
	minimum	6150.182671	13.11218945	43.70729818	60750	66957.00216

Table 4.7 (cont.)

	Population prediction	Disposal area	Faculative pond	Stabilized pond	Miscel-laneous area	SUM
Bo Tru	maximum	29879.98897	63.70413649	212.3471216	60750	90906.04023
	mean	25418.23621	54.1916796	180.638932	60750	86403.06682
	minimum	23514.54296	50.1330056	167.1100187	60750	84481.78599
Prick	maximum	14964.6592	31.90465342	106.3488447	60750	75852.9127
	mean	12830.85815	27.35538957	91.1846319	60750	73699.39817
	minimum	11920.43059	25.41435802	84.71452674	60750	72780.55948
Padang Besa	maximum	31309.44412	66.75173486	222.5057829	60750	92348.70163
	mean	26624.58515	56.76361555	189.2120518	60750	87620.56082
	minimum	24625.69932	52.50199096	175.0066365	60750	85603.20795
Patong	maximum	18962.85237	40.42880125	134.7626708	60750	79888.04384
	mean	16205.02216	34.54910724	115.1636908	60750	77104.73496
	minimum	15028.34048	32.0404219	106.8014063	60750	75917.18231
Pangla	maximum	21305.63659	45.4236172	151.4120573	60750	82252.47226
	mean	18182.14979	38.76434336	129.2144779	60750	79100.12861
	minimum	16849.45365	35.92303518	119.7434506	60750	77755.12013
Ranote	maximum	16203.83745	34.54658145	115.1552715	60750	77103.53931
	mean	13876.62819	29.58497131	98.61657104	60750	74754.82974
	minimum	12883.67928	27.46800423	91.56001411	60750	73752.7073

4.2 Geological Barrier Identification

The database, which were used for identification of geological barrier, comprised of 1:50,000 and 1:250,000 geological map, Landsat TM5 (bands 4, 5, and 7), and borehole data of the study area. The methodology was categorized into 3 main steps, as follows. (see figure 4.6)

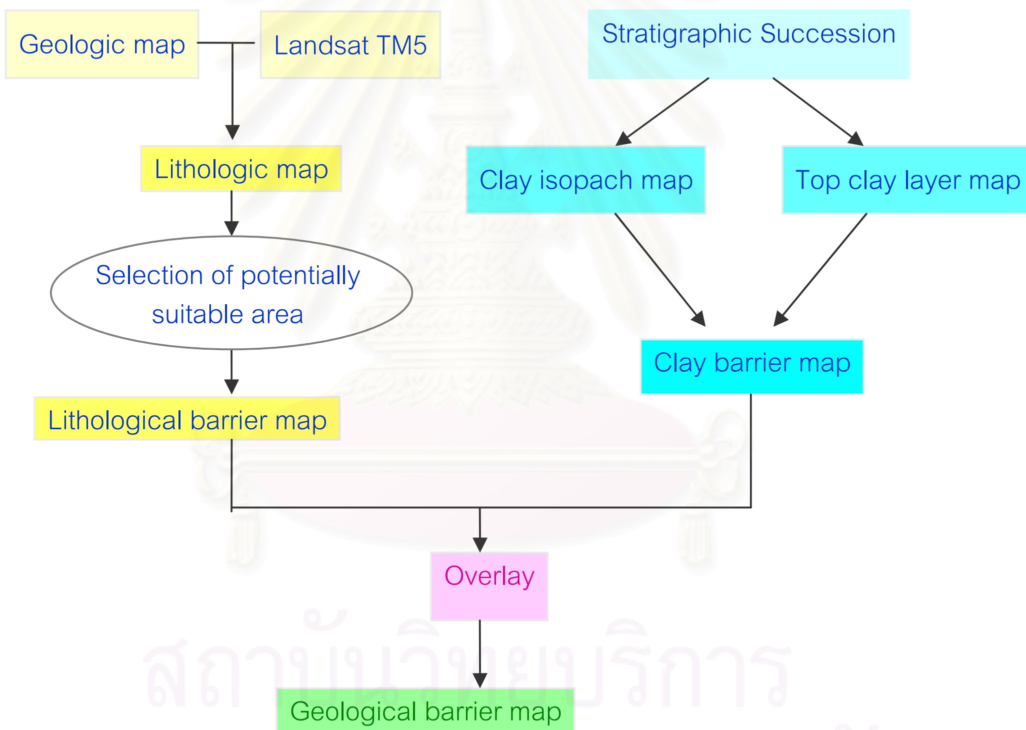


Figure 4.6 The schematic diagram of geological barrier mapping in present study.

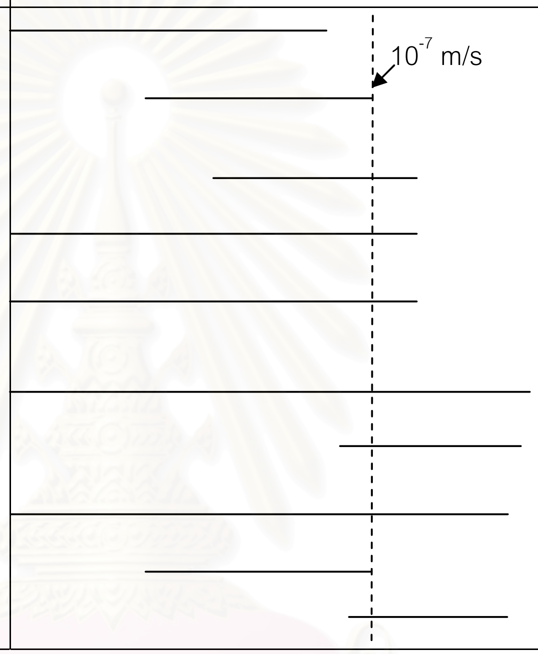
4.2.2 Lithological Barrier Mapping

The Lithological barrier map is a map based entirely on the information of the lithologic map. No other information or borehole data was used to compile it. The lithological barrier of the rocks in the Songkhla area was determined by estimating their potential permeability based on the lithological description of lithologic map

The initializing step was to prepare a lithological map. All of geologic maps and Landsat TM5 were analyzed to construct this map. The lithologic units of the geologic maps, just only rock units, were interpreted and reboundary with Landsat TM5. Then, each lithologic unit was reclassified into potential levels according to its property as a lithological barrier. The potential are represented in 4 levels as, high, medium, low, and non potential

Geologic map of Songkhla shows several of chronostratigraphic units from Cambrian to Quaternary deposits with two periods of granitic rocks. Each geological unit was composed of different lithology. Landsat TM5 was used to lithologic interpretation with geologic map to reboundary of the lithologic map. Then lithologic map can be divided into 7 main units as presented in table 4.8. The lithological barrier map was classified from permeability in each lithologic character, as none, low, medium, and high potential levels. The high potential area cover Amphoe Hat Yai and Sadao, Southern part of Nathawi, and the central part of Saba Yoi (see figures 4.7 and 4.8)

Table 4.8 Permeability and barrier properties of lithological unit in Songkhla area based on the lithologic map.

lithology	Permeability range (k_f m/s)* 10^0 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10}	LITHOLOGICAL BARRIER
Conglomeratic sandstone		None**
Sandstone		Low**
Shale interbedded sandstone		Low**
Shale interbedded sandstone with high fracture zone		None***
Shale interbedded sandstone with dyke		None***
Shale, sandstone and conglomerate interbedded		None***
Mudstone or shale		High**
Limestone		None**
Quartzite		Low**
Granite		Medium***

Note: * permeability range applied from Bell (1992)

** classified from Matias and Tantiwanit (2000)

*** defined in this study

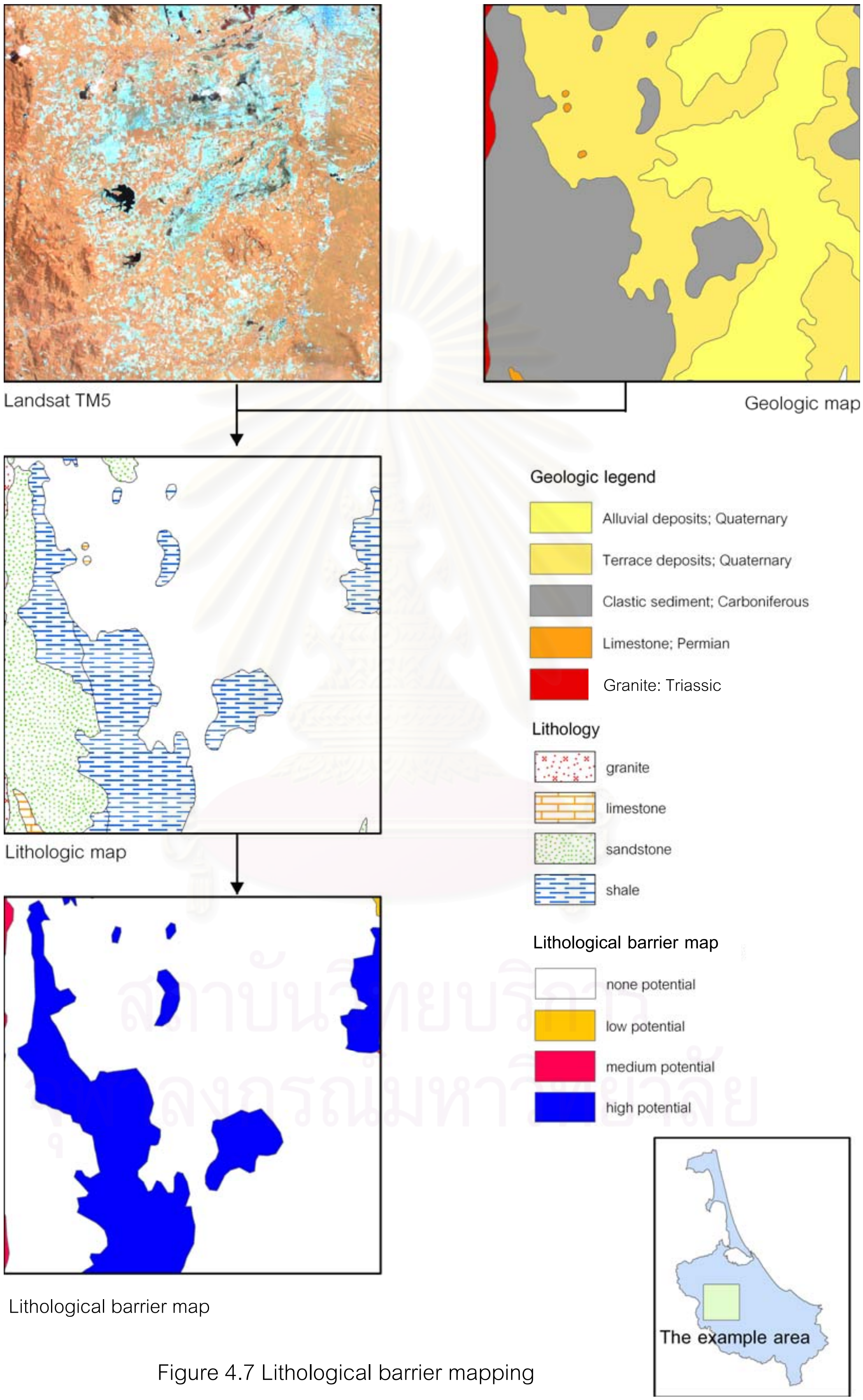


Figure 4.7 Lithological barrier mapping

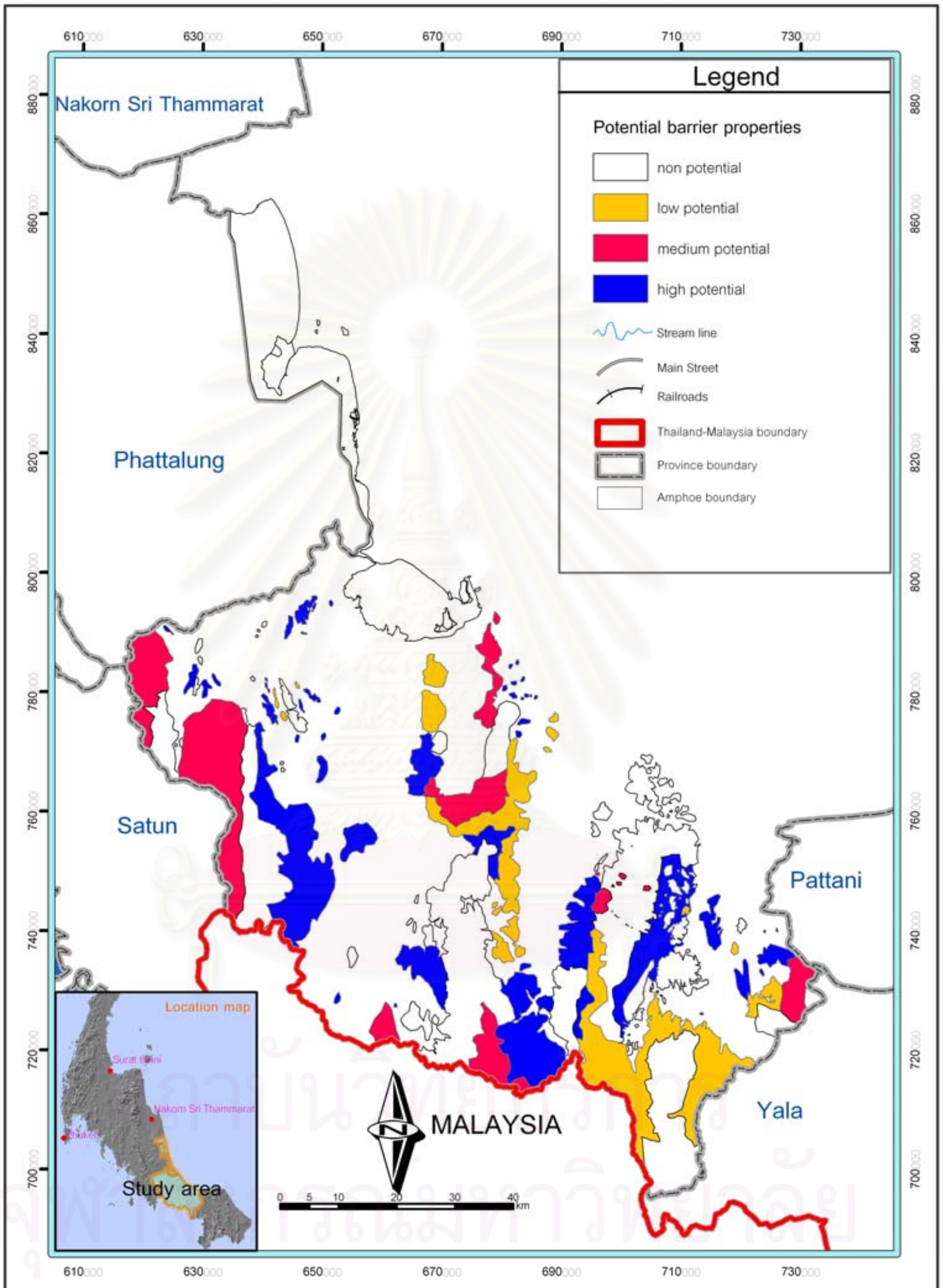


Figure 4.8 Lithological barrier map of Songkhla.

Area Selection for Solid Waste Disposal in Changwat Songkhla

Rottana Ladachart

Department of Geology, Faculty of Science, Chulalongkorn University, 2002

4.2.3 Clay Barrier Mapping

A barrier map shows delineation of the sediment which is the potential barrier with permeability (k_f) less than 10^{-7} m/s (clay or silt) and the layer is thicker thickness than 10 m.

4.2.3.1 Recompiling the Borehole Data

The data was collected from hydrogeological well logging from Hydrogeological Section, Department of Mineral Resources. The data are composed of well number, northing and easting coordinates, litholo-stratigraphy, level of water table, ground water quality, etc. To make them suitable for analysis, the data must be simplified by compiling into a new table that suitable for interpolation and further analysis in a in GIS program.

The simplified data for analysis as shown in figure 4.9 comprised the following fields:

[TOP] is the depth from top surface to first boundary of clay layer. If the borehole material is other than clay or clay layer is deeper than 30 m, then assign the [TOP] to be 50.

[THICKNESS] is the thickness of first clay layer. If the borehole does not have clay layer or the clay layer is deeper than 30 m, then assign the [THICKNESS] to be 0.

[TYPE_OF_WELL] is the borehole data type It has the value “t” if it is a true borehole data, otherwise assign as “f” to it.

4.2.3.2 Hypothetical Boreholes

The results from preliminary interpolation into isopach map and top clay layer map were not realistic. In the study area, there are many mountains or outcrop exposures, but the results showed that the clay layers extend under the mountain and outcrop exposures. To eliminate these illusoriness data adjustment for be done by assuming a hypothetical borehole with the values of [TOP] and [THICKNESS] equal to 50 and 0 respectively. In addition, [TYPE_OF WELL] would be “f”.

4.2.3.3 Interpolation

Spatial interpolation is the procedure of estimating the value of properties at unobserved sites within the area covered by existing observations. There are many interpolation techniques such as DWS, kriging etc. The technical method, which was used in this study is kriging method linear, point of kriging type, linear semi-variogram model with variogram slope = 1, anisotropy angle = 0 anistropy ratio = 1, and polynomial drift order = 0.

4.2.3.4 Isopach Map

Isopach map is a map showing the thickness isoline. The isopach map was interpolated from [TOP] field and displayed with the contour of 2, 5, 10 and 15 m thick.

4.2.3.5 Top of Clay Layer Map

Top of clay layer map is a map showing the depth from surface to the top of clay layer from top surface isoline. The top clay layer map was interpolated from [TOP] field and displayed with the contour of 2, 5, 10 and 15 m deep.

4.2.3.6 Analyzed the Clay Barrier Map

Both isopach map and top of clay layer map, were analyzed used to synthesize the clay barrier map according to the criteria, which were summarized in table 4.9

Table 4.9 Criteria for synthesizing the clay barrier map.

Top / Thickness	> 15 m	10 – 15 m	5 – 10 m	2 – 5 m	< 2 m
< 2 m	none	none	none	none	None
2 – 5 m	none	none	low	low	low
5 – 10 m	none	low	low	medium	medium
10 – 15 m	none	low	medium	medium	high
> 15 m	none	low	medium	high	high

The method and result of the clay barrier ware shown figure 4.10 and 4.11, respectively.

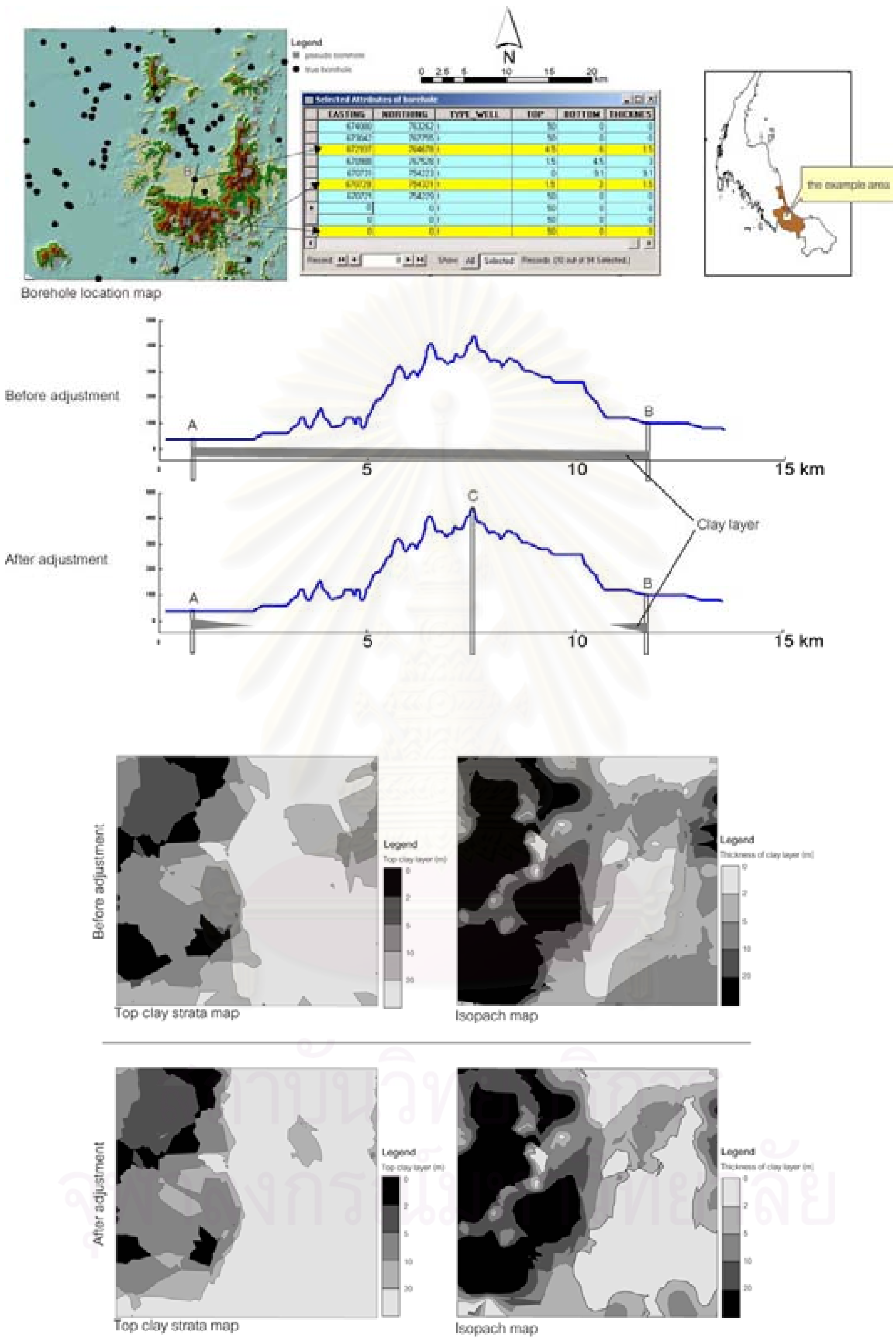


Figure 4.9 Comparing between before and after adjustment of the hypothetical borehole.

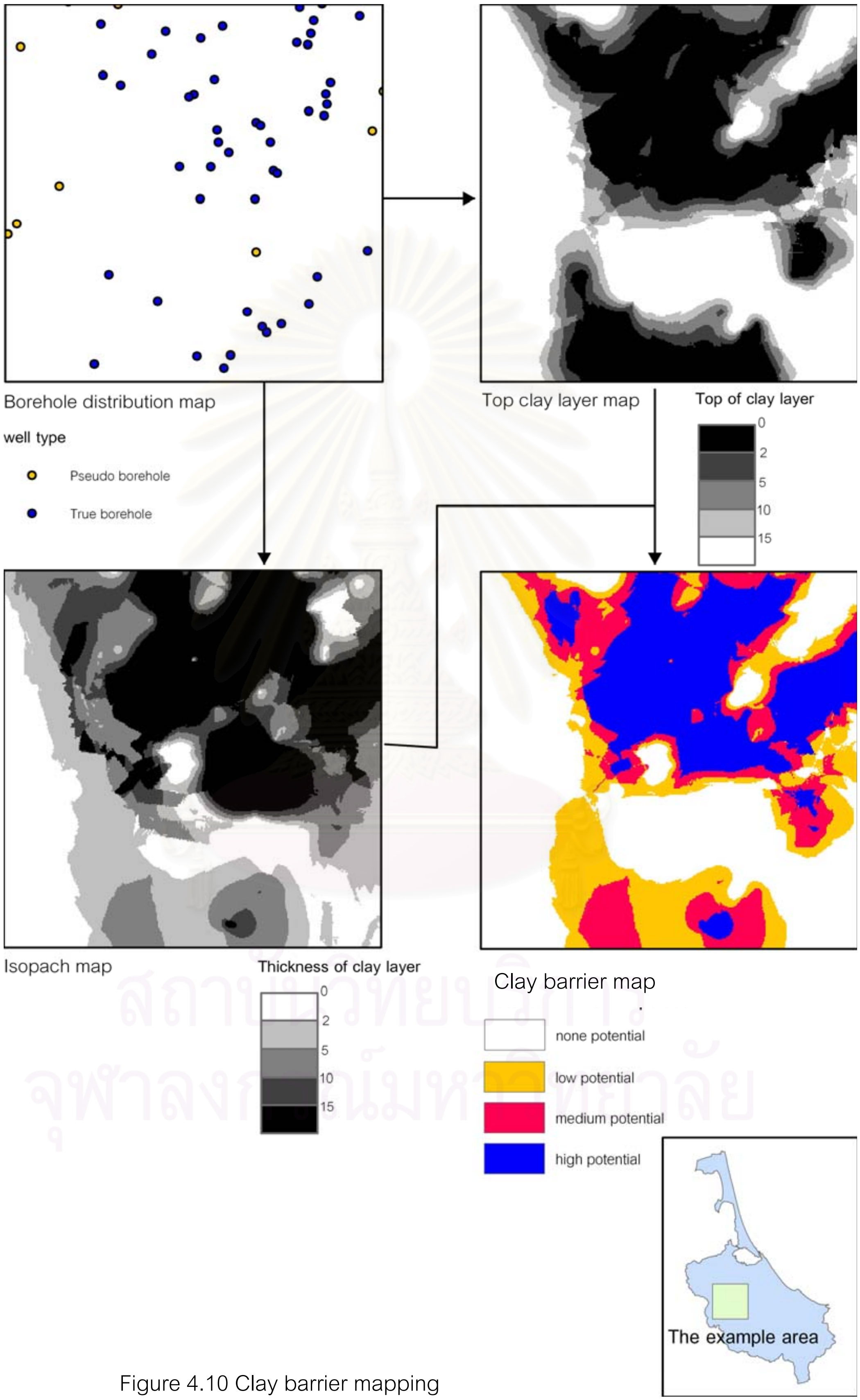


Figure 4.10 Clay barrier mapping

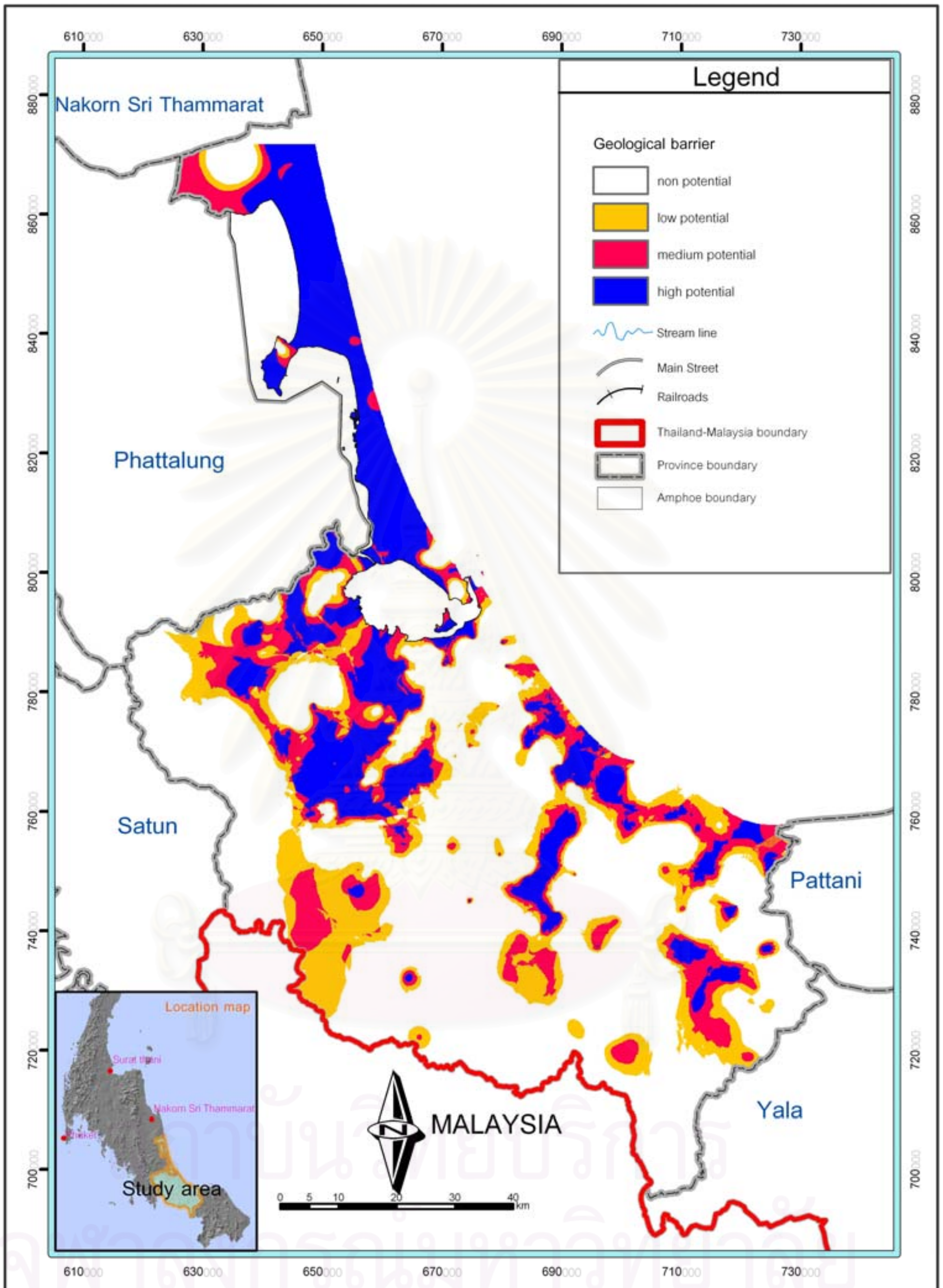


Figure 4.11 Clay barrier map of Songkhla

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Department of Geology, Faculty of Science, Chulalongkorn University, 2002

4.2.4 Geological Barrier Mapping

From the past steps, 2 maps were created as lithological barrier map and clay barrier map. Both maps similar by show 4 categories of the potential as high, medium, low and non potential. The lithological barrier map shows potential according to rock units, and the clay barrier map shows the potential according to sedimentary properties. Both maps were combined to single map using following conditions:

$$P_{GB} = \begin{cases} P_{LB} \text{ if } P_{LB} = \{\text{low, medium, high}\} \\ P_{CB} \text{ if } P_{LB} = \{\text{none}\} \end{cases}$$

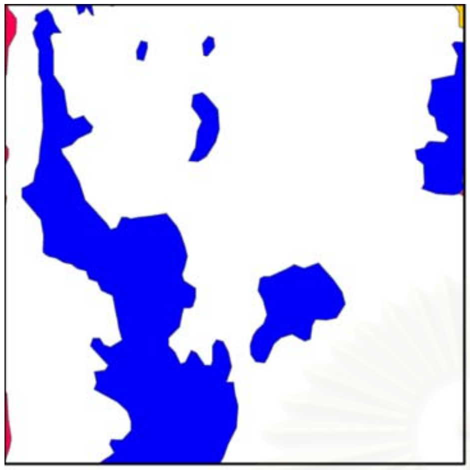
Where; P_{GB} = potential levels of the geological barrier

P_{LB} = potential levels of the lithological barrier

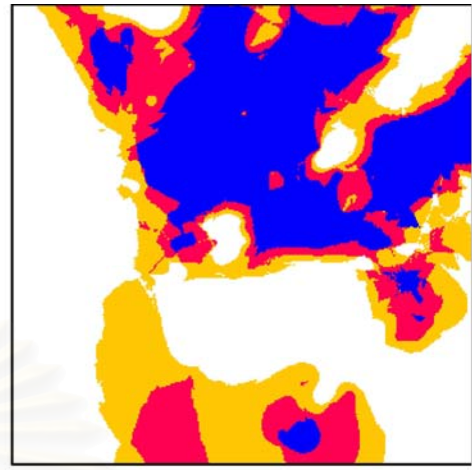
P_{CB} = potential levels of the clay barrier

After combined the lithological barrier and clay barrier maps, the geological barrier map shows the potential required for landfill suitability analysis. The high potential areas mainly cover Hat Yai to Sadao and South of Saba Yoi They cover area about 140 km^2 or 19% of total area (figure 4.13).

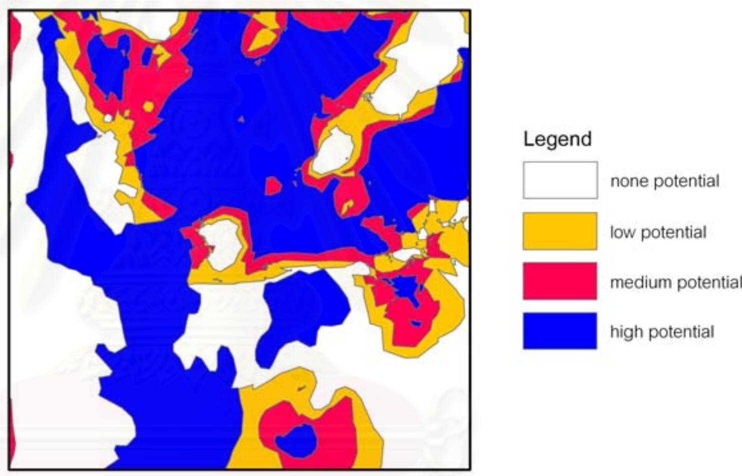
Figure 4.13 show some of the area, which was found in the field investigation for geological barrier. There are many of outcrop exposure by quarry show the thick layer of clay.



Lithological barrier map



Clay barrier map



Geological barrier

Figure 4.12 Geological barrier mapping

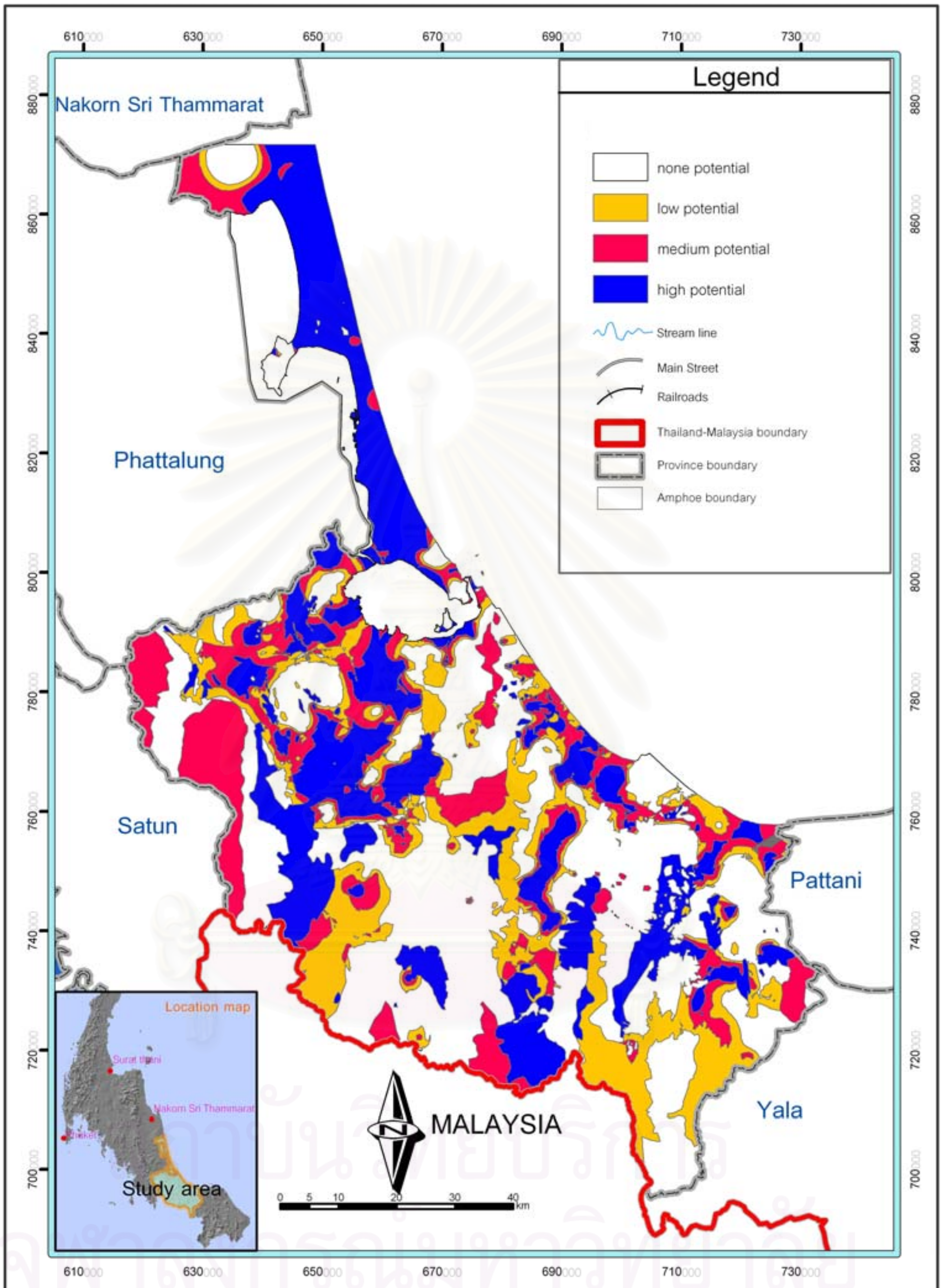


Figure 4.13 Geological barrier map of Songkhla

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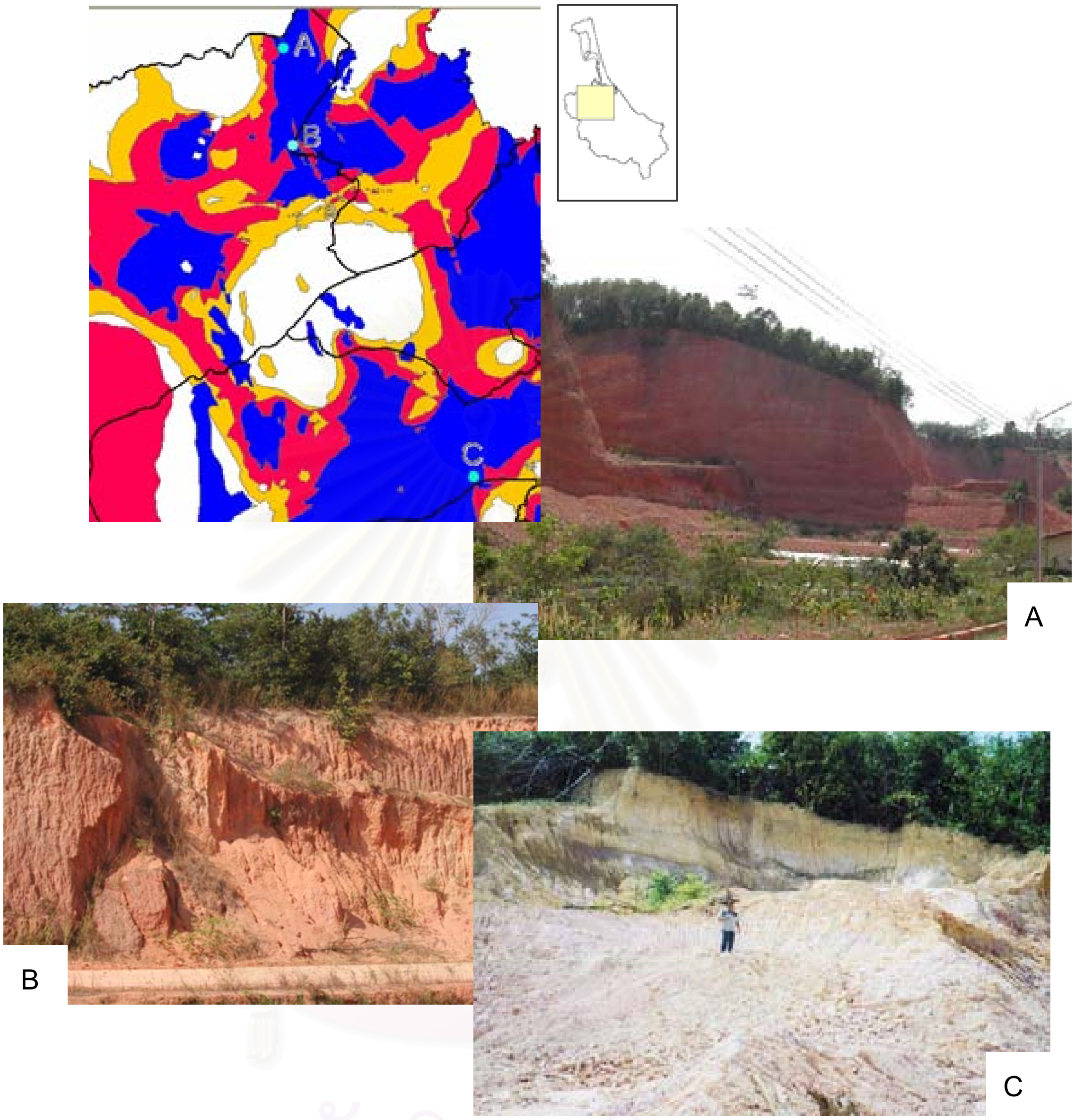

Figure 4.14 Field investigation for the geological barrier in Songkhla.

(A) More than 15 m-thick bedded of silty clay

(B) More than 10 m-thick bedded of clay

(C) More than 10 m-thick bedded of clay with sand lens. In nearly area was found latheritic layer.

4.3 Preparation Database and Analysis Using GIS techniques

After forecasted the quantity of solid waste and the area for sanitary landfill in section 4.1, the next step is a GIS application for area selection within environmental and geological conditions. The application of GIS for selection of potential solid waste disposal area is considered to be most effective in establishing the linkage between all parameters concerned.

In this study, 2 types of area selecting were considered, i.e. using and not using the geological barrier map.

The positive/negative-mapping was used in this study. The negative-map was derived with respect to slope, intensive and urban areas, villages, transportation systems, historical and archeological sites, watershed, surface water runoff, groundwater well locations, forest, geological structures, and flood prone areas. . In the other hand, the positive-mapping was derived with respect to soil map, hydrogeological map, and geological map

4.3.1 Data Collection and Management

The existing data related to this study have been acquired in the form of maps, digital map, reports, publications, and historical statically records. Some of the data were produced from the existing data, such as, landform map are combined data of soil map and Landsat TM5 images. All of the data for identifying the area for solid waste disposal are summarized in table 4.10.

4.3.2 Criteria Identification in the Study

After data collection and management, the next step was the identification of criteria for selecting suitability areas for solid waste disposal. This process can be classified into two criteria as negative and positive perspectives.

Table 4.10 The GIS database used for area selection of solid waste disposal.

No.	Theme	Spatial and attribute data base
Basic coverages		
1.	Land tenure	Administrative of Amphoe, Tambon, Municipal and Municipality districts, village site
2.	Topography	Elevation, slope classification and aspect.
3.	Surface water	Catchment area boundary, stream line, water body and pond.
4.	Geology	Geological boundary, fault and joint, and mineral resources
5.	Hydrogeology	Aquifer type, yield, groundwater table, well location
6.	Geomorphology:	Landform unit
7.	Soil	soil boundary, soil type, soil characteristic
8.	Land use:	land use type in year 1982, 1992, and 2000, forest area, cultural and amenity tourism location
9.	Transportation	Road, rail road, port, and air port.
10.	Flood	Flood prone area
Derived coverages		
11.	Lithological barrier	Lithological boundary, Lithological barrier, Landsat TM5
12.	Clay barrier	Borehole location, top clay layer data, clay barrier.
13.	Geological barrier	Geological barrier
14.	Positive-/negative-criteria	Positive criteria, negative criteria

4.3.2.1 Negative-criteria

The negative criteria for the sanitary landfill selection are in general incompatible waste disposal site because of the existing land use of the characteristic of areas. The landfill needs controlling and preventing environmental impacts in long term. The negative criteria are described in table 4.11.

4.3.2.2 Positive-criteria

Postitive criteria is the criteria that suitability by natural justification that have a positive effects for landfill sites. Van der Wall and other (1992) suggested general demands for areas suitable for waste disposal as those areas having:

- permeability of natural underlining $< 10^{-7}$ m/s;
- thickness of natural underlining (sediment) > 5 m;
- thickness of natural underlining (hard rock) > 20 m; and
- distance from groundwater table to ground surface > 2 m

Table 4.11 Summary of negative criteria for area selection for waste disposal.

Parameters	Negative criteria
1. Area requirement	Area of sanitary landfill is less than 80,350 m^2. See section 4.1
2. Slope	Slope is more than 20% (Disatian, 1992)
3. Flood prone area	Area that is very high and high possibility of flooding.
4. Municipality area	Area that located within 5 km from municipality areas (Kerdput, 1999)
5. Village	Area that located within 500 m from village (Boonlue, 1998)
6. Historical, archaeological, and tourist attraction area	Area that located far within 1 km from their boundaries (Pollution Control Department, 1998)
7. Transportation	Area that located within 300 m from main road (Kerdput, 1999)
8. Surface water	Area that located far within 300 mfrom natural/man-made surface water including stream, wetland and water body (Pollution Control Department, 1998)
9. Groundwater well	Area that located far within from groundwater well and waster supply station (Pollution Control Department, 1998)
10. Airport	Area that located within 5 km from air port (Pollution Control Department, 1998).
11. Watershed area	Area in the watershed Class 1A, 1B, and 2 (Pollution Control Department, 1998)
12. Forest area	Area under forest conservation type area (Boonlue, 1998)
13. Fault	Area that located within 500 m from a fault (Boonlue, 1998)

4.3.3 Analysis for the suitability area for solid waste disposal base on GIS techniques

There were two main steps using GIS tools ain this study, i.e., the deriving of positive and negative maps. And the classification of area suitability.. The detailed results are described as below.

4.3.3.1 Producing the Negative Map

All of the negative criteria shown in Table 4.10 were bounded and integrated for preparation of the negative map. Figure 4.9 shows non-suitable area for sanitary landfill.

4.3.3.2 Producing the Positive Map

In order to examine the capability of the geological barriers, the study produced two types of positive maps. The first positive map was derived from geological barrier map and will be called the ***"Proposing model"***. The second map did not use geological barrier but was base on soil and hydrogeology conditions which had been applied in Van der Wall (1992). The latter model will be called the ***"Controlling model".*** Both models were compared to investigate their ability in identifying waste disposal areas.

The Proposing model

From geological barrier map as displayed in figure 4.8, the legends of the geological barriers are displayed as high, medium, low, and non potential. Each legend represents the potential for the sanitary landfill as follows;

- The high potential is an excellence for disposing waste. The groundwater can be kept from leachate of landfill. It has shallow and thick clay layer.

- The medium potential is a good potential for disposing waste. Groundwater can be kept from the leachate of landfill. It has clay layer that is deeper and thinner than high potential.

- The low potential is a fair area for disposing waste. The groundwater may be contaminated from the leachate of landfill if the landfill failed. It has clay layer that is deeper and thinner than medium potential.

- The none-potential is unsuitable area for landfill. Groundwater is likely to be contaminated by leachate, if landfill failed. Clay layer is either too deep or too thin prevent leachate contamination.

The Controlling model

The technique used by Van der wall(1992), was adapted. It can be divided into suitable conditions as follows;

- The suitable phisical conditions
  This condition was derived from soil condition. The suitable condition for sanitary landfill is clay dominant and deep soil.

- The suitable geological conditions
  This condition was derived from lithological condition from lithologic map (section 4.2.2).

- The suitable hydrogeological conditions

This condition was derived from yield map and groundwater table map (section 3.2.6)

All of the suitable conditions are summarized and presented in Table 4.12

Table 4.12 Summary of suitable area classification of the controlling model.

Data	Suitablility		
	High	Medium	Low
Soil unit	3, 6, 22, 23	2, 10, 11, 14, 16, 17, 23	3, 25, 26, 32, 34, 35, 39, 41, 42, 43, 45, 50, 51, 53, 58, 52
Lithological unit	Mudstone or shale	Granite	Sandstone, Shale interbedded sandstone,
Groundwater Yield	< 2 m^3/hr	2 -10 m^3/hr	10 -20 m^3/hr
Groundwater table	> 10 m	5 – 10 m	2 – 5 m

4.3.4 The Suitability Map

The results of GIS analysis were summarized in Figure 4.16 and 4.19 as show analytical models of potential solid waste disposal area selection using GIS technique in which proposing model and controlling model, respectively.

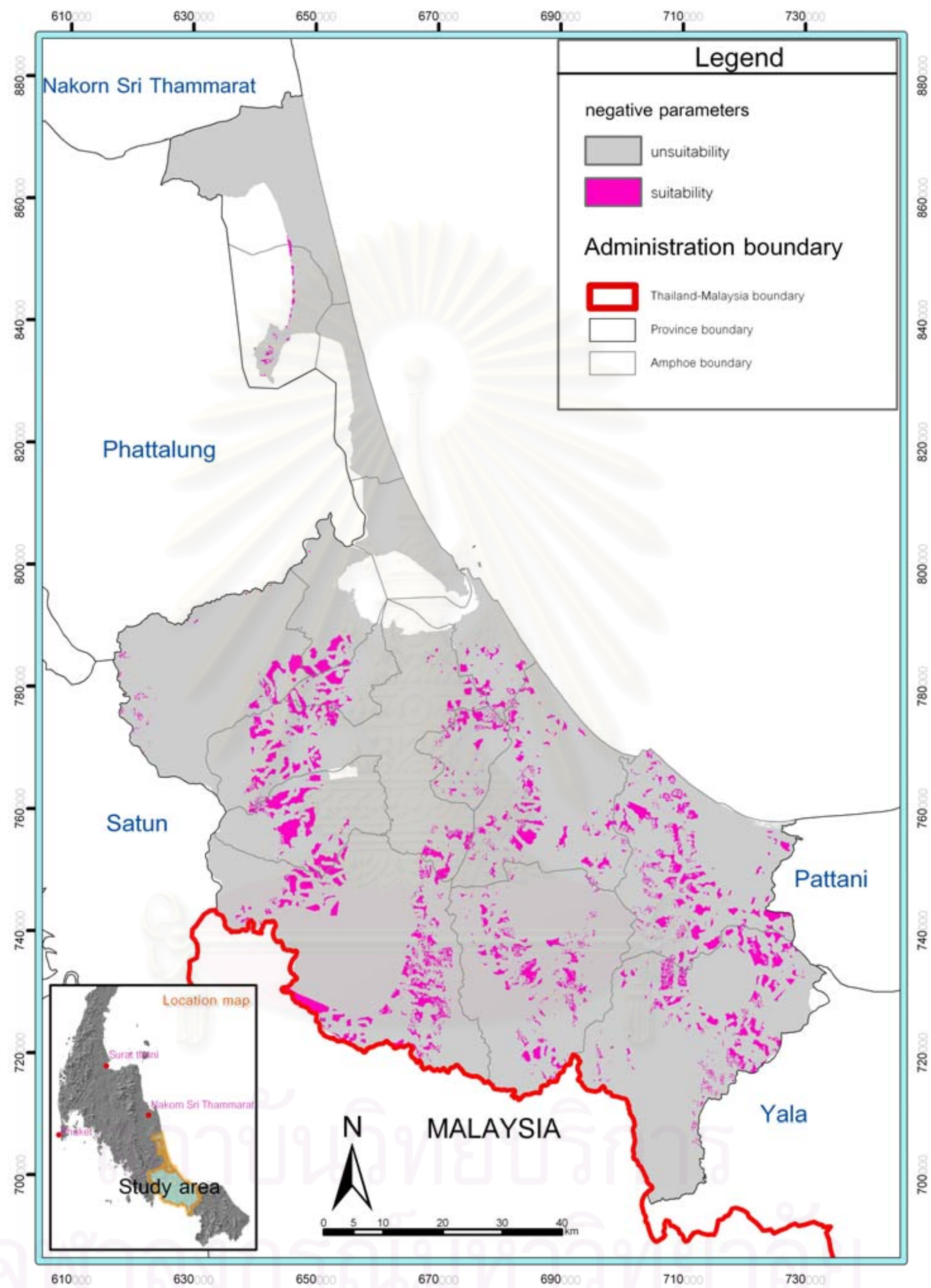

Figure 4.15 Negative map

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Rottana Ladachart

Department of Geology, Faculty of Science, Chulalongkorn University, 2002

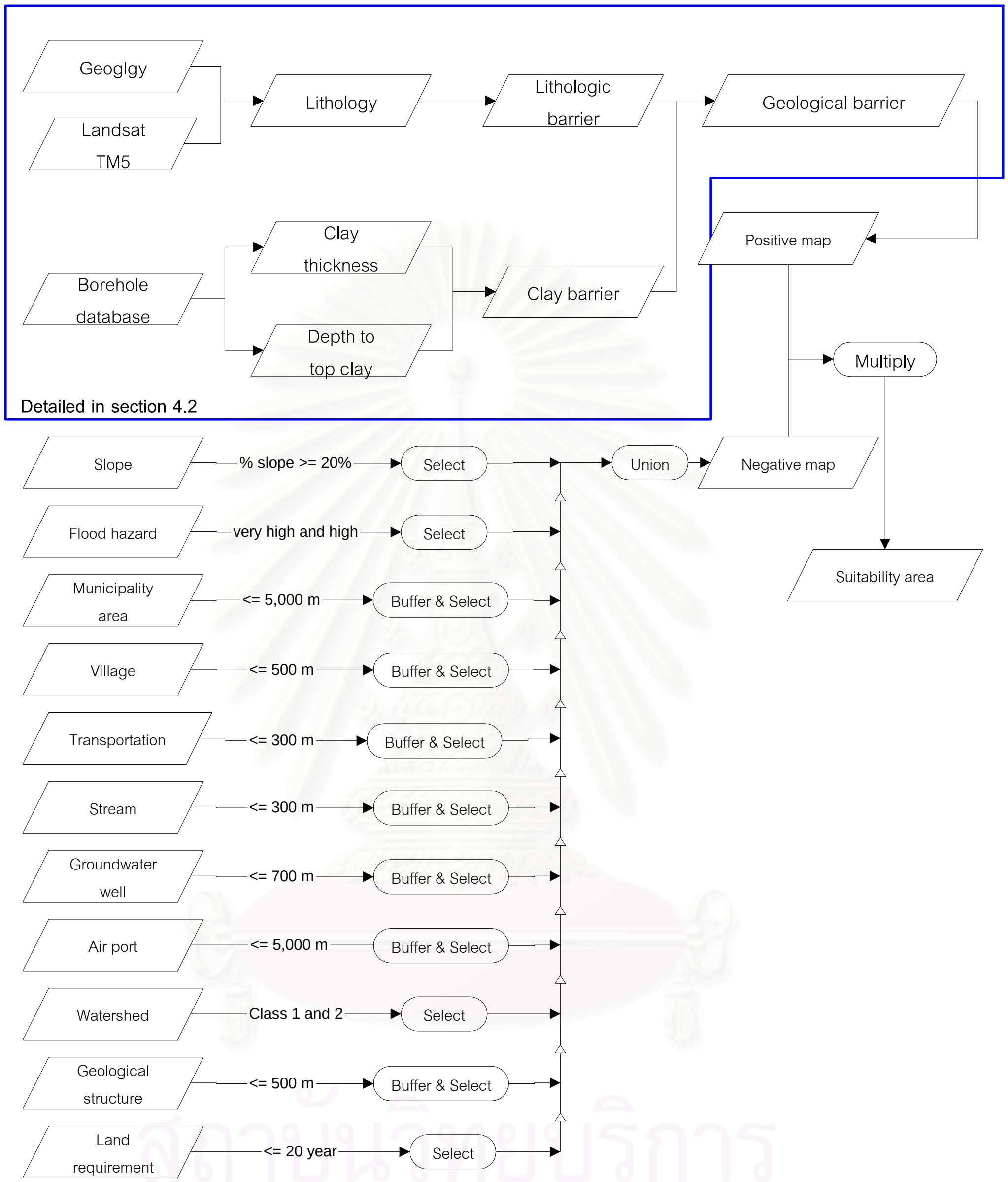

Figure 4.16 Waste disposal potential mapping using the proposing model (positive map from geological barrier).

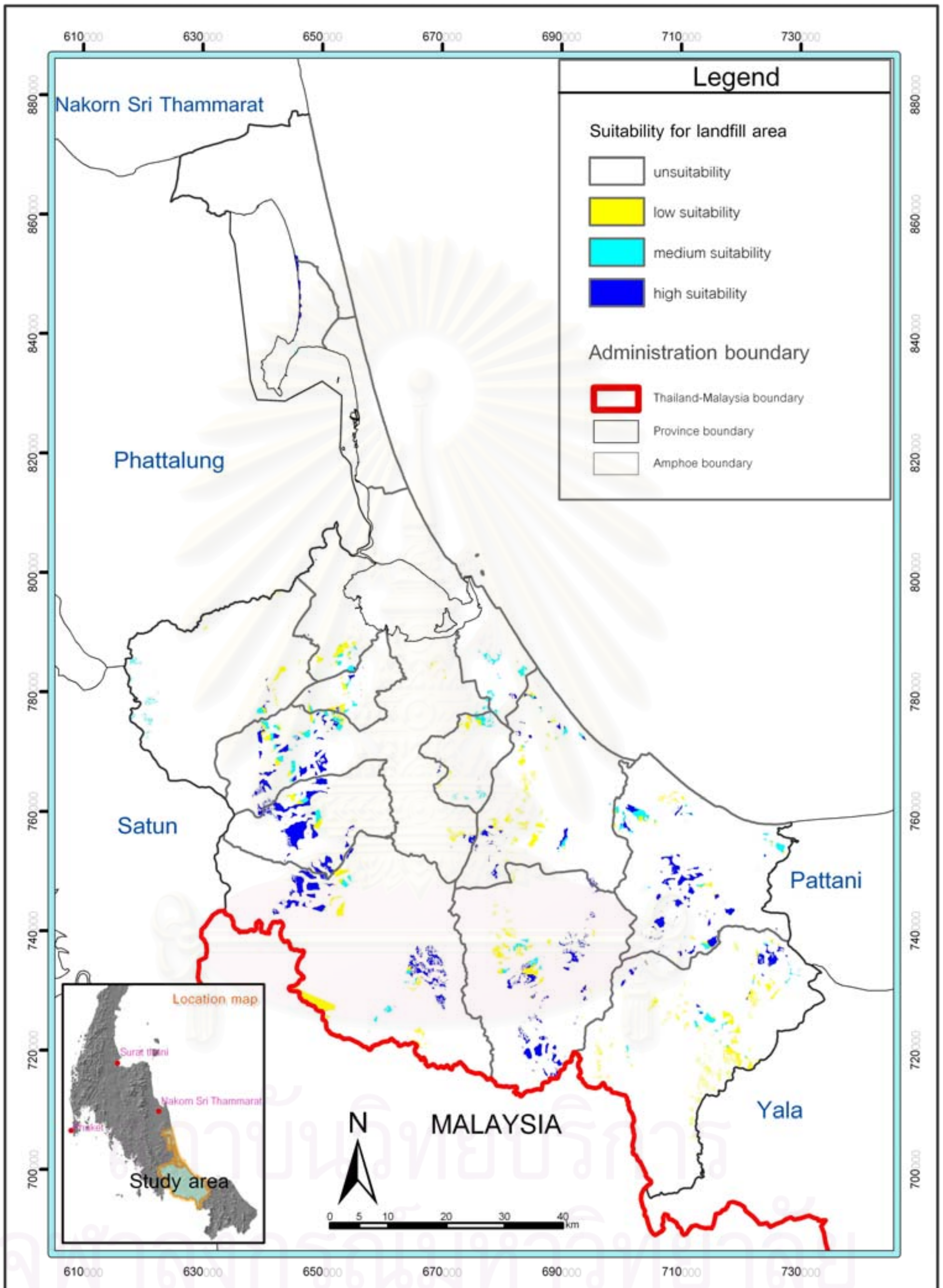

Figure 4.17 Area suitable for landfill generated with the proposing model. (derived from geological barrier map)

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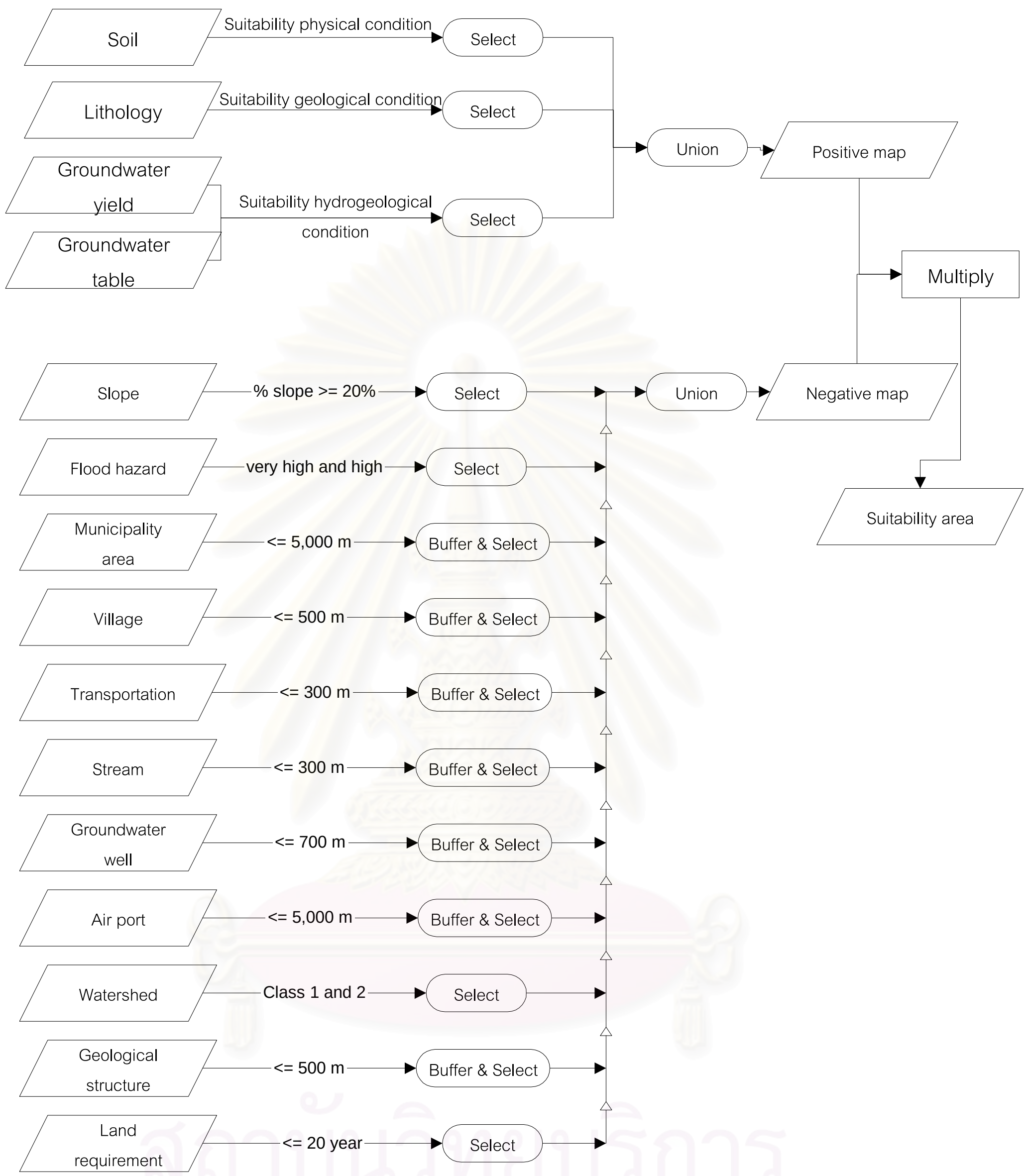

Figure 4.18 Waste disposal potential mapping using the controlling model (positive map from soil, hydrogeologic and lithologic map).

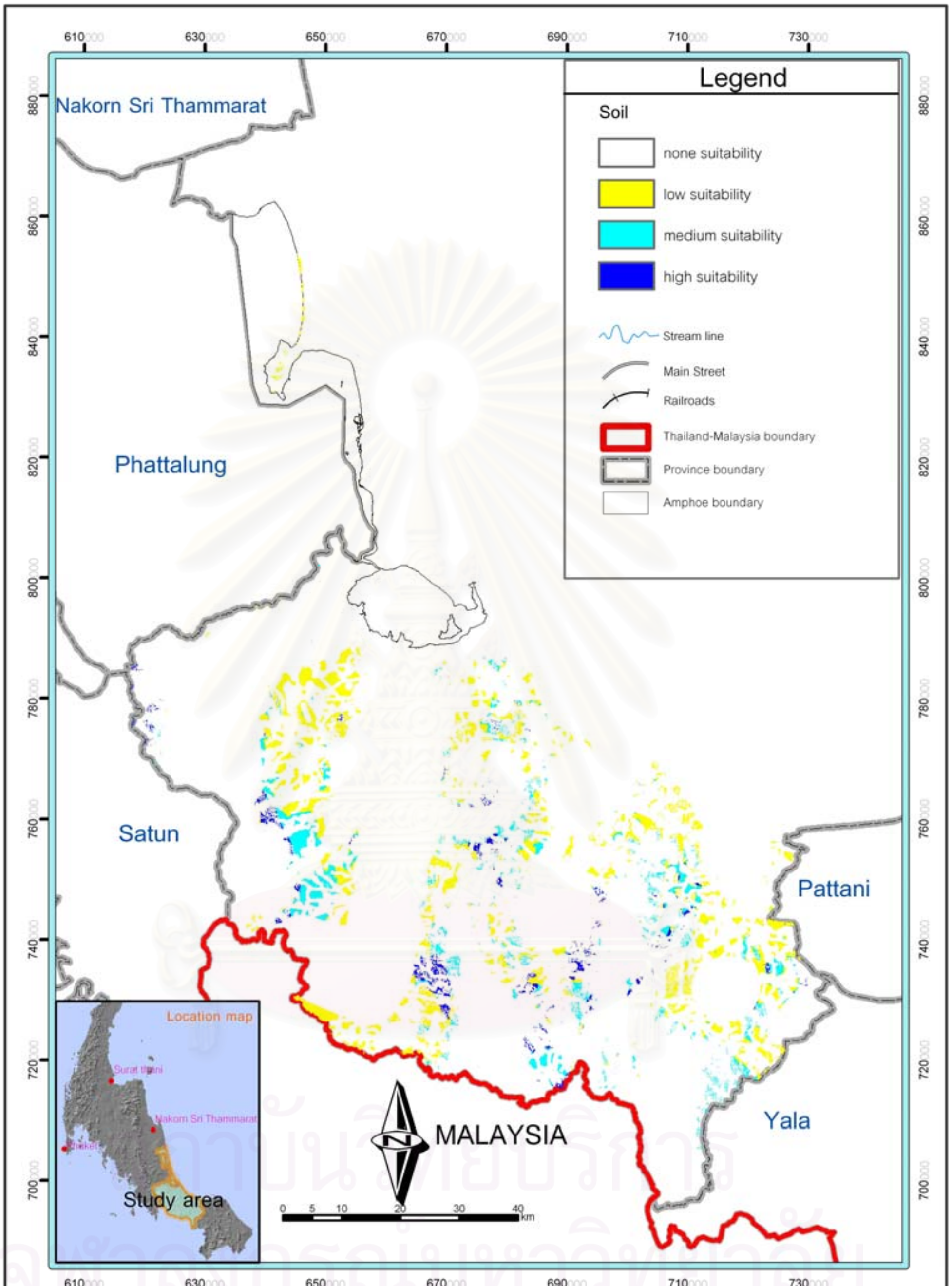

Figure 4.17 Area suitable for landfill generated with the controlling model.
(derived from soil, hydrogeologic and litholodic map)

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Figure 4.17 proposing model has high, medium, and low suitability areas for solid waste disposal cover 165, 86, and 137 locations with areas of 110.6, 40,7, and 70,8 km^2, respectively. The controlling model (figure 4.18) has high, medium, and low suitability areas for solid waste disposal cover 105, 86, and 137 locations with areas of 110.6, 40,7, and 70,8 km^2, respectively. Comparing results are showed in Figure 4.20.

There are slightly contrasting results between the proposing and controlling model that the proposing model yields has more high suitability areas than the control. Some areas in the controlling model, that show low suitable, have high suitable in the proposing model. It can explain that soil map, which was used in the controlling model, shows legends of soil cover material in the deepest of 1.5 to 2 m depth but geological barrier map, which compiled in this study, shows the deepest clay layer more than 20 m. So, it has a possibile to some areas that have soil cover with a suitability identification; but in a deeper than 2 m, it could have high suitable material for solid waste disposal. (for instance, see figure 4.21)

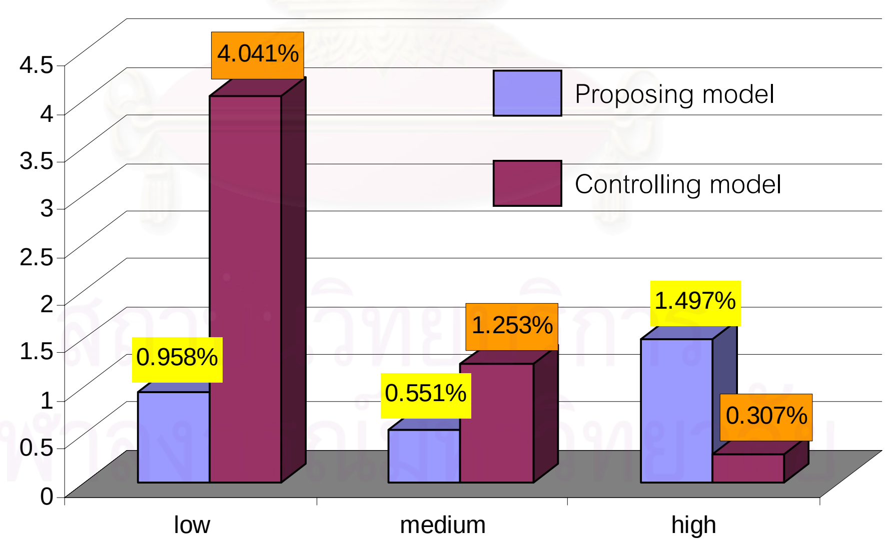
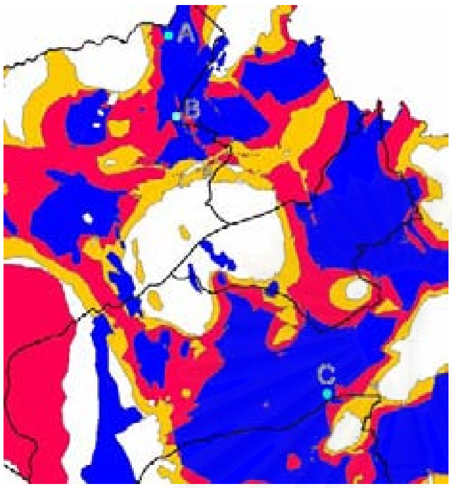
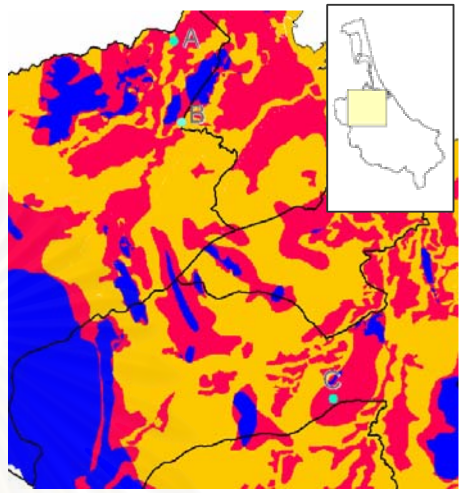


Figure 4.20 A comparison between area suitability in proposing and controlling models.



(a) Proposing model

A	High	top = 0.42 thickness = 15.68
B	High	Top = 0.27 Thickness = 11.66
C	High	Top = 0.77 Thickness =52.97



(b) Controlling model

A	Medium	Soil unit = 17 Gw.Yield = 2-10 m^3/hr Gw.level = 5-10 m.
B	Low	Soil unit = 45 Gw.Yield = < 2 m^3/hr Gw.level = 5-10 m.
C	Medium	Soil unit = 45 Gw.Yield = 2-10 m^3/hr Gw.level = >10 m.

Figure 4.21 The comparable between proposing model and controlling model with spots of field investigation which found thick of clay layer.

CHAPTER V

CONCLUSIONS

Based on the study for area selection of solid waste disposal in Changwat Songkhla, the following conclusions and concluding remarks have been reached.

5.1 Conclusions

The area selection for solid waste disposal in Changwat Songkhla in this study covered waste generation projection, waste disposal area requirement and area selection based on physical and environmental data using GIS techniques.

In the first part of the work, estimation of area size for solid waste disposal, was divided into 2 steps as solid waste generation projection and area required solid waste disposal. Calculations in this part were based on 16 municipalities, which generate waste to For this study , the municipality that generated the highest waste volume, was Hat Yai municipality and the lowest was Nasrithong municipality where the recorded waste generations were 109,304 and 1,580 kg/day, respectively.

Initially, population projection of Songkhla was predicted from existing population growth in 1987 to 2001. Then, the existing waste generation in each municipality were used to predict amount of waste generation. The results of waste generation projection were calculated using the maximum, mean, and minimum of population projection. From the calculation, total solid waste generated in the next 20 year (from 2002 to 2022) are ranging from 2,911,400 to 2,263,100 metric-tons. The municipality that will generate the highest waste volume, is Hat Yai Municipality with 886,984 to 1,141,067 metric-tons of waste generated and the lowest is Nasrithong Municipality with 12,822 to 16,495 metric-tons.

Consequently, size of area required for solid waste disposal was estimated from the amount of solid waste generated. The area requirements covered landfill area, faculative pond, stabilization pond, miscellaneous area and plus 20% of area for contingency resources. From the calculation, Hat Yai municipality would require 481,365 to 597,925 m^2 of land and Nasrithong municipality would require 80,348 to 82,033 m^2.

In the second part, the geological barrier map was identified. The concept of the geological barrier is natural material underlining the landfill that have low permeability, low (effective) porosity, large thickness, and high natural retention capacity for hazardous substances. The geological barrier identification method can be divided into 3 steps as lithological barrier mapping, clay barrier mapping, and geological barrier mapping.

The lithological barrier map was mapped by reclassification of lithological map based on permeability. The argillaceous rocks in Songkhla were identified as high potential. Sedimentary covers were omitted in this identification step.

The clay barrier map was prepared by interpolating mapped borehole data into clay isopach and depth of top clay layer map. Hypothetical borehole data were introduced to areas, such as hills and outcrop exposures, where clay layer should not exist. Ranking potential technique criteria in table 4.9 shows that high potential can be found in area with shallow and large thickness of clay layer. As a result, the areas of high potential of clay barrier cover areas in intermontain basin and along coast. The largest area that has high potential found along the coastline of Songkhla Lake. In addition, the second and third largest areas were found in Amphoe Hat Yai, and Amphoe Bangklam, respectively.

The last step of this part was to overlay the lithological barrier map over the clay barrier map. The result was the geological barrier map that reflects information from both lithology and sedimentary covers. As a result, the geological barrier cover mainly along the coastline of Songkhla lake, and Amphoe Bangklam, Hat Yai, and Sadao.

In the final par, the "Positive/Negative-mapping" technique was used in the analysis. The data and information in GIS covered physical environment and socio-economic parameters, were used for landfill area. Two model were compared in this part. They were referred as the proposing model (the model used geological barrier for the positive map) and the controlling model (the model used soil unit and hydrogeological condition for the positive map). Both models used the same data layers for the negative map.

The negative map was compiled from refusal criteria for area selection as, area requirement, slope terrain, flood prone areas, watershed conservation area, forest conservation area, distance to municipalities, distance to villages, distance to historical archaeological and tourist attraction areas, distance to transportation lines, distance to surface water resources, distance to groundwater well locations, distance to airports, and distance to faults or lineaments.

The proposing model, which positive map referred to geological barrier map was excluded by negative map. The high, medium, and low suitability areas for solid waste disposal cover 165, 86, and 137 areas patches of land with total areas of 110.6, 40,7, and 70,8 square kilometers, respectively.

The controlling model, which positive map was compiled from soil map, lithological map, groundwater yield map, and groundwater table map, was excluded by negative map. There are high, medium, and low suitability area for solid waste disposal cover 105, 86, and 137 areas and 110.6, 40,7, and 70,8 km^2, respectively.

As results, there are contrast between proposing model and controlling model that proposing model has more high suitability areas than controlling model. Some areas in controlling model that show low suitable have high suitable in proposing model. It can explain that soil map, which was used in controlling model, shows legends of soil cover material in the deepest of 1.5 to 2 m deep but geological barrier map, which compiled in this study, shows the deepest clay layer more than 20 m. So, it have possibility to some areas that have soil cover shows suitability but in a deeper than 2 m, it could be found the high suitability material for solid waste disposal.

In conclusion, geological barrier can be a good criteria for solid waste disposal area selection.

5.2 Concluding Remarks

In this study, it found some analytical limit and application of geological barrier as follows;

5.2.1 Scale of analysis in this study was limited to area selection only (in scale of 1:100,000 to 1:10,000). For specific site selection more of parameters such as detailed ground survey, public hearing, socio-economic conditions, etc, must be conducted.

5.2.2 Accuracy of result is based upon quality and quantity of the data used. For example, borehole data need may not have a good distribution, since these borehole logs acquired from groundwater well log that belong to village sites. So, the other areas that do not have village would lack of data. For a better result, distribution of boreholes must be analyzed and more hle should be added in some area that lack of data.

5.2.3 Increasing of the suitability areas provides more chances for selecting of solid waste disposal areas. However, it should be realized that the high suitability area suggested in this study may not be a good site at all if it does not meet social and economic concerns. So, more areas of high suitability only providing site suitability on for detail study whether they have social or economic problems.

5.2.4 The geological barrier map is not only important for the area selection for landfill, but will be a very useful tool for all types of planning purposes:

It will give a quick and uncomplicated first assessment if groundwater pollution is possible. If the groundwater is exposed to contamination, the geological barrier map can help determine whether the contaminants will infiltrate quickly underground.

It will aid assessment of abandoned waste sites: areas will be hazardous to groundwater if they lie in an area with no PBR, and it will be less hazardous if there are geological barrier.

The geological barrier map can assist planning purposes such as the construction of a pipeline or a new industrial settlement. Utilities should only be built where the subsurface and groundwater are protected by geological barrier.

In general, the geological barrier map can be used for any activities that influence the subsurface and groundwater.

5.2.5 Population projection in this study used only a simplified forecasting technique. Serious users may take migratory effects, which are depending on economic developing activities in the area, into account. These influences, however, are beyond the scope of this study.

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BIOGRAPHY

Mr.Rottana Ladachart was born on June, 6, 1979 at Hat Yai, Songkhla. He received the B.Sc. degree of Geology from Faculty of Science, Chulalongkorn University on May, 2000. Then he has continued his study for the M.Sc. degree of Geology from Faculty ofScience Chulalongkorn University.