

**SELECTION OF A POTENTIAL SOLID WASTE LANDFILL SITE  
IN NAKHON PATHOM PROVINCE BY USING  
GEOGRAPHIC INFORMATION SYSTEM (GIS)**



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THE DEGREE OF MASTER OF SCIENCE  
(TECHNOLOGY OF INFORMATION SYSTEM MANAGEMENT)  
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Thesis  
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*Janjira Jamjan*  
Miss Janjira Jamjan  
Candidate

*[Signature]*  
Assist. Prof. Thatchavee Leelawat,  
Ph.D. (Concrete Technology),  
Chair

*[Signature]*  
Asst. Prof. Ranjna Jindal  
D.Tech.Sc. (Environmental  
Engineering),  
Member

*[Signature]*  
Asst. Prof. Bunlur Emaruchi,  
Ph.D.(Environmental Systems Engineering),  
Member

*[Signature]*  
Mr. Chao Nokyoo,  
Ph.D. (Environmental Engineering),  
Member

*[Signature]*  
Lect. Somchai Pathomsiri,  
Ph.D. (Transportation Systems  
Engineering and Planning),  
Member

*[Signature]*  
Prof. Banchong Mahaisavariya,  
M.D.  
Dean  
Faculty of Graduate Studies  
Mahidol University

*[Signature]*  
Asst. Prof. Rawin Raviwongse,  
Ph.D. (Engineering Management),  
Dean  
Faculty of Engineering  
Mahidol University

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**SELECTION OF A POTENTIAL SOLID WASTE LANDFILL SITE  
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*Janjira Jamjan*

Miss Janjira Jamjan

Candidate

*B. Emaruchi*

Asst. Prof. Bunlur Emaruchi,  
Ph.D. (Environmental Systems Engineering),  
Major-Advisor

*Somchai Pathomsiri*

Lect. Somchai Pathomsiri,  
Ph.D. (Transportation Systems  
Engineering and Planning),  
Co-Advisor

*Ranjna Jindal*

Asst. Prof. Ranjna Jindal,  
D.Tech.Sc. (Environmental Engineering),  
Co-Advisor

*B. Mahaisavariya*

Prof. Banchong Mahaisavariya,  
M.D.  
Dean  
Faculty of Graduate Studies  
Mahidol University

*Pornchai Chanyagorn*

Lect. Pornchai Chanyagorn,  
D. Sc. (Computer Engineering),  
Chair  
Master of Science Programme in  
Technology of Information System Management  
Faculty of Engineering Mahidol University

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As usual, the author is solely responsible for all analyses and discussions that appeared in this thesis.

Janjira Jamjan

**SELECTION OF A POTENTIAL SOLID WASTE LANDFILL SITE IN NAKHON PATHOM PROVINCE BY USING GEOGRAPHIC INFORMATION SYSTEM (GIS)**

JANJIRA JAMJAN 4936788 EGTI/M

M.Sc. (TECHNOLOGY OF INFORMATION SYSTEM MANAGEMENT)

THESIS ADVISORY COMMITTEE: BUNLUR EMARUCHI, Ph.D. (ENVIRONMENTAL SYSTEMS ENGINEERING), SOMCHAI PATHOMSIRI, Ph.D. (TRANSPORTATION SYSTEMS ENGINEERING AND PLANNING), RANJNA JINDAL, D.Tech.Sc. (ENVIRONMENTAL ENGINEERING)

**ABSTRACT**

During the past decade, Nakhon Pathom Province has experienced relatively fast growth due to several reasons including the expansion of economic activities from Bangkok, the construction of more residences and government offices, as well as increasing investment in the agricultural industry. Inevitably, this results in increases in solid wastes and the burden of waste disposal. Effective solid waste management is therefore an important countermeasure. It is anticipated that the existing solid waste landfill at Tambon Takong will reach its capacity in the near future. Therefore, preparedness to handle this situation is very urgent.

This research had the main objective to study the whole area of Nakhon Pathom Province and choose the most preferable site for a landfill that could accommodate solid waste during the next 20 years. To accomplish the objective, the future waste amount was estimated based on the increased population and the rate of waste generation, and by utilizing ArcGIS - the Geographic Information System (GIS) technology. Within the GIS environment, multiple criteria corresponding to the guidelines and recommendations provided by the Department of Pollution Control and international standards were considered. These consisted of land-use compatibility, appropriate soil type, right topography, inexpensive land price, convenient transportation, distance from rivers and water bodies, non flooded area, deep groundwater level, size suitability and the lowest transportation cost.

The results suggested the best site is at Nakhon Chai Si District, Tambon Bangrakam. This site has about 1,485.34 Rai areas. The best site shows the least total fuel cost for transportation as 10,406.63 baht. Nevertheless, the final decision should also take into consideration the social aspect in order to reduce the negative impacts on the community near the candidate site.

**KEY WORDS: GIS/ SOLID WASTE/ LANDFILL/NAKHON PATHOM/ ENVIRONMENT**

113 pages

การเลือกพื้นที่ฝังกลบขยะที่เหมาะสมสำหรับจังหวัดนครปฐม โดยใช้ระบบสารสนเทศทางภูมิศาสตร์  
 SELECTION OF A POTENTIAL SOLID WASTE LANDFILL SITE IN NAKHON PATHOM PROVINCE  
 BY USING GEOGRAPHIC INFORMATION SYSTEM (GIS)

จันจิรา แจ่มจันทร์ 4936788 EGTI/M

วท.ม. (เทคโนโลยีการจัดการระบบสารสนเทศ)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์ : บัณฑิต เอมะรุจิ, Ph.D. (ENVIRONMENTAL SYSTEMS ENGINEERING), สมชาย ปฐมศิริ, Ph.D. (TRANSPORTATION SYSTEMS ENGINEERING AND PLANNING), รัญจนา จินดัล, D.Tech.Sc. (ENVIRONMENTAL ENGINEERING)

บทคัดย่อ

ในหลายปีที่ผ่านมาจังหวัดนครปฐมมีอัตราการเจริญเติบโตอย่างรวดเร็วจากหลายสาเหตุ เช่น การแผ่ขยายกิจกรรมทางเศรษฐกิจของกรุงเทพมหานครไปทางด้านทิศใต้ การก่อสร้างโครงการที่อยู่อาศัยและอาคารของหน่วยงานราชการ รวมไปถึงมีการลงทุนเพิ่มมากขึ้นในอุตสาหกรรมทางการเกษตร การเจริญเติบโตของเมืองนครปฐมส่งผลให้ปริมาณขยะเพิ่มมากขึ้นอย่างไม่อาจหลีกเลี่ยงได้ ก่อให้เกิดผลกระทบต่อสิ่งแวดล้อมและเป็นอันตรายต่อสุขภาพของประชาชน การบริหารจัดการขยะจึงเป็นมาตรการที่จำเป็นอย่างยิ่ง การกำจัดขยะโดยการคัดแยกและฝังกลบเป็นวิธีการหนึ่งที่ถูกนำมาใช้กับจังหวัดนครปฐม ในปัจจุบันทางจังหวัดมีแหล่งฝังกลบหนึ่งแห่งอยู่ในตำบลตาก้องเป็นที่คาดว่าในอนาคตอันไม่ไกล สถานที่ฝังกลบแห่งนี้ อาจจะไม่สามารถรองรับขยะได้เพิ่มอีก จำเป็นต้องเตรียมความพร้อมในการขยายขีดความสามารถเพื่อรองรับปริมาณขยะที่เพิ่มขึ้น

งานวิจัยนี้จึงทำการศึกษาเพื่อเลือกทำเลที่ตั้งสถานที่ฝังกลบขยะที่เหมาะสม ให้สามารถรองรับปริมาณขยะที่ประมาณว่าจะผลิตขึ้นในอีก 20 ปีข้างหน้า มีการนำเอาเทคโนโลยีระบบภูมิศาสตร์สารสนเทศมาใช้ให้เป็นประโยชน์ โดยการสร้างตัวแบบที่มีการพิจารณาเกณฑ์ต่างๆ ตรงตามข้อกำหนดของหน่วยงานควบคุมมลพิษและสิ่งแวดล้อมในประเทศไทยและสอดคล้องกับมาตรฐานสากลด้วย เช่น ไม่ขัดกับลักษณะการใช้ประโยชน์ ลักษณะดินมีความเหมาะสม อยู่ในภูมิประเทศที่ดี ราคาไม่แพง การคมนาคมขนส่งสะดวก ห่างไกลจากแม่น้ำลำคลอง น้ำไม่ท่วม ระดับน้ำใต้ดินลึก ขนาดของแปลงที่ดินกว้างใหญ่เพียงพอ และต้นทุนการขนส่งที่ต่ำที่สุด เป็นต้น

ผลการวิเคราะห์ได้เสนอสถานที่ซึ่งเหมาะสม โดยที่สถานที่ฝังกลบขยะแห่งใหม่ในเขตอำเภอนครชัยศรี ตำบลบางระกำ มีเนื้อที่ประมาณ 1,485.34 ไร่ มีค่าใช้จ่ายจากการใช้น้ำมันเชื้อเพลิงเพื่อการขนส่งขยะจากทุกพื้นที่ในเขตจังหวัดนครปฐมต่ำที่สุดเท่ากับ 10,406.63 บาท อย่างไรก็ตามควรจะได้มีการศึกษาผลกระทบที่มีต่อชุมชนเพิ่มเติมด้วย เพื่อเป็นการลดข้อโต้แย้ง อันจะทำให้โครงการเป็นจริงได้

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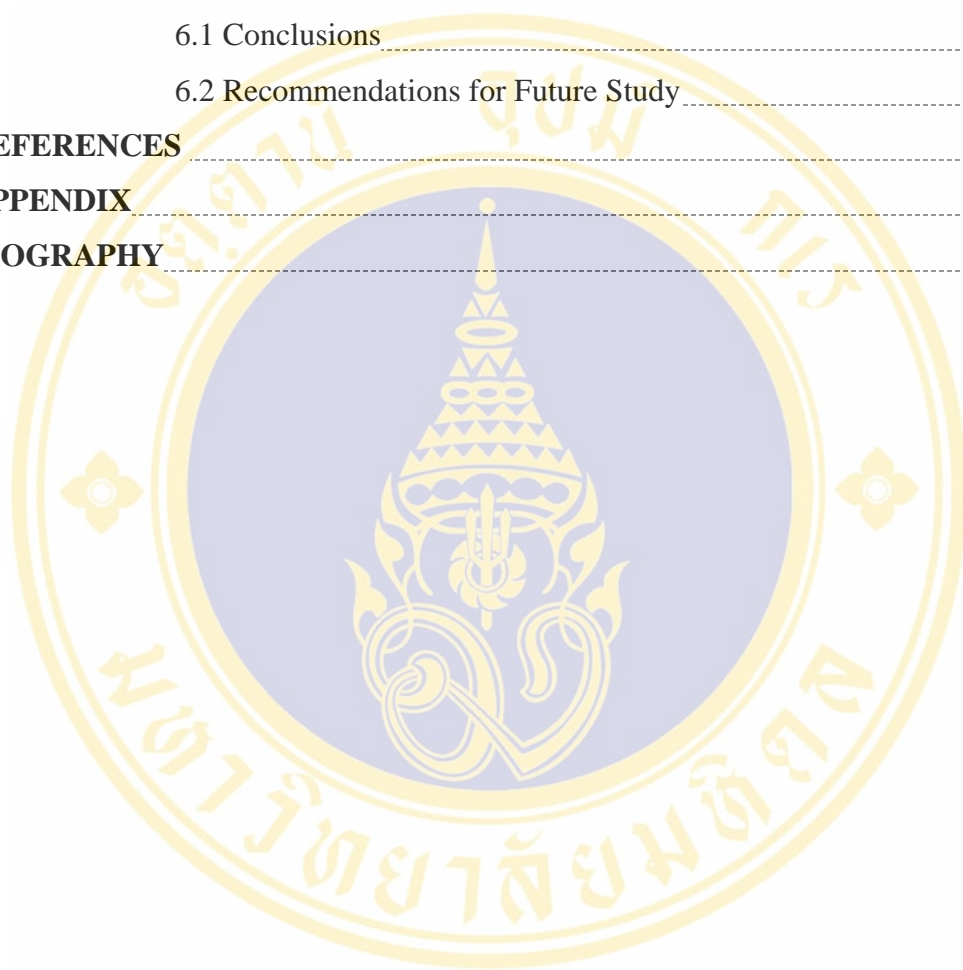
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## CHAPTER I

### INTRODUCTION

#### 1.1 Statement of Problem

The improper management of solid waste can cause contamination of the soil surface, groundwater and the surrounding air. Solid waste can also affect human health. It is impossible to eliminate the various kinds of solid wastes because they are an unavoidable part of our lifestyle. However, we can decrease the amount of solid waste produced each day, for example through re-use and or reduction.

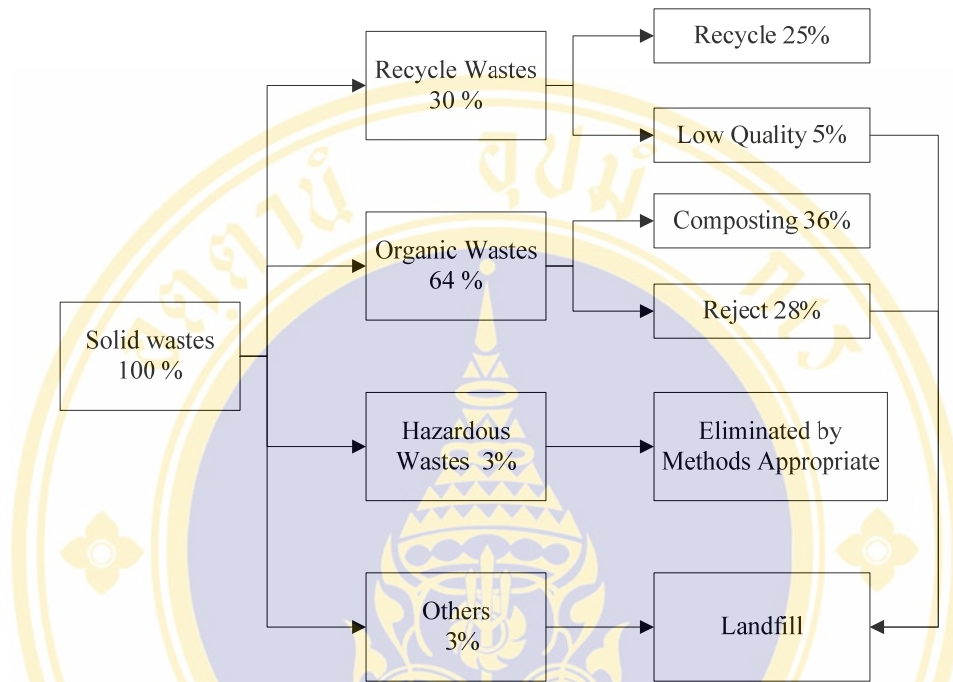
Nakhon Pathom Province is experiencing rapid development due to its close proximity to Bangkok and the expansion of factories within the region. More people moving there, due to industrial expansion, are causing an increase in solid wastes generation. Solid waste problem will continuously affect the environment in Nakhon Pathom Province. Table 1 shows the Quantity of Solid Waste generation in Nakhon Pathom Province by District and Municipality in 2003. Nakhon Pathom City Municipality has three sanitary landfill sites locate in Tambon Takong. These sites also support solid wastes from other institutes such as Thammasala Subdistrict Municipality, Samphran Subdistrict Municipality and the Local Administration Organization. Sanitary landfill of Nakhon Pathom City Municipality can support about 130 tonnes per day. However there is a lot of solid waste left over, in fact about 400 tonnes per day (Kasetsart U., 2002). Any leftover waste is moved to one of the two remaining local landfill sites (the 3<sup>rd</sup> site was filled to its capacity in just six years through supporting local areas). It is predicted that the two remaining landfill sites may reach to their capacity in next 10 years (Thawatchai et al., 2007).

**Table 1** Quantity of Solid Waste Generation in Nakhon Pathom Province by District and Municipality: 2003 (Pollution Control Department, 2003)

District/Minor district and municipality	Quantities in ton per day
Mueang Nakhon Pathom District	
Nakhon Pathom City Municipality	196.46
Don Yai Hom Municipality	6.47
Thammasala Municipality	5.03
Phrong Maduea Municipality	6.07
Kamphaeng Saen District	
Kamphaeng Saen Municipality	4.00
Nakhon Chai Si District	
Nakhon Chai Si Municipality	6.98
Huai Phlu Municipality	1.20
Don Tum District	
Sam Ngam Municipality	7.32
Bang Len District	
Bang Len Municipality	7.01
Bang Luang Municipality	2.20
Rang kra Thum Municipality	2.18
Lam Phraya Municipality	1.00
Sam Phran District	
Sam Phran Municipality	15.65
Om Yai Municipality	18.93
Phutthamonthon District	
Salaya Municipality	4.66
Total	285.17

The general idea of this study was to find an efficient method to gather solid waste from municipalities and select potential areas suitable for a solid waste landfill site.

Sources of solid waste can be divided into 4 types; recyclables, organics, hazardous wastes and others, as shown in figure 1.



**Figure 1** Household Solid Wastes Generation in Thailand (Pollution Control Department, 2004)

This research has studied methods to locate potential areas for a solid waste landfill site using a Geographic Information System (GIS) technique. Presently, non-recyclable and re-usable solid wastes are taken to landfill sites.

In other words, landfill is the final method in solid waste management that didn't involve hazardous solid waste. If hazardous solid waste is kept in landfills, it may be harmful in the future. Hazardous waste is not placed in landfill sites as it can contaminate and course future problems to the area and human health.

### 1.2 Objectives

The overall aim of this thesis was to investigate and evaluate a method to select the most suitable landfill site in the area of Nakhon Pathom Province using Geographic Information System (GIS) technique.

Specific Objectives included:

1.2.1 To suggest a method for selecting a potential area for a solid waste landfill site.

1.2.2 To find a potential area for solid waste landfill in Nakhon Pathom Province using the proposed method by using GIS technique.

### **1.3 Scope of Work**

This study was aimed at the selection of potential sites for sanitary landfill. The Application of GIS technique is used to help identify potential sites. The scope of the study included the following:-

1.3.1 The potential of selecting a solid waste landfill site was limited to Nakhon Pathom Province area. Total area is approximately 2,168.32 square kilometres.

1.3.2 The volume of solid waste to consider was assessed from the solid waste management practice within the municipality boundary. The volume of solid waste was predicted for the next 20 years.

1.3.3 The criteria for determining the potential landfill site included 9 factors i.e. land-use map, soil types, topography map, land price, roads, rivers, water bodies, flood areas, groundwater depth and the overall area of the solid waste landfill. These factors were used in the ArcGIS program according to regulations from the Pollution Control Department were also considered. However, weighting conditions of each factor is important. It should be flexible depending on present situations and social involvements.

### **1.4 Research Concept**

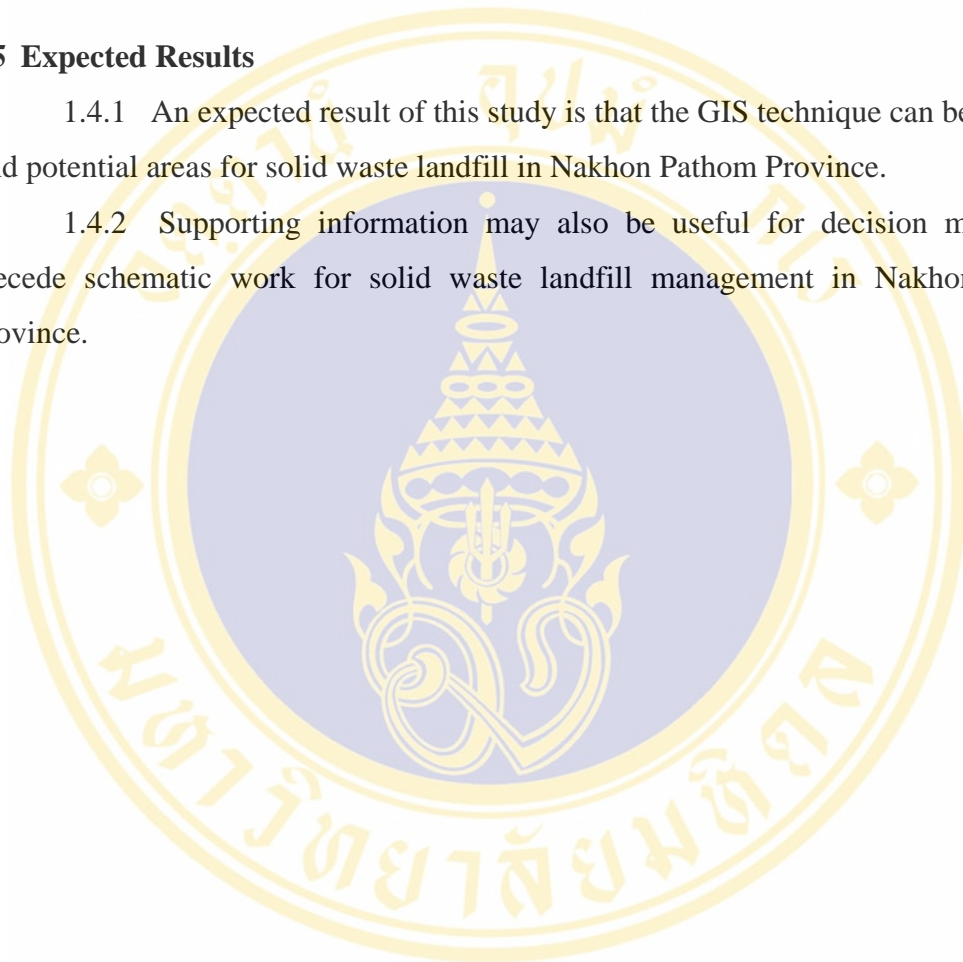
This research considered multiple criterion corresponding to the guidelines and recommendations provided by the Department of Pollution Control and international standards. To accomplish the multi-criteria analysis in Geographic Information Systems (GIS) environment, GIS shapefiles collection, consisting of land-use, soil type, land price, roads, flood area, ground water depth, river and water bodies. Thus, the analysis was done in three steps. First, unsuitable areas were screened out by imposing exclusionary criteria within the GIS environment. Second, this step applied

three non-exclusionary criteria to areas were screened from previous step. Output from this stage was the shapefile showing candidate areas with their corresponding rating scores. Third, the distance from each Tambon to candidate site was used in this step was to analyze fuel cost for transportation from second step.

## 1.5 Expected Results

1.4.1 An expected result of this study is that the GIS technique can be used to find potential areas for solid waste landfill in Nakhon Pathom Province.

1.4.2 Supporting information may also be useful for decision making to precede schematic work for solid waste landfill management in Nakhon Pathom Province.



## CHAPTER II

### LITERATURE REVIEW

#### 2.1 Municipal Solid Wastes

##### 2.1.1 Definitions

Department of Environmental Conservation (2007) in New York State defined solid wastes as Non-liquid, non-soluble materials ranging from municipal garbage to industrial wastes that contain complex, and sometimes hazardous, substances. Solid wastes also include sewage sludge, agricultural refuse, demolition wastes, and mining residues.

Chalermchat et al. (2000) defined solid waste as paper, shred, food waste, goods waste, plastics, tableware, dung or carrion including something that clears away from roads, markets, farms or other.

For this study, municipal solid waste is defined as waste arising from human activities in household, commercial and institutional areas that are useless or unwanted.

##### 2.1.2 Sources of Solid Waste

Knowledge of the sources and types of solid wastes, along with data on the composition and rates of generation, is basic to the design and operation of the functional elements associated with the management of solid wastes. To avoid confusion, the term *refuse*, often used interchangeably with the term *solid wastes*, is not used in this text.

Sources of solid wastes in a community are, in general, related to land use and zoning. Although any number of source classifications can be developed, the following categories are useful: 1. Resident, 2. Commercial, 3. Institutional, 4. Industrial, 5. Agricultural and 6. Public area (Tchobanoglous et al., 1993).

### 2.1.3 Types of Solid Wastes

As a basis for subsequent discussions, it will be helpful to define the various types of solid wastes that are generated (see Table 2.1). It is important to be aware that the definitional of solid waste terms and the classifications vary greatly in the literature and in the profession. Consequently, the use of published data requires considerable care, judgment, and common sense.

**Table 2.1** Sources and types of solid wastes within a community (Tchobanoglous et al., 1993).

Source	Typical facilities, activities, or locations where wastes are generated	Types of solid wastes
Residential	Single family and multifamily detached dwellings, low-, medium-, and high-rise apartments, etc.	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, tin cans, aluminum, other metals, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires), household hazardous wastes.
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops, etc.	Paper, cardboard, plastics, wood, food waste, glass, metals, special wastes, hazardous wastes, etc.
Institutional	Schools, hospitals, prisons, governmental centers	As above in commercial
Industrial	Construction, fabrication, light and heavy manufacturing, chemical plants, power plants, demolition, etc.	Industrial process wastes, scrap materials, etc. Non-industrial wastes including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazardous wastes
Agricultural	Field and farms	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes
Public Areas	Streets, parks, recreation areas, etc.	Special wastes, rubbish

## 2.2 Landfills

### 2.2.1 Types & Construction Methods

Most modern landfills are classified according to the type(s) of waste material disposed of into them. Landfills can be engineered to a high standard in order to contain liquid leachate or landfill gas produced by decomposing organic waste. Modern landfills generally require a minimum of one landfill liner, consisting of a layer of compacted clay with a minimum required thickness and a maximum allowable hydraulic conductivity. Others also require the addition of one or more layers of impermeable membrane. Various final cover systems are used to 'cap' landfills (such as clay or topsoil), depending on the type of wastes present within the landfill. Landfills, based on the waste type that is disposed within them, may be classified as (Wikipedia, 2007):

**2.2.1.1 Dumps:** also simply called landfills, dumps are landfills that are not engineered with the special protective measures required by sanitary landfills. They are most common in rural, remote, and developing areas. Many jurisdictions prohibit the use of non-sanitary landfills for the disposal of municipal solid waste. Other jurisdictions that do allow dumps may require them to be constructed according to some engineering standard to mitigate the risk for environmental contamination, such as by limiting the slope, requiring compaction, or ensuring that the cell is high enough above the groundwater table.

**2.2.1.2 Sanitary Landfills:** also called **modern, engineered** or **secure landfills**, these usually have physical barriers such as liners and leachate collection systems, and procedures to protect the public from exposure to the disposed wastes. The term sanitary landfill normally refers to those where municipal solid waste is disposed of, as well as other wastes high in organic material. In some countries, all landfills are sanitary landfills.

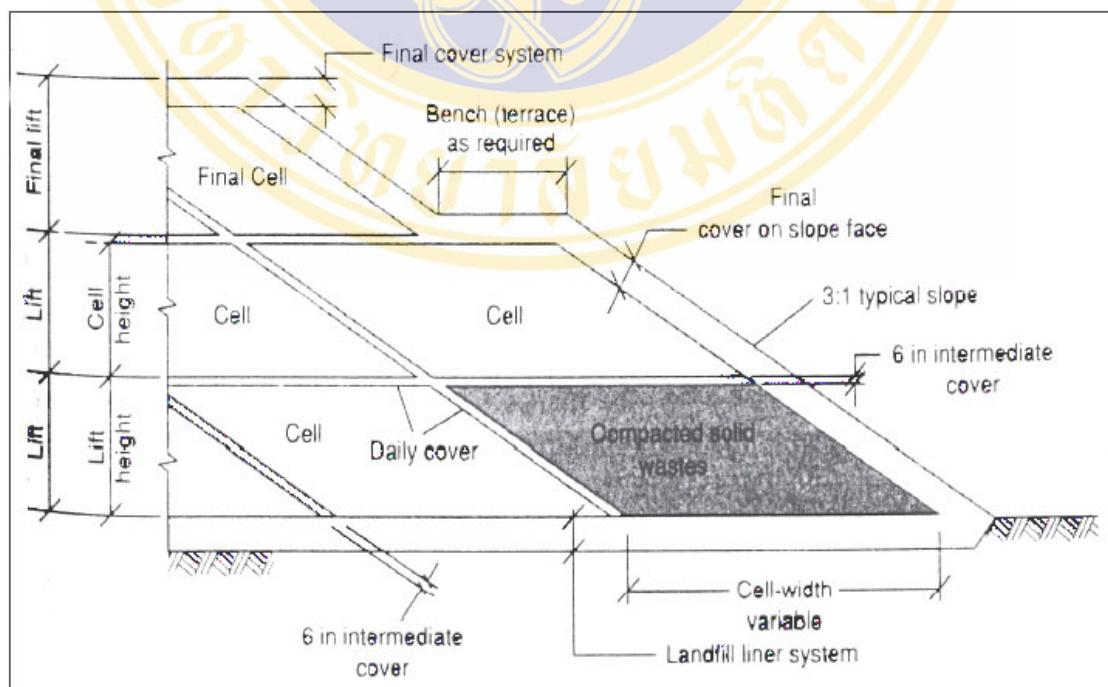
**2.2.1.3 Hazardous Waste Landfill:** waste disposal units constructed to specific design criteria and which receive wastes meeting the local definition of hazardous waste. These landfills are generally constructed to be secure repositories for material that presents a serious hazard to human health, such as high-level radioactive waste. They are restricted, by law, to the types of waste that they may handle

(chemical vs. radioactive, liquid vs. dry). Double liner systems are the norm for hazardous waste landfills. Deep geological repository of high level radioactive waste is not generally classified as landfilling (Wikipedia, 2007).

This study aims at the selection of potential sites for sanitary landfill. Application of GIS technique is used to help identify the potential sites.

*Sanitary Landfill* refers to an engineered facility for the disposal of municipal solid waste designed and operated to minimize public health and environmental impacts. Landfills for the disposal of hazardous wastes are called secure landfills. A sanitary landfill is also sometimes identified as a solid waste management unit. Landfilling is the process by which residual solid waste is placed in a landfill. Landfilling includes monitoring of the incoming waste stream, placement and compaction of the waste and installation of landfill environmental monitoring and control facilities.

The term cell is used to describe the volume of material placed in a landfill during one operating period, usually one day (see Figure 2.1). A cell includes the solid waste deposited and the daily cover material surrounding it (Coelho et al., 2005).



**Figure 2.1** Sectional view through a sanitary landfill (Ujang, 2004)

A lift is a complete layer of cells over the active area of the landfill as shown in figure 2.1. Typically, landfills are comprised of a series of lifts. The final lift includes the cover layer. The final cover layer is applied to the entire landfill surface after all landfilling operations are complete (Tchobanoglous et al., 1993).

## **2.2.2 Criteria of Selection of Potential Area for a Solid Waste Landfill**

The construction of a landfill requires a staged approach. Landfill designers are primarily concerned with the viability of a site. To be commercially and environmentally viable a landfill must be constructed in accordance with specific requirements, which are related to:

### **2.2.2.1 Size of Land requiring**

In designing a solid waste landfill system, calculations should be made to enable the site to be in operation for about 20 years, in order to manage the cost of construction of the site (Kalya & Sopa, 1995). Geology state area or underground area is stable enough to support solid waste.

### **2.2.2.2 Distance between place of management and waste generation**

Distance of elimination site should not be far because much fuel can be used up to transportation. Therefore the selection of the place should not over 30 kilometers from the source (Pollution Control Department, 2004), making collection of solid waste in the service area to be efficient and not remain solid waste (Kalya & Sopa, 1995).

### **2.2.2.3 Characteristic of land using**

Selection area should be clear land, which can't be developed or is not well-suited for agriculture, like deserted mines, acid soil area, alkaline soil area etc (Kalya & Sopa, 1995).

### **2.2.2.4 Considering environment around area**

Nearby areas shouldn't be temples, schools, important historical places, ditches, watercourses, or good view areas. The selected site should be in an out of sight area.

Keep distance from historical sites, ancient areas and including international museums should not be less than 1 kilometer.

Keep the distance from well-water or water supply for manufacturing not less than 1 kilometer away (Chang et al., 2007).

Keep the distance from the road not less than 750 meters away (Chang et al., 2007).

Keep the distance away from rivers of not less than 1 kilometer (Chang, 2007).

Moreover the selected area shouldn't often flood (Kalya & Sopa, 1995) because it will increase the construction cost.

In addition, the landfill should be situated at a significant distance away from urban residential areas due to public concerns, such as aesthetics, odor, noise, and decrease in property value. Urban buffers may range from 150 meters to 5 kilometers. A buffer distance of 1 kilometer was chosen for the study area (Chang et al., 2007).

#### **2.2.2.5 Geographical Features**

Shouldn't select over lowland area and over be high and steep terrain because it causes limits to access. Keep select plain area (Kalya & Sopa, 1995).

#### **2.2.2.6 Watershed Flow**

Watershed Flow has an effect on construction. If it's raining season it will pay for expenses to prevent watershed flow (Kalya & Sopa, 1995).

#### **2.2.2.7 Soil Type**

The characteristic soil type was determined by drainage. The suitable soil should offer poor drainage for example clay. So that it forms an appropriate buffer for water to wash solid waste (Chiangmai U., 2003).

#### **2.2.2.8 Groundwater Depth**

In case of a high depth landfill, consideration should be given to groundwater depth. This is especially a main issue of groundwater contamination. The area should be located where there is deep groundwater depth. Because in case of sites where there is shallow groundwater depth, there will be a rate of high contamination (Chiangmai U., 2003).

### 2.2.3 Calculating Size of Landfill

2.2.3.1 To find the volume of solid waste to dispose of in the landfill, consideration must be made of the number of years the landfill will be used, quantity and composition of solid waste, density of solid waste after compression, quantity of material for daily cover, and material needed for the final step. Generally, procedure to find volume of solid wastes to use landfill can be calculated from equation as follow (Chiangmai U., 2003).

$$V = \frac{N \times W}{D}$$

Where

- $V$  = Volume of solid wastes for landfill use ( $m^3$ )
- $N$  = Number for landfill (years)
- $W$  = Amount of solid wastes to use in landfill per year (tonnes/year)
- $D$  = Density of solid wastes compressing (to use  $0.55 \text{ ton}/m^3$ )

2.2.3.2 Size of area for construction of required landfill system can be calculated from the following equation:

$$A = \left( \frac{V}{H} \right) \times k$$

Where

- $A$  = Size of total area required for landfill system ( $m^2$ )
- $V$  = Volume of solid waste to use in landfill ( $m^3$ )
- $H$  = Height of landfill's class (not including cover soil)
- $K$  = Constant of buffer zone around constructed buildings, liquid waste system and tree planting. (To use 1.5)

Remarks:

- 1) The amount of solid waste over a 10 year period, assuming that there volume is 1.4 times the current daily amount.
- 2) Increase of population has not been considered.
- 3) Size of area can calculate from height of landfill's class does not include soil to cover = 6.00 meters (each class contains 2 meters with a total of 3 classes) and has a buffer zone for construction of public utilities in 50% of the calculated area.

### **2.3 Siting Criteria of Landfill Facility from Pollution Control Department**

Site selection shall exclude the following area: (Pollution Control Department, 2001)

2.3.1 Within the watershed area class 1 and class 2 as defined under the Cabinet Resolution on May 28, B.E.2528 in Setting up the watershed classification.

2.3.2 Within the 1 kilometer distance from the property boundary of any ancient monuments as defined under the Ancient Monument, Relics, Antiques and National Museum Act.

2.3.3 Within the 5 kilometers distance from the property boundary of any licensed and operating airport runway.

2.3.4 Within 700 meters of an existing potable water well or existing community water treatment plant.

2.3.5 Within 300 meters of any natural or man-made water bodies, including wetlands, except bodies of water contained completely within the property boundary of the disposal site.

2.3.6 In an area where geological formations or other subsurface features will not provide support for the solid waste.

2.3.7 Unless in the high land area. In an area subject to frequent and periodic flooding unless flood protection measures are in place.

2.3.8 Unless in an area where the normal water table is sufficiently low. In high water level area unless special design is provided.

### **2.4 Waste Management in Thailand**

In 2008, the quantity of the municipal solid waste produced was around 41,213 tons per a day (Ministry of Natural Resources and Environment, 2008). The management of collecting solid wastes from the public home still has some problems. A pattern of service for collection must improve to reduce the service charge. However the service in manipulation has increased and so has reduced the quantity solid waste. Solid waste management within big city boundaries must create a place for sanitary solid waste management, however most will still encounter processing

problems due to lack of budget and effective management of waste disposal fees. To solve the problem it will require support from central management and cooperation along with a strong knowledge of the situation (Pollution Control Department, 2004).

From industry solid waste that isn't damaged and is able to be recycled in quantity has risen to 40%. If recycled waste throughout the country can increase it will be possible to reduce the import of some base materials. There are still high amounts of waste from smaller industries that is abandon through solid waste manipulation. Some industries hire private companies to clear their waste however in many cases the waste is simply abandon or burnt which is an environmental problem and can cause contamination of soil, water and air (Pollution Control Department, 2004).

#### **Problem and Cause**

1. Lack of land for system management.
2. Lack of efficient processing and maintaining of system management.
3. Lack of specialist employees.
4. Limit put on budgets.
5. Formality and approach within practice not defined.
6. A lack of recycling.
7. Restrictions within the law, and a lack of consideration for local needs and overall a bad attitude towards waste management.
8. A lack of understanding by the homeowner and small business management to the seriousness of the situation and educating the attitude throughout.
9. People objecting to the construction of solid waste management systems.

#### **2.4.1 The Existing Solid Waste Landfill at Nakhon Pathom Province**

The waste management facility is located in the Takong Sub-district of Nakhon Pathom Province. It consists of 176 Rai of land and is only 5 kilometers away from the municipal area along the Nakhon Pathom - Dontoom Road. Turning left and following the road along the Chonpratan Canal across from the Twinpattana-Boplab intersection the area consists of rice fields. To the North are rice fields and there is a canal which connects to the Chonpratan Canal cutting across the waste management property (Nakhon Pathom City Municipality, 2001).

### **Systems of Landfill Management**

In 2001, the appropriate sanitary method of waste management for the Nakhon Pathom City Municipality is a sanitary landfill. This is because it is an efficient method of landfill, construction costs are not high, operational and maintenance costs are rather low, doesn't require many people, and doesn't require high technology. The Nakhon Pathom City Municipality district chose to combine two methods which are the area method and the trench method because they are able to use the dirt left over from the trench to form embankments. In addition they are able to use less space this way as well (Nakhon Pathom City Municipality, 2001).

#### **Burying and covering landfill work**

The area used for the landfill is 176 Rai which is divided so that 100 Rai (58 percent of the whole) is used for landfill, and the remaining area is used for water treatment ponds, roads, water canals, trees which are planted around the perimeter, office buildings, housing, tool sheds, repair facilities and parking facilities.

The landfill allows for 5 layers of fill, 2 layers below the old surface, each layer 2 meters, and 3 layers above the old surface, with each layer being 2.5 meters. Together all the layers of waste measure to be 11.5 meters thick, with 0.30 meters of cover for each layer (Intermediate Cover) and on the top a covering of 0.60 meters (Final Cover). In digging the pit to be filled, it is first lined with clay and then with a plastic liner. Water pipes are installed to drain off waste water. As waste is dumped into the pit each day, it is covered with 0.20 meters of dirt to keep away the flies, rodents and other animals that come in and dig around, and foul smelling odors. The lower levels 1 and 2, which are below the original surface of the land, are filled during the dry season each year. The upper levels 3, 4 and 5 are filled during the rainy season. In order to do this it is necessary to locate a place to keep dirt for the covering process. The dirt cannot be stored for too long a time else it gets compacted and machinery must be used to dig it up again before being able to place it in a truck to move it to the waste area. When possible, dirt that is dug up is used immediately to cover the fill. If not that, it is stored close the area it will be used (Nakhon Pathom City Municipality, 2001).

## **2.5 Relevant Information about Nakhon Pathom Province**

### **2.5.1 Location and Boundary**

Nakhonpathom covers an area of 2,170.96 square kilometers (Department of Mineral Resources, 2001). It is divided into 7 administrative districts, they are: Muang Nakhon Pathom District, Putthamonthon District, Sam Phran District, Nakhon Chai Si District, Bang Len District, Kamphaeng Saen District, and Don Tum District (Figure 2.2). Its boundary is the followings:

North bounded by Suphanburi and Pranakhon Sri Ayuthaya Province

South bounded by Samutsakhorn province and Ratburi Province

East bounded by Nonthaburi, Bangkok and Pranakhon Sri Ayuthaya Province

West bounded by Ratburi and Khanchanaburi Province

### **2.5.2 Geography**

Geographical feature of Nakhon Pathom Province in general consists of a flat plain and mainly flat lowlands occupy the greater parts of the province, with no hills or forests. The difference between levels lies between 2-10 meters above the sea level. The area is higher than the average sea level around 6 meters. The geographical location slopes from the north to the south and from the west to the east. Tha Chin River flows from the north to the south. The area in the north and northeast mostly consist of highland with its height around 6-10 meters. The area in the middle of the province consists of plains with highland and water resources scattered all around. The area in the east and south is a plain which locates along Tha Chin River. There are a lot of natural and constructed canals which are used for agricultural and transportation purposes. The height of this area from the sea level is around 2-4 meters. (Roj, 1982)

### **2.5.3 Geology**

A host of parent materials derive from fresh water and brackish water sediments in the periods of late quaternary. The geomorphologic patterns associated with the parent materials can be derived from 3 types - former tidal flats, flood plains, and alluvial terraces which flood plains have a high uniformity of texture as clay and dark gray silt covers the majority of the fields. The depth of soil is about 100-80 cm

where the major texture is clay. Soil reaction here was acidic. The alluvial terraces major texture is sandy loam (SL) and clay loam (CL) (Noy, 1991).

#### 2.5.4 Soil Type

Types of absorbent soil are present characters about area management system. The types of soil in each area that are suitable for solid waste landfill must be determined. This investigation used the soil type data from the Land Development Department. Major textures found in the area clay (C), sandy clay loam (SCL), sandy loam (SL) and clay loam (CL). The amounts of organic matter are of medium aggregate and moderately high decomposed which are suitable for agricultural practice (Noy, 1991).

#### 2.5.6 Land-Use (Specific of agriculture) and Economic Situation

According to soil suitability classification, soils that are well suited for paddy make up 73.24 % of the total area; soils which are well suited for non-flooded annual crops make up 18.09 %; soils which are well suited for permanent pasture or range land for livestock farming occupy a major part of the province and soils which are well suited for fruit trees make up 18.90 % of the total area. The most important water supply of Nakhon Pathom Province is Nakhon Chai Si River and the irrigation canals that divert water from the Chao Phaya Dam and the Vajiralongkon Dam. The major portions of the province are used for paddy fields, cash crops, field crops and fruit tree plantations. Summary of each land-use type in Nakhon Pathom Province is shown in table 2.2.

**Table 2.2** Summary landuse: Nakhon Pathom Province year 2001

(Land Development Department, 2001)

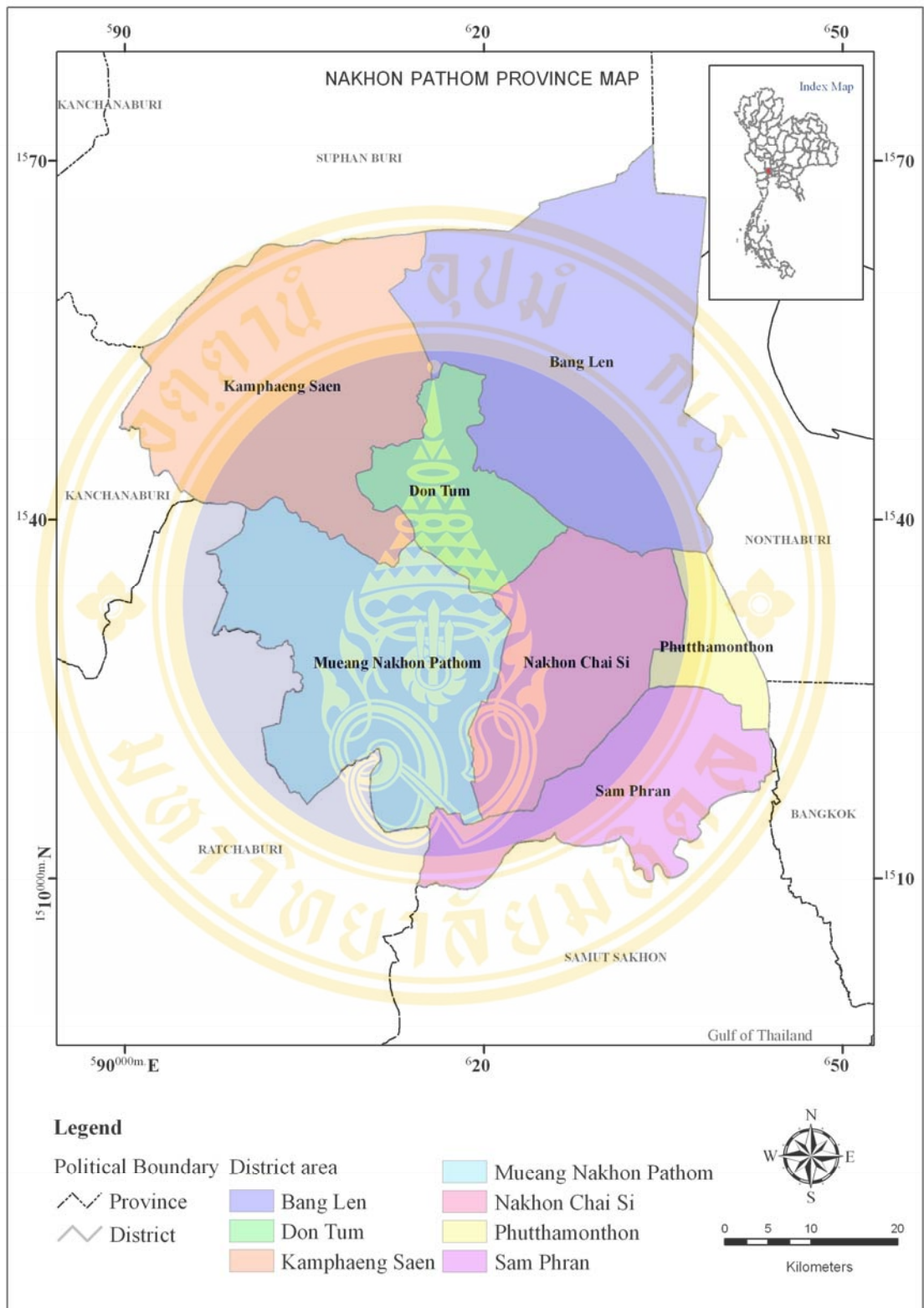
Land-Use Type	Size of Area	
	(Rai)	(%)
Community area and buildings	188,149	13.88
Agriculture area	1,132,587	83.57
Forest area	539	0.04
Water resource area	20,607	1.53
Miscellaneous area	13,322	0.98

### 2.5.7 Price of Land-Property

Price of land property considered in the study compares each areas low price. This investigation used the price of land property data from The Treasury Department. For example, the price of land property estimates for the years 2004 - 2007 are summarized in Table 2.3.

**Table 2.3** Price of land property estimate year 2004 - 2007 (The Treasury Department, 2007)

No	District	Maximum (Baht/square wah)	Minimum (Baht/square wah)
1	Mueang Nakhon Pathom	90,000	150
2	Sam Phran	30,000	500
3	Phutthamonthon	22,500	750
4	Bang Len	20,000	200
5	Nakhon Chai Si	17,500	500
6	Kamphaeng Saen	12,000	125
7	Don Tum	5,000	300



**Figure 2.2** Location and Boundary of Nakhon Pathom Province  
(The Treasury Department, 2007).

## **2.6 Geographic Information System**

### **2.6.1 Definition of Geographic Information System**

The Agency for Toxic Substances and Disease Registry (ATSDR) in Atlanta (Agency for Toxic Substances and Disease Registry, 2007) defined a GIS as a mapping system that uses computers to collect, store, manipulate, analyze, and display data. For example, GIS can show the concentration of a contaminant within a community in relation to points of reference such as streets and homes.

Geographic Information System, Remote Sensing, and Telemetry Working Group (The Wildlife Society, 2005) defined the Geographic Information System as "Decision support system involving the integration of spatially referenced data in a problem solving environment".

On the other hand, a geographic information system (GIS) is a system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically-referenced information. In a more generic sense, GIS is a tool that allows users to create interactive queries (user created searches), analyze the spatial information, edit data, maps, and present the results of all these operations. Geographic information science is the science underlying the geographic concepts, applications and systems.

### **2.6.2 Techniques used in GIS**

#### **2.6.2.1 Input**

Before geographic data can be used in a GIS, the data must be converted into a suitable digital format. The process of converting data from paper maps into computer files is called digitizing. Modern GIS technology can automate this process fully for large projects using scanning technology; smaller jobs may require some manual digitizing (using a digitizing table). Today many types of geographic data already exist in GIS-compatible formats. These data can be obtained from data suppliers and loaded directly into a GIS (ESRI, 1998).

#### **2.6.2.2 Manipulation**

It is likely that data types required for a particular GIS project will need to be transformed or manipulated in some way to make them compatible with system.

For example, geographic information is available at different scales (detailed street center line files; less detailed census boundaries; and postal codes at a regional level). Before this information can be integrated, it must be transformed to the same scale (degree of detail or accuracy). This could be a temporary transformation for display purposes or a permanent one required for analysis. GIS technology offers many tools for manipulating spatial data and for weeding out unnecessary data (ESRI, 1998).

### **2.6.2.3 Management**

For small GIS projects it may be sufficient to store geographic information as simple files. However, when data volumes become large and the number of data users becomes more than a few, it is often best to use a database management system (DBMS) to help store, organize, and manage data. A DBMS is nothing more than computer software for managing a database. There are many different designs of DBMSs, but in GIS the relational design has been the most useful. In the relational design, data are stored conceptually as a collection of tables. Common fields in different tables are used to link them together. This surprisingly simple design has been so widely used primarily because of its flexibility and very wide deployment in applications both within and without GIS (ESRI, 1998).

### **2.6.2.4 Query and Analysis**

Once we have a functioning GIS containing geographic information, we can begin to ask simple questions such as

- How far is it between two places?
- Where is land zoned for industrial use?

And analytical questions such as

- Where are all the sites suitable for building new landfill?
- What is the dominant soil type for landfill?

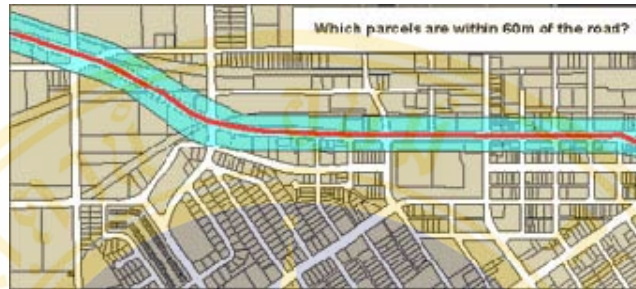
GIS provides both simple point-and-click query capabilities and sophisticated analysis tools to provide timely information to managers and analysts alike. GIS technology really comes into its own when used to analyze geographic data to look for patterns and trends and to undertake "what if" scenarios. Modern GISs have many powerful analytical tools, but two are especially important (ESRI, 1998).

#### **Proximity Analysis**

- Which parcels are within 1 kilometer of the river?

- Which parcels are within 750 meters of the road?

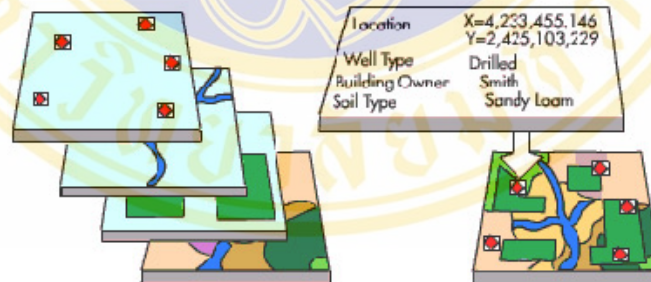
To answer such questions, GIS technology uses a process called buffering to determine the proximity relationship between features as shown in figure 2.3.



**Figure 2.3** Proximity Analyses (ESRI, 1998)

### Overlay Analysis

The integration of different data layers involves a process called overlay. At its simplest, this could be a visual operation, but analytical operations require one or more data layers to be joined physically. This overlay (see figure 2.4), or spatial join, can integrate data on soils, land price, and groundwater depth (ESRI, 1998).



**Figure 2.4** Overlay Analyses (ESRI, 1998)

## 2.7 The Analytic Hierarchy Process

The analytic hierarchy process (AHP) is a popular decision tool used to rank items based on subjective pair-wise comparisons. To make a decision in an organized way to generate priorities we need to decompose the decision into the following steps (Saaty, 2008).

1. Define the problem and determine the kind of knowledge sought.

2. Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).

3. Construct a set of pair-wise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.

4. Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.

To make comparisons, we need a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared. Table 1 exhibits the scale. Application of the AHP model requires definition of a hierarchy of criteria by which alternatives will be evaluated. The evaluation is based on a pair-wise comparison of two indicators as shown in table 2.4.

**Table 2.4** The fundamental scale of absolute numbers (Saaty, 2008).

<i>Intensity of Importance</i>	<i>Definition</i>	<i>Explanation</i>
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated important	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	
Reciprocals of above	For inverse comparison	

Subsequently, a matrix  $C$  is constructed in which the entries are the result of pair-wise comparisons between indicators is as follow:

1. if  $C_{ij} = \alpha$ , the  $C_{ji} = 1/\alpha$
2. if  $i = j$  then  $C_{ij} = C_{ji} = 1$

### 2.7.1 Ranking Method using the Fuzzy Dominance

The first step in this method is to establish the data matrix  $X$ . This matrix is made up of a set  $m$  alternatives (rows) and the set of the  $n$  performance variables (columns).

	$C_1$	$C_2$	$C_3$	...	$C_n$
$C_1$	1				
$C_2$		1			
$C_3$			$X_{ij}$		
.					
.					
$C_n$					1

After all matrices are developed and all pair-wise comparisons are obtained, eigenvectors or the relative weights (the degree of relative importance amongst the elements), global weights, and the maximum eigenvalue ( $\lambda_{\max}$ ) for each matrix are then calculated. The  $\lambda_{\max}$  value is used as a reference index to screen information by calculating the consistency ratio of the estimated vector in order to determine if the pair-wise comparison matrix provides a completely consistent evaluation. The consistency ratio is calculated as follows (Ahmad & Laplante, 2006):

1. Calculate the eigenvector or the relative weights and  $\lambda_{\max}$  for each matrix of order  $n$ .
2. Compute the consistency index (CI) for each matrix of order  $n$  by the formulate:  $CI = (\lambda_{\max} - n)/(n - 1)$
3. The consistency ratio (CR) is then calculated using the formulate:  
 $CR = CI/RI$

Where RI is a known random consistency index obtained from a large number of simulations run and varies depending upon the order of matrix as shown in table 2.5.

**Table 2.5** Random consistency index (RI)

	<i>n</i>										
	3	4	5	6	7	8	9	10	15	20	25
RI	0.525	0.882	1.115	1.252	1.341	1.404	1.452	1.484	1.583	1.630	1.654

The acceptable CR range varies according to the size of matrix, that is 0.05 for a 3 by 3 matrix, 0.08 for a 4 by 4 matrix, and 0.1 for all larger matrices,  $n \geq 5$ . If the value of CR is equal to or less than the acceptable value, it indicates a good level of consistency in the comparative judgments represented in that matrix. In contrast, if CR is more than the acceptable value, inconsistency of judgments within that matrix has occurred, and the evaluation process should therefore be reviewed, reconsidered, and improved. An acceptable consistency property helps to ensure decision-maker reliability in determining the priorities of a set of criteria.

## 2.7 Related Research

Dorhofer and Siebert (1998) had studied the search for landfill sites requirements and implementation in Lower Saxony, Germany. The proposed approaches Geographical Information Systems (GIS) are the most adequate tools to work on all involved data and to present and outline the results. GIS make the results transparent and understandable to the public. For a landfill site search, information is required on the availability of all relevant areas as well as information of specific relevance to landfills. This may include: 1) geological structures; 2) permeability coefficients; 3) hydraulic gradients; 4) adsorption capacity of the strata below the landfill, their clay content and composition; 5) depth to the groundwater table; 6) information on already existing landfills and the year of their construction; 7) operator(s); 8) capacity and input rate; 9) groundwater quality data from observation wells; 10) proximity of receiving streams; 11) susceptibility to settlement; and 12)

pedological assessment. In conclusion, selection of a potential solid waste landfill site should study elementary information about geological structures, depth to the groundwater and the existing landfill.

Sener et al. (2006) had studied landfill site selection by using geographic information systems. Candidate sites for an appropriate landfill area in the vicinity of Ankara are determined by using the integration of geographic information systems and multicriteria decision analysis (MCDA). For this purpose, 16 input map layers including topography, settlements (urban centers and villages), roads (Highway E90 and village roads), railways, airport, wetlands, infrastructures (pipelines and power lines), slope, geology, land use, floodplains, aquifers and surface water are prepared and two different MCDA methods (simple additive weighting and analytic hierarchy process) are implemented to a geographical information system. Comparison of the maps produced by these two different methods shows that both methods yield conformable results. Field checks also confirm that the candidate sites agree well with the selected criteria. Criteria decision analysis in this journal used for select candidate sites landfill. Then weight of candidate sites are analyzed by AHP method.

Gemitzi et al. (2007) had studied combining geographic information system, multicriteria evaluation techniques and fuzzy logic in siting MSW landfills. This study presents a methodology for siting municipal solid waste landfills, coupling geographic information systems (GIS), fuzzy logic, and multicriteria evaluation techniques. Both exclusionary and non-exclusionary criteria are used. Factors, i.e., non-exclusionary criteria, are divided in two distinct groups which do not have the same level of trade off. The first group comprises factors related to the physical environment, which cannot be expressed in terms of monetary cost and, therefore, they do not easily trade off. The second group includes those factors related to human activities, i.e., socioeconomic factors, which can be expressed as financial cost, thus showing a high level of trade off. GIS are used for geographic data acquisition and processing. The analytical hierarchy process (AHP) is the multi-criteria evaluation technique used, enhanced with fuzzy factor standardization. Besides assigning weights to factors through the AHP, control over the level of risk and trade off in the siting process is achieved through a second set of weights. In this study AHP method was used for assigns weight to select candidate sites.

Lunkapis (2004) had studied GIS as decision support tool for landfills siting. Their criteria were then analyzed using Constraint Mapping Technique to evaluate and to seek potential locations of sanitary landfills. Their study has identified 6 Potential Search Areas for sanitary landfills sites. This study, potential sites were found in several locations, appropriate ranking techniques were then applied to decide the best choices produce by GIS (Geographic Information System).

Despotakis and Economopoulos (2007) had studied a GIS model for landfill sitting. The use of Geographical Information Systems (GIS) for Landfill Sitting had studied. The necessary spatial information required to determine the candidate sites for any type of terrestrial area (Community/Prefecture/Region/Country) had examined. The method had tested for the whole region of the island of Crete, producing spatial numerical results, which could be used as points of reference for any future Landfill Sitting study for this area. This spatial information is then used for this research to select via successive spatial operations: Buffering, overlaying and attribute calculations.

## **CHAPTER III**

### **RESEARCH METHODOLOGY**

This chapter describes materials and research methodology for selection of a potential solid waste landfill site in Nakhon Pathom Province by using geographic information system (GIS). The details can be given below:

#### **3.1 Data Collection**

In this study, GIS data sets of topography, land-use, river, soil types, land price, roads, flood areas and groundwater depth were evaluated and prepared for use in ArcGIS Software. The information compiled from literature about the safe distances to a landfill site was used to determine the buffer zones for each layer. All information was overlaid for initial suitable sites. Analysis of GIS data is as follows:

3.1.1 Land-use: Potential sites should not be located in residential, commercial, institutional or industrial areas. They should also be located not less than 1 kilometer from these areas follow minimum criteria of Pollution Control Department. Potential sites should be located in empty areas and not possible areas for agriculture or development (Chang et al., 2007).

3.1.2 Soil types: The characteristics of soil types were determined by drainage quality. An appropriate soil which is poor for drainage such as clay is preferable, so that the flooding wastes can be stored for dry season uses (Chiangmai U., 2003).

3.1.3 Land price: Potential landfill sites should be located on low priced land.

3.1.4 Rivers and water bodies: The landfill sites should be located at least 700 meters from rivers and water bodies to prevent the water resources from being polluted. This follows minimum criteria of Pollution Control Department.

3.1.5 Roads: Potential sites should be at least 750 Metres away to prevent any nuisances (Chang et al., 2007).

3.1.6 Flood area: Potential sites should not be located in likely flood areas (Chiangmai U., 2003).

3.1.7 Groundwater depth: Potential sites should be located at a deep groundwater depth (Chiangmai U., 2003).

### 3.2 Determination of Landfill Size

3.2.1 To find the required landfill volume, the following equation can be used (Chiangmai U., 2003):

$$V = \frac{N \times W}{D}$$

Where

- $V$  = Volume of solid wastes for landfill use ( $m^3$ )
- $N$  = Number for landfill (years)
- $W$  = Amount of solid wastes to use in landfill per year (tonnes/year)
- $D$  = Density of solid wastes compressing ( $ton/m^3$ )

3.2.2 Size of area required for constructing a landfill system can be calculated from the following equation:

$$A = \left( \frac{V}{H} \right) \times k$$

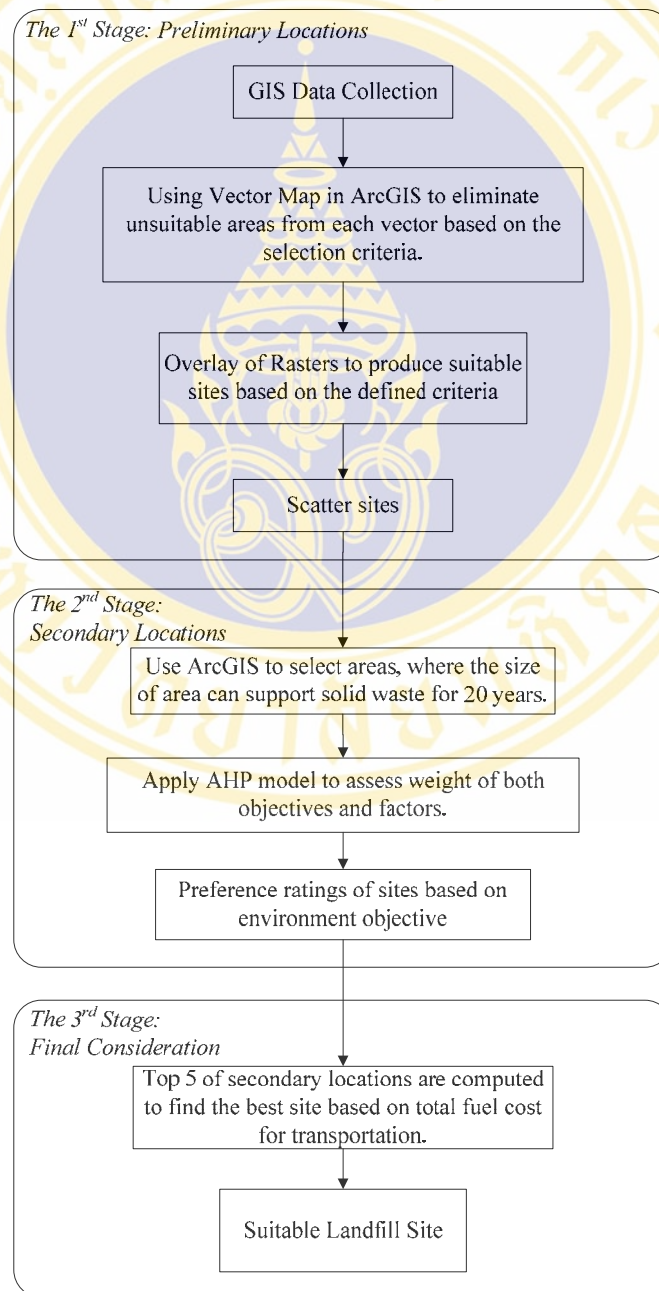
Where

- $A$  = Size of total area required for landfill system ( $m^2$ )
- $V$  = Volume of solid wastes to use in landfill ( $m^3$ )
- $H$  = Height of landfill's class (not including soil to cover)
- $k$  = Constant of buffer zone around a constructed building, liquid waste system and tree planting. (To use 1.5)

The period of 20 years is normally used for designing a landfill site so that the investment should be economically sound.

### 3.3 Methodology

Finding a landfill site based on Pollution Control Department's guidelines and an international standard is a complicated task. Fortunately, GIS technology can simplify the task efficiently. Figure 3.1 illustrates the procedures applying the GIS for initial landfill siting. The landfill site selection process was completed in three stages and was described as follows:



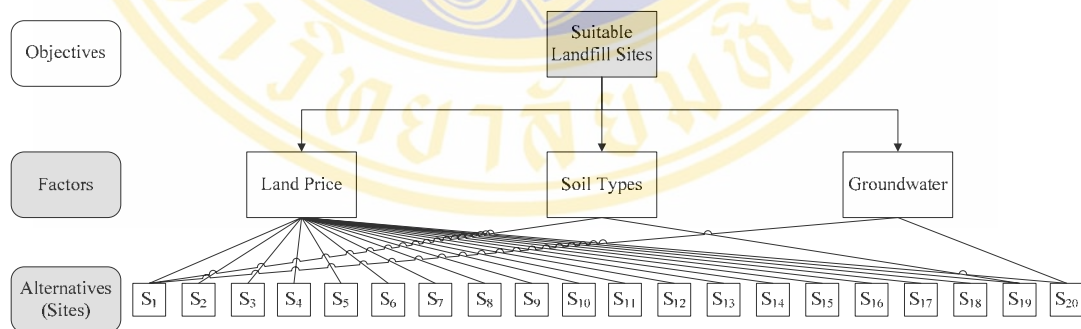
**Figure 3.1** Flowchart of the methodology

### 3.2.1 Preliminary Locations: Screening of Potential Areas for Landfill Sites

Selection of potential areas for a solid waste landfill depends on many factors as described in the previous sections. Unsuitable landfill sites are those within flooding areas, water bodies, roads, urban areas, historical sites, parks temples and schools and their buffer zones. These areas were derived from the base maps and the GIS techniques were used to create buffers. Results of this selection are scatter areas in Nakhon Pathom Province, which aren't suitable for landfill sites. The remaining areas are therefore suitable for landfill sites and then further selection is implemented as follows.

### 3.2.2 Secondary Locations: Selected Potential Landfill Sites

After the suitable areas for landfill were screened out, the next step is to consider the size of each area. ArcGIS was used to select areas having the size large enough to be used for 20 years. The method of AHP (Analytical Hierarchy Process) was used to classify the degree of landfill site suitability into 3 levels as shown in figure 3.2.



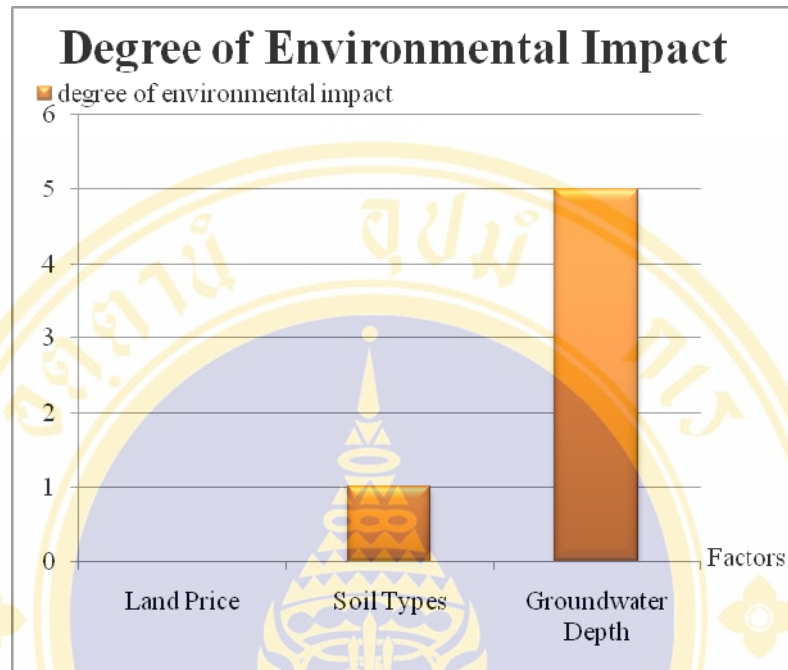
Remark: S refers to alternative landfill sites.

Figure 3.2 Proposed AHP hierarchy

3.2.2.1 Level 1, the selection is based on environmental concerns.

3.2.2.2 Level 2, the selection is based on, land price, soil types and groundwater depth, at different degrees of each factor's importance. Impact assessment techniques was used to evaluate the various impacts of the proposed

landfill sites (Muhammad & Jess, 1996). These procedures result in an impact rating which is interpreted as the relative suitability of each potential landfill site.



**Figure 3.3** Degree of environmental Impact

Figure 3.3 can be described as follows; the groundwater depth has variety of environmental effects, more than soil type and land price (Chiangmai U., 2003). When pollution find contamination in groundwater, 1) it can cause of serious health problems. 2) It propagates contamination into water sources and land. 3) When polluted water flows into the soil. Soil quality will be deteriorated. 4) When polluted water flows into the rivers, the water quality will be deteriorated. 5) Moreover, leachate infiltrates into groundwater and caused contamination. It has an effect to the people as they must consume water. In the case of soil type and land price, soil type has capital and environmental effects; usable soil is that which water cannot pass through. It's proper to be steps to protect from leachate including cannot use other purposes. And land prices have a capital effect.

**3.2.2.3 Level 3** are alternative sites. Output of this level is preference ratings of alternative sites. The alternative sites are pairwise comparisons subjected to each factors respectively (soil types, land price and groundwater depths). Therefore, rate score of each factor are explained as follows:

**Soil types:** The characteristics of soil types are determined by drainage. The suitable soil should have poor drainage ability such as clay. Soil types were categorized the quality of drainage ability into four classes. The rating of each candidate site is shown in table 3.

**Land price:** Intuitively, the best site should be the cheapest piece of land, given that all other characteristics are the same. The land price was categorized into five classes by its use and how useful that is. The rating of each candidate site is shown in table 3.

**Groundwater depth:** The site should be located in an area with deep groundwater depth to prevent contamination by leachate. Groundwater depth was also categorized by its depth into five classes. The rating of each candidate site is shown in table 3.

**Table 3** The rating of each candidate site

Map layer	Scale	Data Source	Ranking and Description
Soil Type	1:50,000	Land Development Department	Excellent: Poor Drainage (2) Good: Medium Drainage (3) Fair: Good Drainage (5) Poor: Excellent Drainage (9)
Land Price	1:50,000	The Treasury Department	Excellent: 0 – 600 Baht/wah <sup>2</sup> Good: 601 – 1200 Baht/wah <sup>2</sup> Fair: 1201 – 1800 Baht/wah <sup>2</sup> Poor: 1801 – 2400 Baht/wah <sup>2</sup> Very Poor: > 2400 Baht/wah <sup>2</sup>
Groundwater Depth	1:50,000	Department of Ground Water Resources	Excellent: 50-41 Metres Good: 40-31 Metres Fair: 30-21 Metres Poor: 20-11 Metres Very Poor: 10-0 Metres

(Chang et al., 2007; Sener et al., 2006)

So, each level has a methodology which involves pairwise comparisons to create a ratio matrix. It takes pairwise comparisons as input and produces relative weights as output. The pairwise comparison method involves three steps:

1) Development of a pairwise comparison matrix: The method uses a scale with a value range from 1 to 9. The possible values are presented in Table 2.2.

2) Computation of the weights: The computation of weights involves three steps. The first step is the summation of the values in each column of the matrix. Then, each element in the matrix should be divided by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix). Then, computation of the average of the elements in each row of the normalized matrix should be made which includes dividing the sum of normalized scores for each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared.

3) Estimation of the consistency ratio: The aim of this is to determine if the comparisons are consistent or not. It involves the following operations:

a) Determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, finally sum these values over the rows,

b) Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously,

c) Compute lambda ( $\lambda$ ) which is the average value of the consistency vector and Consistency Index (CI) which provides a measure of departure from consistency and has the formula below:

$$CI = (\lambda - n) / (n - 1)$$

d) Calculation of the consistency ratio (CR) which is defined as follows:

$$CR = CI / RI$$

Where RI is the random index and depends on the number of elements being compared (Table 2.5) If  $CR < 0.10$ , the ratio indicates a reasonable level of consistency in the pairwise comparison, however, if  $CR \geq 0.10$ , the values of the ratio indicate inconsistent judgments.

### 3.2.3 Final Consideration

Selection of the best site based on total fuel cost for transportation. The top five candidate sites from the secondary location step were computed to find best site. Total fuel cost for transportations were considered by the summation of the product between the weight of solid waste in each zone and distance to the candidate area. This is shown in the equation below. In the GIS database, a zone represents a sub-district or Municipality. The output of this stage gives the best suitable site which has the lowest total fuel cost for transportation.

$$\text{Total fuel cost for transportation (Baht)} = (\text{Unit fuel cost}) \left( \sum_{i=1}^n (\text{Weight}_i) (D_{i-\text{Area}}) \right)$$

Where

$i$  = Index of Municipality

$n$  = Number of Municipality in Nakhon Pathom Province (15 in total)

$\text{Weight}_i$  = amount of solid waste (ton) generated in Municipality  $i$

$D_{i-\text{Area}}$  = the distance from centroid of Municipality  $i$  to the centroid of a candidate area (kilometer).

$\text{Unit fuel cost} = 2.19$  baht/ton/kilometer

## CHAPTER IV

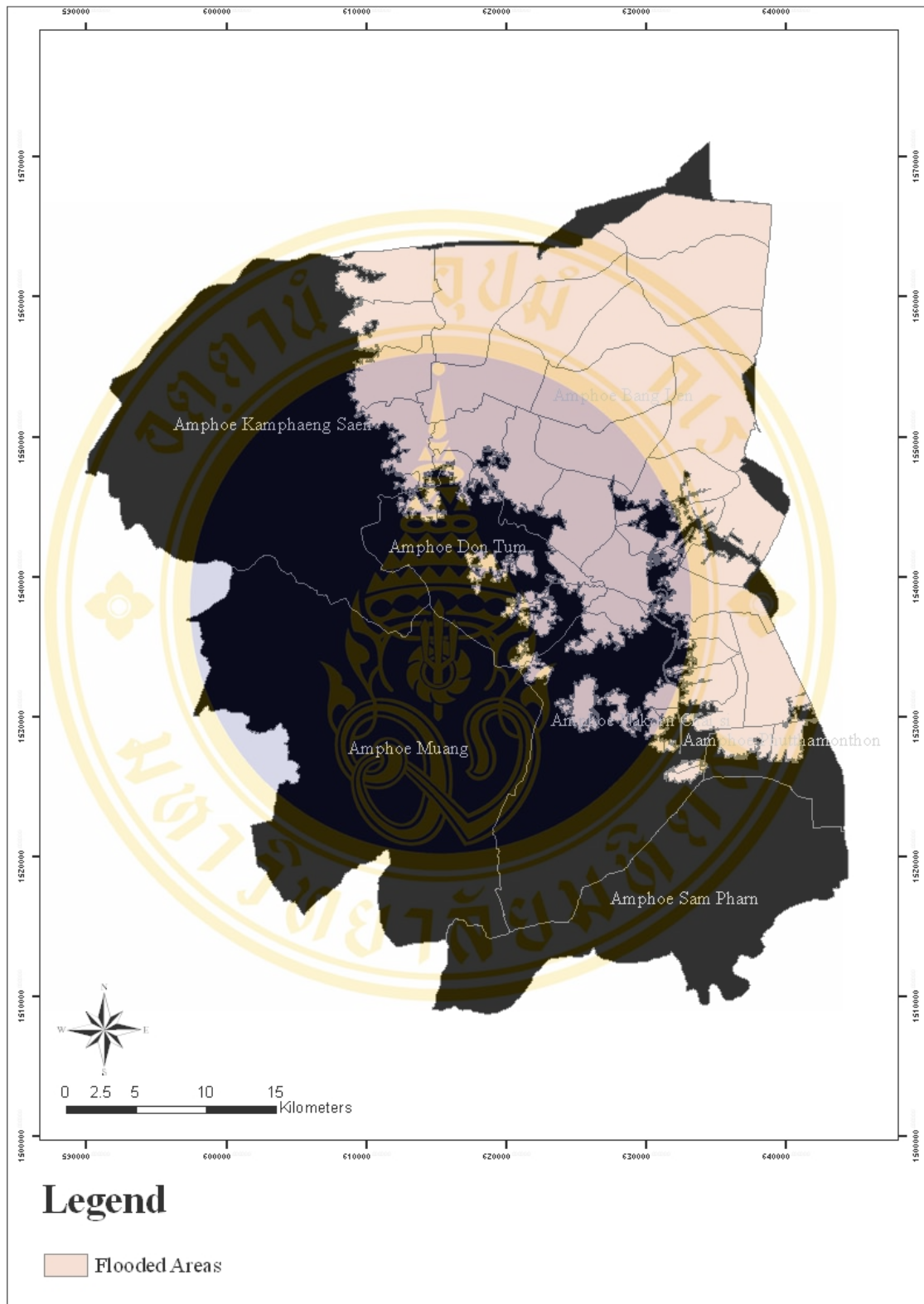
### RESULTS

The previous chapter showed how to use GIS to select the landfill sites capable for at least 20 years. The size of such landfill is about 1,328.37 km<sup>2</sup>. This chapter showed the methods of eliminating unsuitable areas, ranking suitable sites and selecting the most suitable site based on transportation costs. The study of all the stages was described as follows.

#### **4.1 Preliminary Locations: Screening of Potential Areas for Landfill Sites**

Several factors were used in this step such as flooded areas, urban areas, roads, rivers and water bodies. Incidentally, unsuitable areas were screened out by imposing exclusionary criteria within the GIS environment. This was done layer-by-layer or criteria-by-criteria. The screening was proceeded by:

4.1.1 To prevent increased construction costs, flooded areas were eliminated from the base map. The major part flooding areas were located in Amphoe Bang Len and partially of Amphoe Kamphaeng Saen, Don Tum, Nakhon Chai si, and Phutthamonthon (Figure 4.1). So, the areas were screened by flood areas could be shown in Figure 4.2.



**Figure 4.1** Flooded Areas

(Office of Land use Administration and Development, 2007)

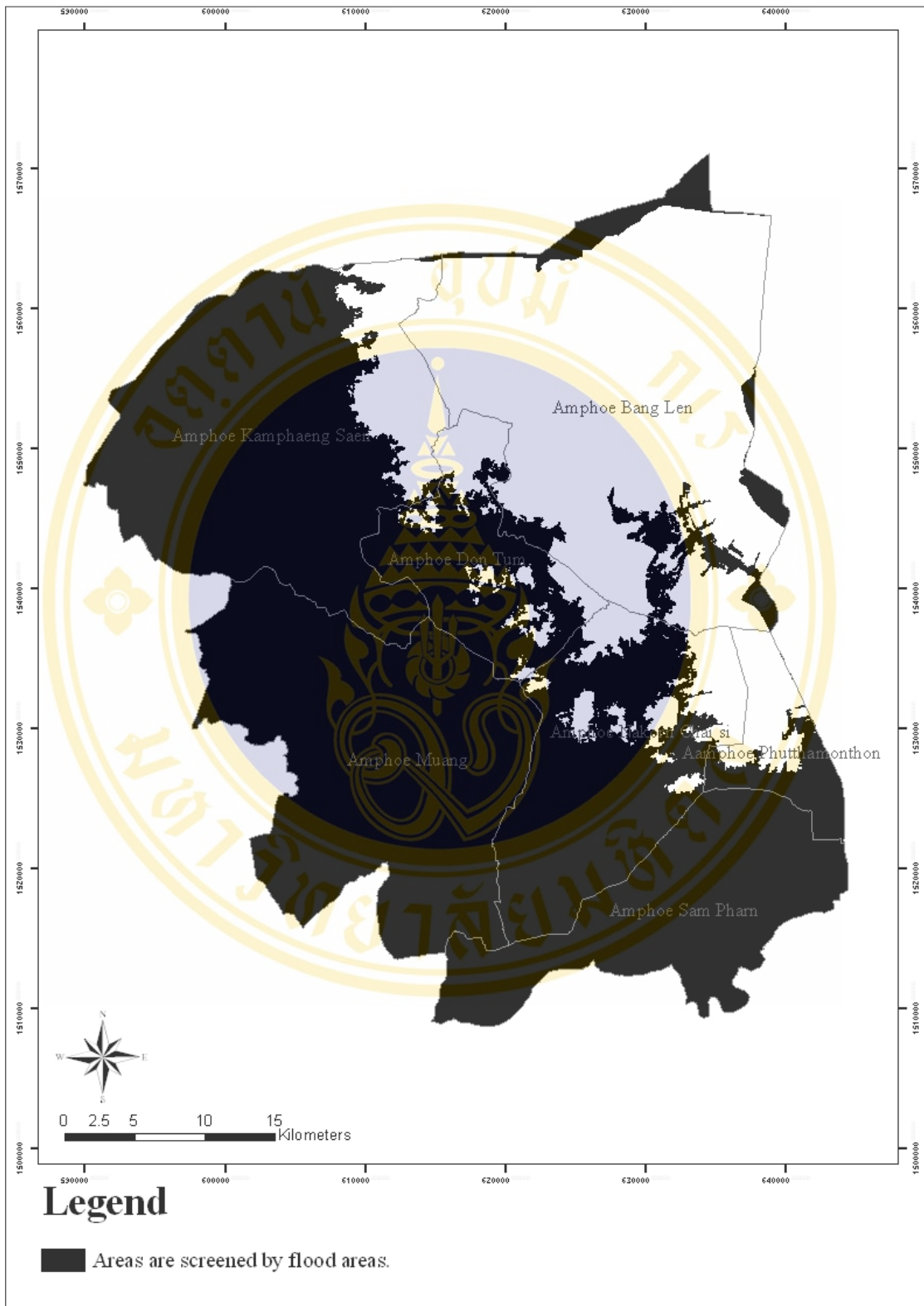
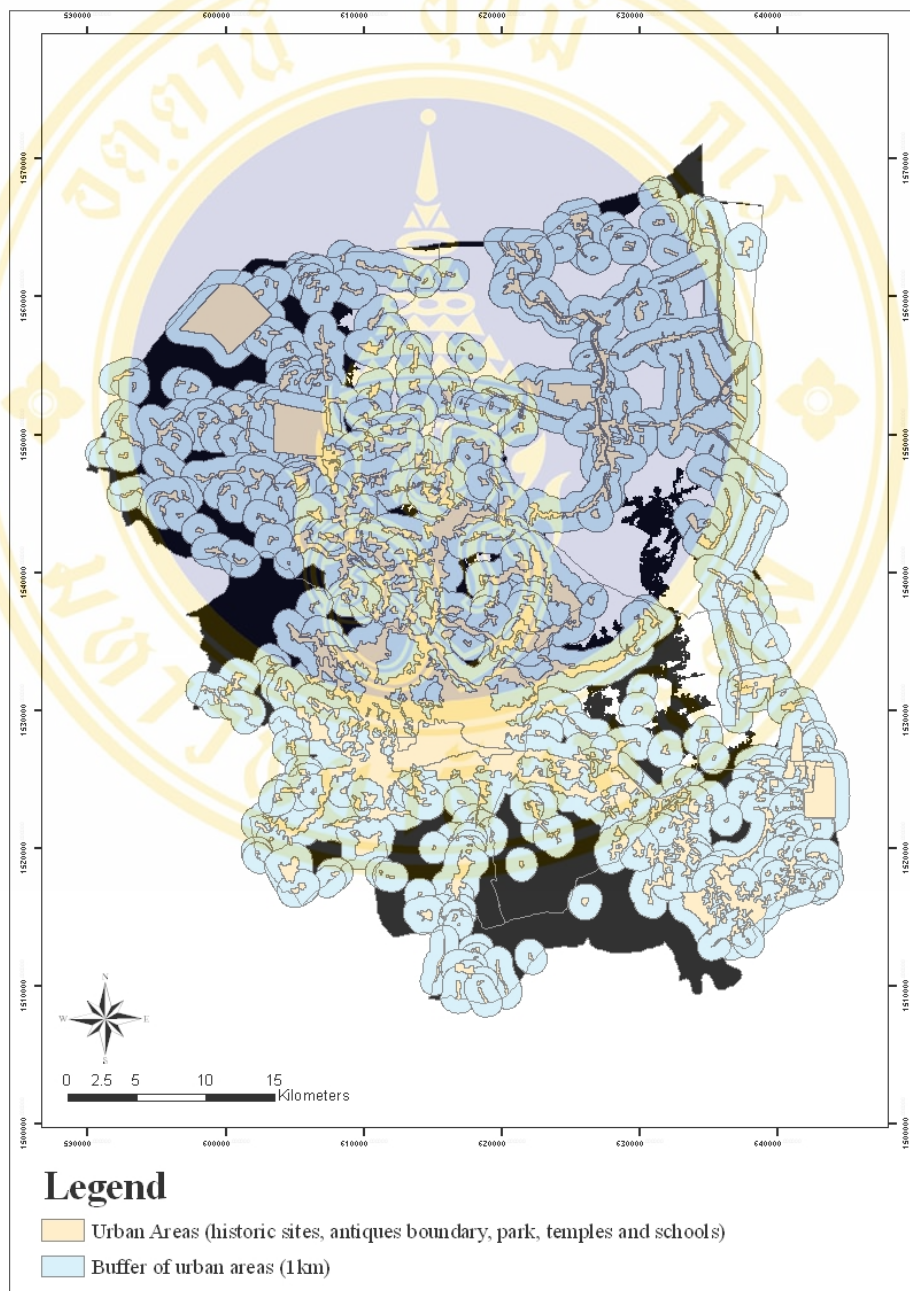
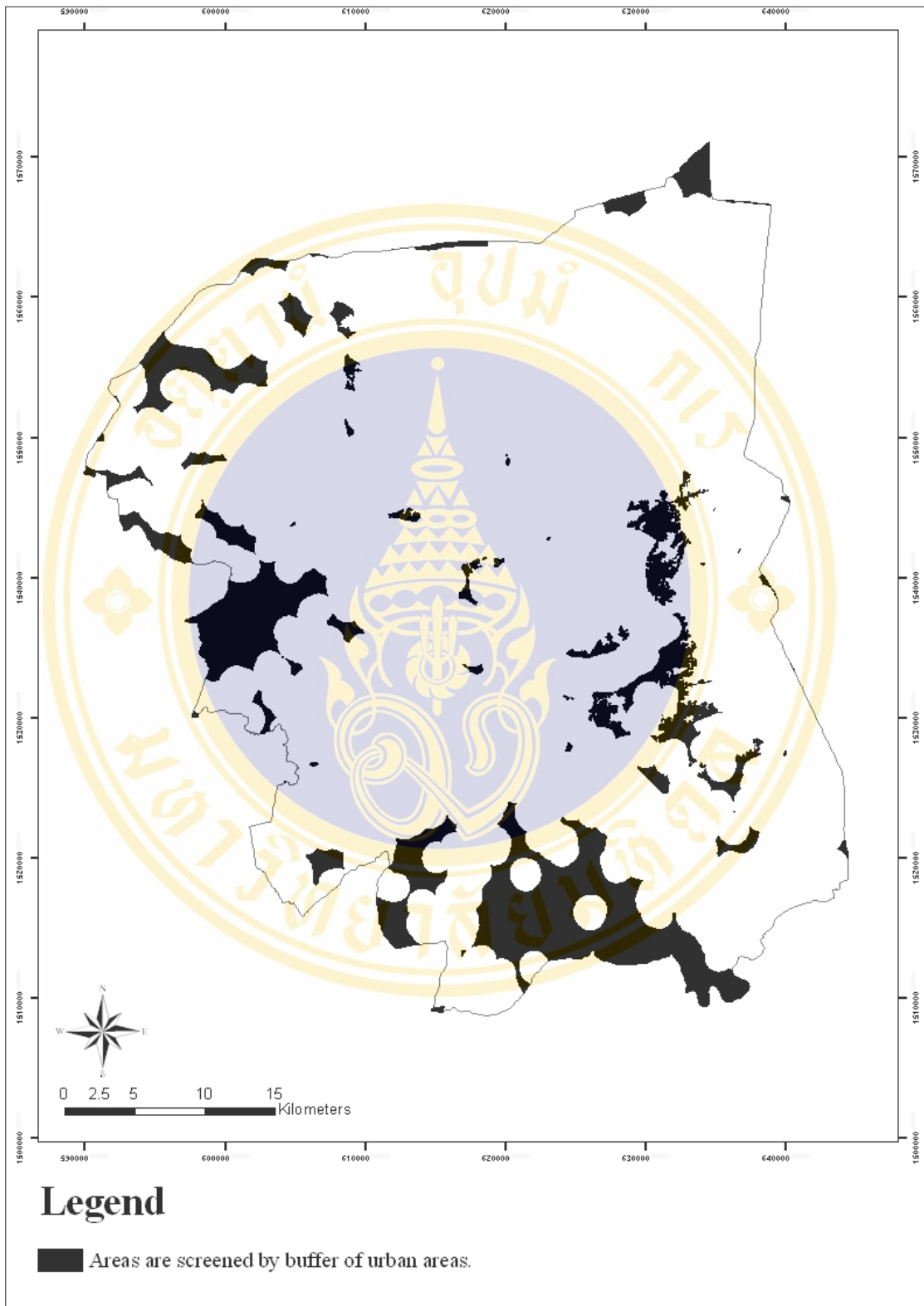


Figure 4.2 Areas were screened by flood areas.

4.1.2 The landfill site should be located at a significant distance away from urban residential areas due to public concerns, such as aesthetics, odour, noise, and health factors (Figure 4.3). One kilometer buffer around residential areas was made according to PCD’s recommendation (Pollution Control Department, 2001) as shown in figure 4.3. So, the areas were screened by buffer of urban areas were shown in figure 4.4.

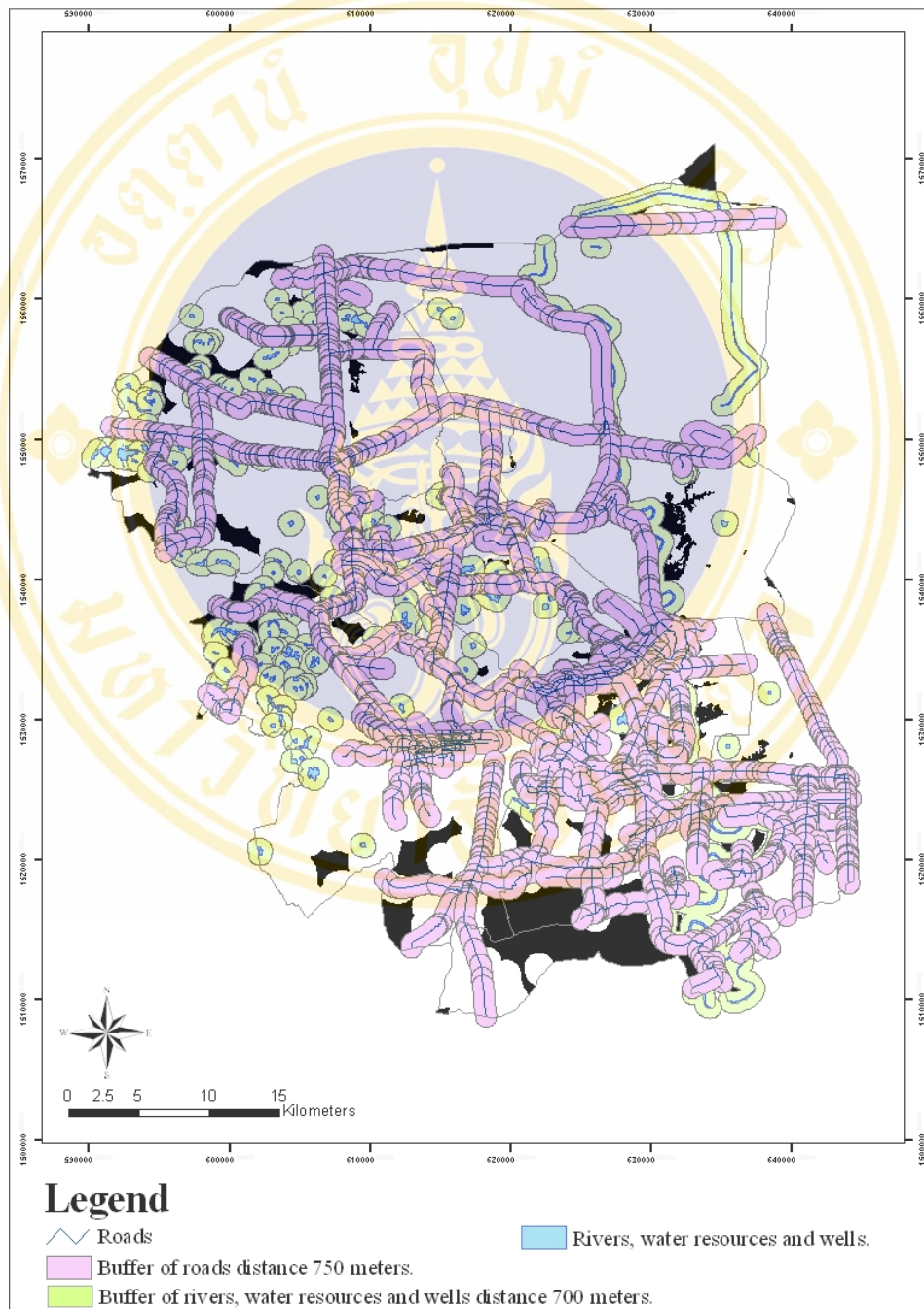


**Figure 4.3** Buffer of urban areas  
(Department of Environment Quality Promotion, 2001)

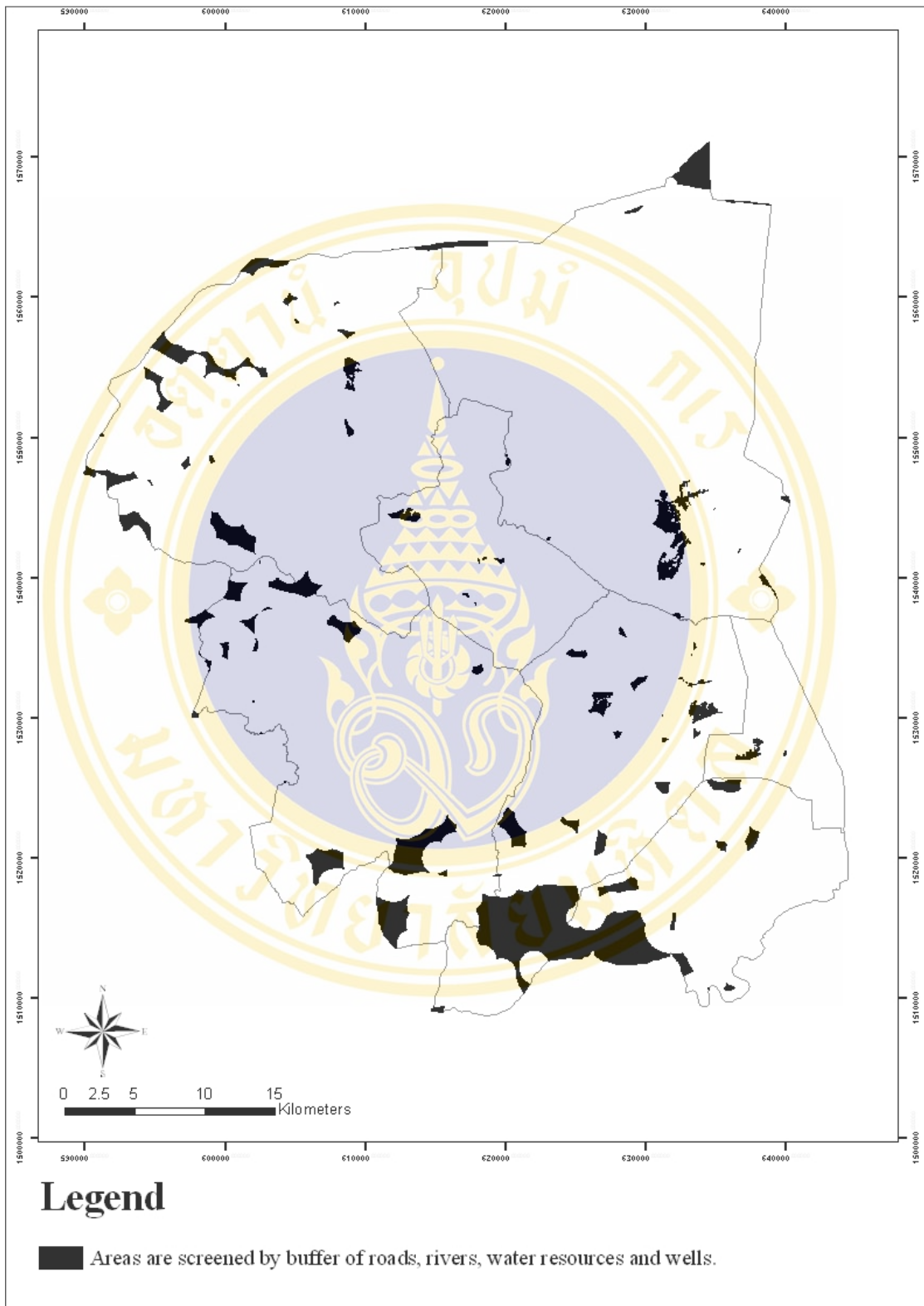


**Figure 4.4** Areas were screened by buffer of urban areas (Historic site, antiques boundary, park, temples and schools).

4.1.3 In addition, the landfill site should be situated at a significant distance away from roads, rivers, water bodies in order to prevent it from the contamination of polluted water through leaching. The buffer of 750 m, 700 m is required for roads and water bodies respectively (Chang et al., 2007) are shown in figure 4.5. The areas were screened by buffer of roads, rivers, water bodies and wells were shown in figure 4.6.



**Figure 4.5** Buffer of roads, rivers, water bodies and wells  
(Department of Environment Quality Promotion, 2001)



**Figure 4.6** Areas were screened by buffer of roads, rivers, water bodies and wells.

The results of eliminating unsuitable areas were shown as scattered areas (see Figure 4.6 and Appendix A). In summary, Nakhon Pathom Province has been defined as a medium sized cluster by The Pollution Control Department. The quantity of solid waste was 285.17 tonnes/day which requires landfill size of 1,328,374 m<sup>2</sup>. The total 20 preliminary candidate areas were shown in figure 4.7.

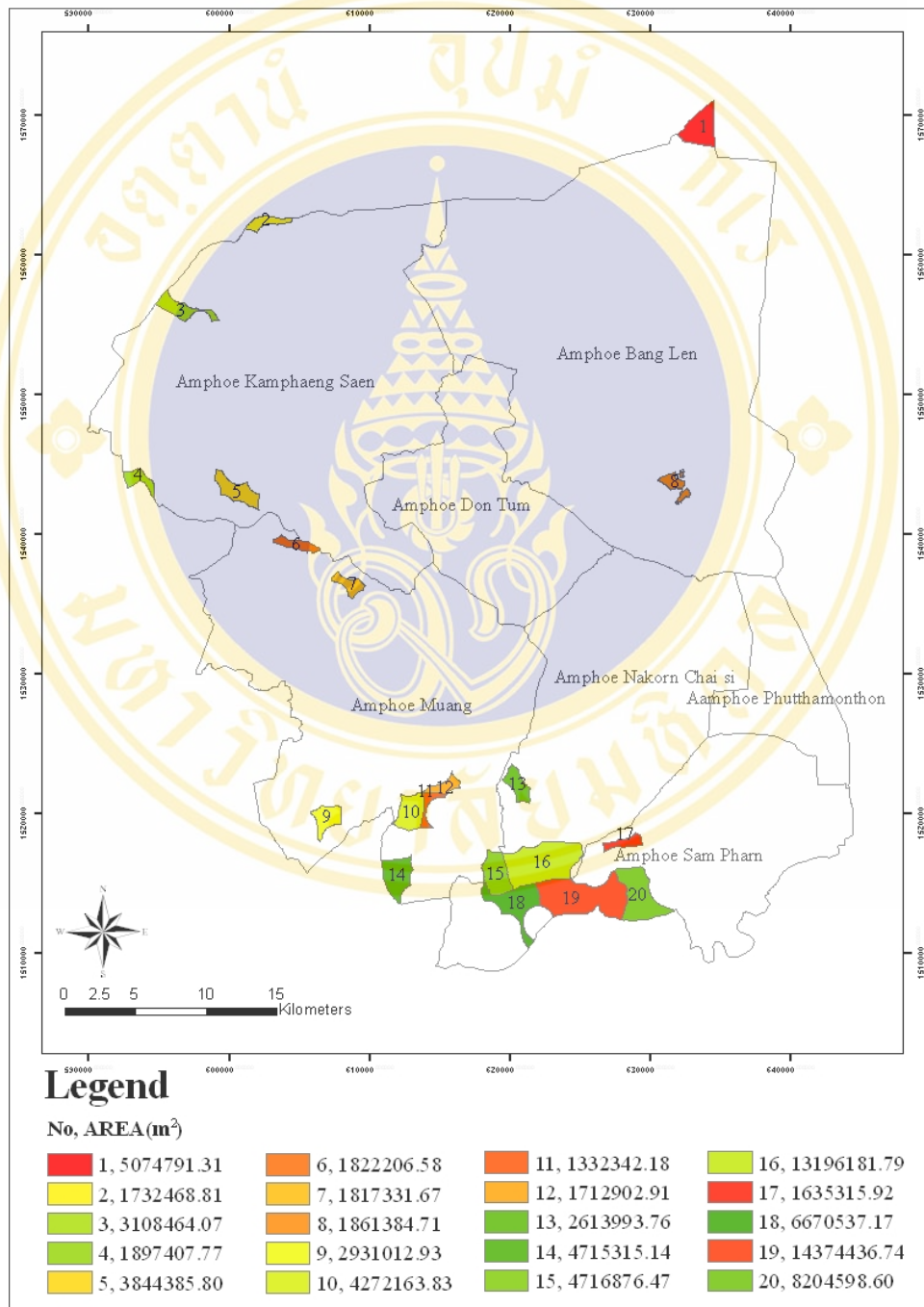


Figure 4.7 Twenty preliminary candidate areas for twenty years

#### 4.2 Secondary Locations: Selected Potential Landfill Sites

After deriving the outputs from the primary locations, analyzing several important factors from 20 preliminary candidate areas was made. Three non-exclusionary criteria (soil type, land price and groundwater depth) were applied to the 20 preliminary candidate areas. Their rating scores were given in table 4.1.

**Table 4.1** Ratings of non-exclusionary criteria for 20 preliminary candidate areas

Sites	Factors		
	Groundwater depth	Soil types	Land Price
1	Fair	Excellent	Fair
2	Poor	Fair	Good
3	Very poor	Fair	Good
4	Poor	Fair	Good
5	Poor	Fair	Very poor
6	Poor	Fair	Very poor
7	Fair	Fair	Very poor
8	Fair	Excellent	Fair
9	Good	Good	Very poor
10	Excellent	Excellent	Very poor
11	Excellent	Excellent	Very poor
12	Excellent	Excellent	Very poor
13	Excellent	Excellent	Good
14	Excellent	Excellent	Very poor
15	Excellent	Excellent	Very poor
16	Excellent	Excellent	Good
17	Excellent	Excellent	Very poor
18	Excellent	Excellent	Very poor
19	Excellent	Excellent	Very poor
20	Excellent	Excellent	Very poor

From table 4.1, an Analytical Hierarchy Process (**AHP** model) was used to present priority landfill objectives. The result was a shapefile showing 20 preliminary candidate areas with their corresponding rating scores. The rating scores can be used to rank the suitability of the candidate areas. The higher scores the more suitable landfill site.

### 4.2.1 Relative Importance Weights

Pair-wise comparisons of all related attribute values were used to establish the relative importance of hierarchy elements. Analysis will judge pairs of grouped elements in terms of their relative importance concerning the objective to which they contribute, that is, the factor they were connected to the next highest level. Finally, all the attribute values for a given attribute were pair-wise compared. For the hierarchy presented in figure 3.2, within a decision factor, the relative importance of each factor pair was compared. For example, the relative importance of land price, soil types and groundwater depth were evaluated pair-wise. In level 2 can define priority of each factor. Impact assessment technique used to evaluate the various impacts of the proposed landfill sites (Muhammad & Jess, 1996). This research is selection of potential landfill site base on environment objective. Finally for the each factor, the relative importance of each of the three possible attributes was compared as shown in table 4.2.

**Table 4.2** Evaluated pair-wise

Suitable Landfill (Consider from environment)		Factors		
		Land Price	Soil Types	Groundwater depth
Factors	Land Price	1	1/3	1/9
	Soil Types	3	1	1/9
	Groundwater depth	9	9	1
Total		13	10.33	1.22

Value from table 4.2 can be described as follow:

- Diagonal line of table is always equal to 1 because it was the same factor comparison. That performs importance also equal such as land price compare with land price or soil type compare with soil type etc.
- Next, Comparison between land price and soil type was equal to 1/3. That means selection of a potential solid waste landfill site by consider with environment mainly and give importance in land price less than soil type moderate. The value can described from figure 3.3, land price (0) had a degree less than soil type (1) was 1 level.

- Comparison between land price and groundwater was equal to 1/9. That means selection of a potential solid waste landfill site by consider with environment mainly and give importance in land price less than ground water extreme. The value can describe from figure 3.3, land price (0) had a degree less than groundwater depth (5) was 5 levels.

- Comparison between soil types and groundwater was equal to 1/9. That means suitable selection of a potential solid waste landfill site by consider with environment mainly and give importance in soil types less than groundwater strong. The value can describe from figure 3.3, soil types (1) had a degree less than groundwater depth (5) was 4 levels.

Then, the normalized matrix value was calculated to find weight scores that made the total of each column as 1. (See Table 4.3)

**Table 4.3** Normalized matrix value

ENV		Factors			Weight
		Land Price	Soil Types	Groundwater	
Factors	Land Price	0.08	0.03	0.09	0.07
	Soil Types	0.23	0.10	0.09	0.14
	Groundwater depth	0.69	0.87	0.82	0.79
Total		1	1	1	1

From table 4.3, it can be concluded that the weight of groundwater depth, soil types and land price are 79%, 14% and 7% respectively. In AHP, an index of consistency, known as the consistency ratio (CR), was used to indicate the probability that the matrix judgments were randomly generated. The indices of 0.05, 0.08 and 0.1 are for 3 by 3, 4 by 4 and  $n$  by  $n$  (where  $n \geq 5$ ) matrices respectively. A consistency ratio above 0.05 required revisions of the judgments in the matrix because of an inconsistent treatment of particular factor rating. In this case the consistency ratio of the matrix of paired comparisons between the three factors in the suitability assessment of suitable landfill site was 0.77 and was inconsistency.

In conclusion, the table 4.5 shows the normalized matrix value of groundwater depth. This table shows the different weight of each site. The weights of site 10-20 were 0.07 which then have more suitable than others sites. On the contrary, unsuitable

sites such as site 2, 4, 5 and site 6 where the weight was 0.01. In groundwater depth factor the consistency ratio of the matrix of paired comparisons between the 20 sites in the suitability assessment of suitable landfill site is -0.06, and was thus acceptable.

Table 4.7 shows the normalized matrix value of soil types. Weight of site 10-20 were 0.06 where had more suitable than others sites. On the contrary, unsuitable sites such as site 2, 3, 4, 5 and site 7 where the weight was 0.01. In soil types factor the consistency ratio of the matrix of paired comparisons between the 20 sites in the suitability assessment of suitable landfill site was 0, and was thus acceptable.

The last, in table 4.9 shows normalized matrix value land prices. Weight of site 4 was 0.13 where had more suitable than others sites. On the contrary, unsuitable sites such as site 5, 6 and site 7 where the weight was 0.01. In land price factor the consistency ratio of the matrix of paired comparisons between the 20 sites in the suitability assessment of suitable landfill site was -0.14, and was thus acceptable.

**Table 4.4** Evaluated pair-wise for groundwater depth

Groundwater depth	Sites																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	3	5	3	3	3	1	1	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
2	1/3	1	3	1	1	1	1/3	1/3	1/5	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7
3	1/5	1/3	1	1/3	1/3	1/3	1/5	1/5	1/7	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9
4	1/3	1	3	1	1	1	1/3	1/3	1/5	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7
5	1/3	1	3	1	1	1	1/3	1/3	1/5	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7
6	1/3	1	3	1	1	1	1/3	1/3	1/5	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7
7	1	3	5	3	3	3	1	1	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
8	1	3	5	3	3	3	1	1	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
9	3	5	7	5	5	5	3	3	1	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3
10	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
11	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
12	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
13	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
14	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
15	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
16	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
17	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
18	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
19	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
20	5	7	9	7	7	7	5	5	3	1	1	1	1	1	1	1	1	1	1	1
<b>SUM</b>	61	95	134	95	95	95	61	61	34	11	11	11	11	11	11	11	11	11	11	11

**Table 4.5** Calculation of relative importance weight for groundwater depth

Groundwater depth	Sites																				weight	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
1	0.02	0.03	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
6	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
7	0.02	0.03	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
8	0.02	0.03	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
9	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
10	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
11	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
12	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
13	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
14	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
15	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
16	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
17	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
18	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
19	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
20	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
<b>SUM</b>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

**Table 4.6** Evaluated pair-wise for soil types

Soil Types	Sites																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
2	1/5	1	1	1	1	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
3	1/5	1	1	1	1	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
4	1/5	1	1	1	1	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
5	1/5	1	1	1	1	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
6	1/5	1	1	1	1	1	2	1/5	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
7	1/5	1	1	1	1	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
8	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
9	1/3	3	3	3	3	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3
10	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
11	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
12	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
13	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
14	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
15	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
16	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
17	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
18	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
19	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
20	1	5	5	5	5	5	5	1	3	1	1	1	1	1	1	1	1	1	1	1
<b>SUM</b>	14.53	74	74	74	74	74	74	75	14.53	42	14.53	14.53	14.53	14.53	14.53	14.53	14.53	14.53	14.53	14.53

**Table 4.7** Calculation of relative importance weight for soil types

Soil Types	Sites																				weight
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
6	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
7	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
8	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
9	0.02	0.04	0.04	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
11	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
12	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
13	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
14	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
15	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
16	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
17	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
18	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
19	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
20	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
<b>SUM</b>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

**Table 4.8** Evaluated pair-wise for land price

Land Price	Site																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1/3	1/3	1/3	5	5	5	1	5	5	5	5	1/3	5	5	1/3	5	5	5	5
2	3	1	1	1	7	7	7	3	7	7	7	7	1	7	7	1	7	7	7	7
3	3	1	1	1	7	7	7	3	7	7	7	7	1	7	7	1	7	7	7	7
4	3	1	2	1	7	7	7	3	7	7	7	7	1	7	7	1	7	7	7	7
5	1/5	1/7	1/7	1/7	1	1	1	1/7	1	1	1	1	1/7	1	1	1/7	1	1	1	1
6	1/5	1/7	1/7	1/7	1	1	1	1/7	1	1	1	1	1/7	1	1	1/7	1	1	1	1
7	1/5	1/7	1/7	1/7	1	1	1	1/7	1	1	1	1	1/7	1	1	1/7	1	1	1	1
8	1	1/3	1/3	1/3	7	7	7	1	5	5	5	5	1/3	5	5	1/3	5	5	5	5
9	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
10	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
11	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
12	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
13	3	1	2	3	7	7	7	3	7	7	7	7	1	7	7	1	7	7	7	7
14	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
15	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
16	3	1	2	3	7	7	7	3	7	7	7	7	1	7	7	1	7	7	7	7
17	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
18	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
19	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
20	1/5	1/7	1/7	1/7	1	1	1	1/5	1	1	1	1	1/7	1	1	1/7	1	1	1	1
<b>SUM</b>	19.60	7.52	8.52	7.52	60	60	60	19.43	58	58	58	58	7.52	58	58	7.52	58	58	58	58

**Table 4.9** Calculation of relative importance weight for land price

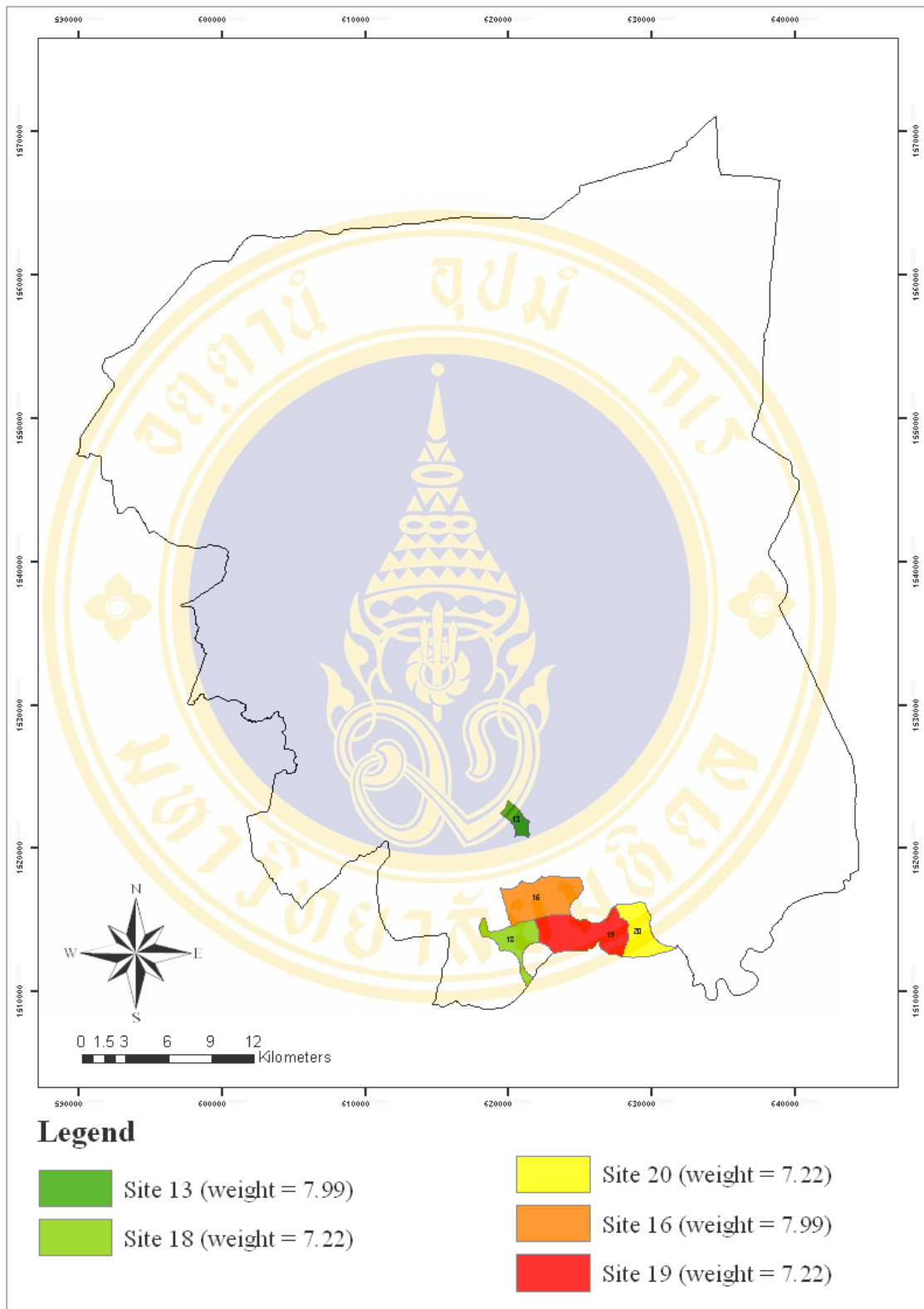
Land Price	Sites																				weight
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	0.05	0.04	0.04	0.04	0.08	0.08	0.08	0.05	0.09	0.09	0.09	0.09	0.04	0.09	0.09	0.04	0.09	0.09	0.09	0.09	0.07
2	0.15	0.13	0.12	0.13	0.12	0.12	0.12	0.15	0.12	0.12	0.12	0.12	0.13	0.12	0.12	0.13	0.12	0.12	0.12	0.12	0.13
3	0.15	0.13	0.12	0.13	0.12	0.12	0.12	0.15	0.12	0.12	0.12	0.12	0.13	0.12	0.12	0.13	0.12	0.12	0.12	0.12	0.13
4	0.15	0.13	0.23	0.13	0.12	0.12	0.12	0.15	0.12	0.12	0.12	0.12	0.13	0.12	0.12	0.13	0.12	0.12	0.12	0.12	0.13
5	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
6	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
7	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
8	0.05	0.04	0.04	0.04	0.12	0.12	0.12	0.05	0.09	0.09	0.09	0.09	0.04	0.09	0.09	0.04	0.09	0.09	0.09	0.09	0.08
9	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
11	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
12	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
13	0.15	0.13	0.12	0.13	0.12	0.12	0.12	0.15	0.12	0.12	0.12	0.12	0.13	0.12	0.12	0.13	0.12	0.12	0.12	0.12	0.13
14	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
15	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
16	0.15	0.13	0.12	0.13	0.12	0.12	0.12	0.15	0.12	0.12	0.12	0.12	0.13	0.12	0.12	0.13	0.12	0.12	0.12	0.12	0.13
17	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
18	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
19	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
20	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
SUM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Based on the aggregation functions, the fuzzy appropriate indices were obtained and presented in table 4.10. This information might help justify the final ranking among these twenty-candidate sites.

**Table 4.10** Weight of twenty-candidate sites

Sites	Factors			Weight
	Groundwater depth (79%)	Soil Types (14%)	Land Price (7%)	
1	(79) (0.02) +	(14) (0.07) +	(7) (0.07)	3.02
2	(79) (0.01) +	(14) (0.01) +	(7) (0.13)	1.90
3	(79) (0.01) +	(14) (0.01) +	(7) (0.13)	1.59
4	(79) (0.01) +	(14) (0.01) +	(7) (0.13)	1.94
5	(79) (0.01) +	(14) (0.01) +	(7) (0.02)	1.14
6	(79) (0.01) +	(14) (0.01) +	(7) (0.02)	1.14
7	(79) (0.02) +	(14) (0.01) +	(7) (0.02)	1.86
8	(79) (0.02) +	(14) (0.07) +	(7) (0.08)	3.05
9	(79) (0.04) +	(14) (0.03) +	(7) (0.02)	3.37
10	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22
11	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22
12	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22
13	(79) (0.08) +	(14) (0.07) +	(7) (0.13)	7.99
14	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22
15	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22
16	(79) (0.08) +	(14) (0.07) +	(7) (0.13)	7.99
17	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22
18	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22
19	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22
20	(79) (0.08) +	(14) (0.07) +	(7) (0.02)	7.22

The ranking values of the fuzzy appropriateness indices for alternatives were presented in figure 4.8. Areas 13 and 16 seem to be the strongest candidate areas with the total rating scores of 7.99. And, alternatives that same weight with the total rating scores as 7.22. Those sites were decided by size of area. Sites 18-20 seem to be the leading candidate areas if considering the size of area. In the next step, the top five candidate areas will make the cut for the final consideration.



**Figure 4.8** Five Secondary Candidate Areas

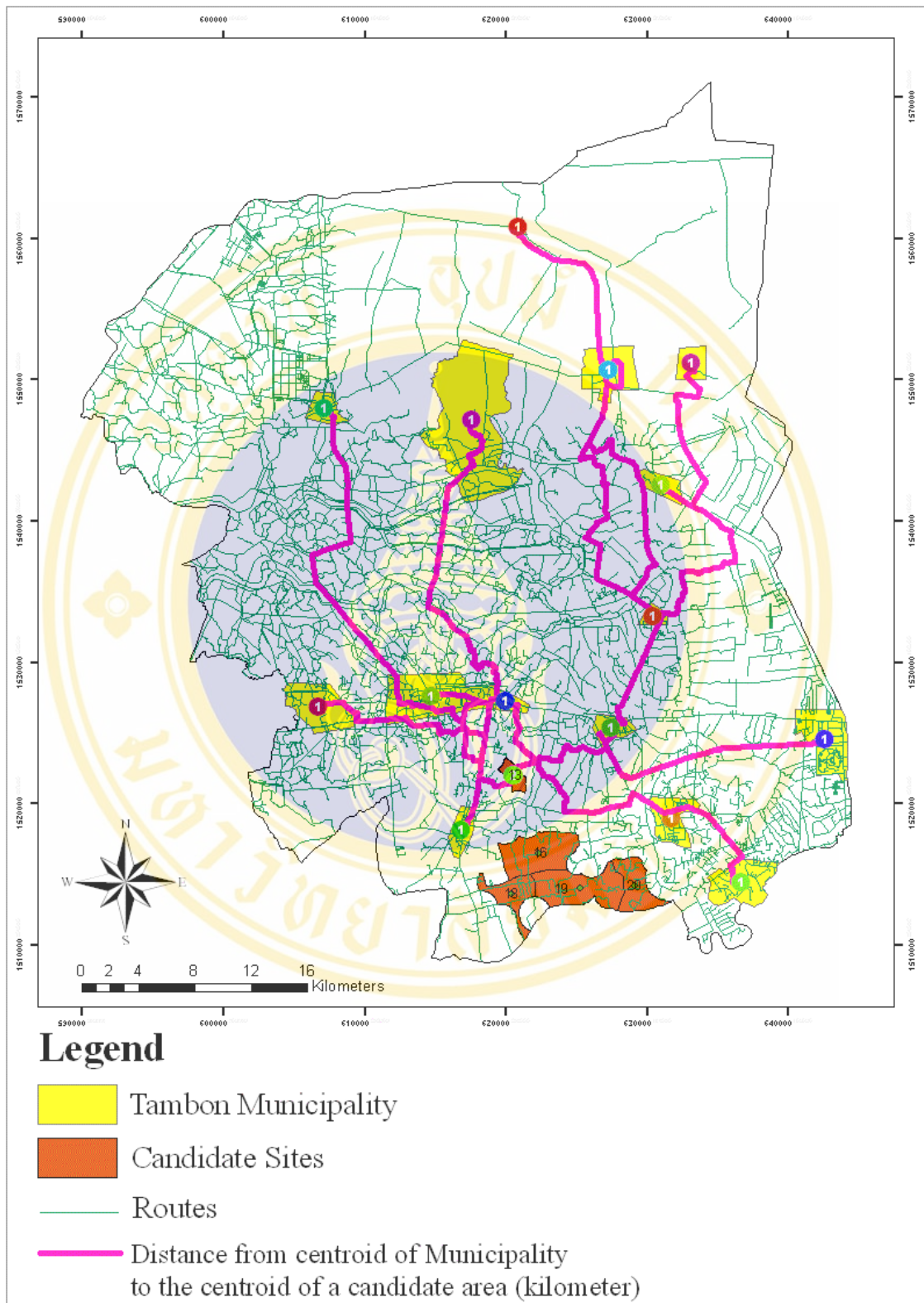
### 4.3 Final Consideration

The criterion used in this step was still non-exclusionary, i.e., the total transportation cost. The top five candidate sites from the secondary candidate areas singled out for consideration here, i.e., 13, 16, 18, 19, and 20. It was assumed that the unit fuel cost for transportation (ton/kilometer) was identical for any zone to any candidate area. The total fuel cost for transportation from all municipalities to a candidate area could be simply computed by the summation of the product between the weight of solid waste in each zone and distance to the candidate area.

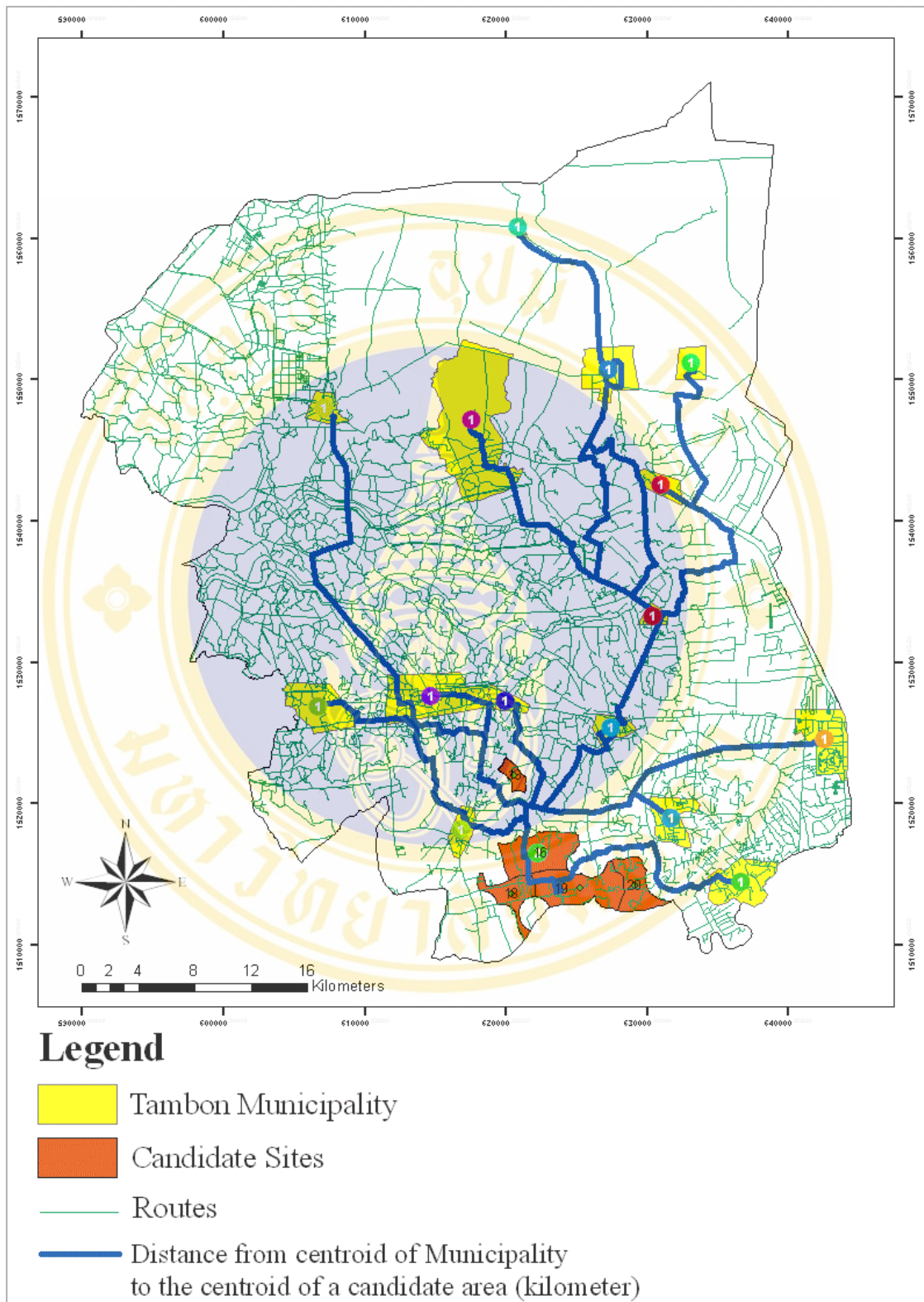
#### 4.3.1 Distance to the Candidate area

The best route to a candidate area, by distance, was found using GIS's network analyst techniques. The best routes were determined by the fastest route that uses time as impedance and another condition was a hierarchy route. So, the first step to creating a route using a hierarchy was to have a network hierarchy dataset. This hierarchy was stored as a network attribute. The hierarchy attribute reclassifies the hierarchy classes of edge sources into three ranks: 1) Primary roads, which had the highest rank, for example; can road surfaces that could be used in all seasons, hard road surfaces and roads wide enough for two ways of traffic. 2) Secondary roads, which had the middle rank, for example; can road surfaces that could be used in all seasons, soft road surfaces and roads wide enough for two ways of traffic. 3) Local roads, which had the lowest rank, for example; can road surfaces be used in all seasons, both hard and soft road surfaces and roads wide enough for one way traffic. A hierarchical route was created when the routing solver favours primary roads over secondary roads and secondary roads over local roads.

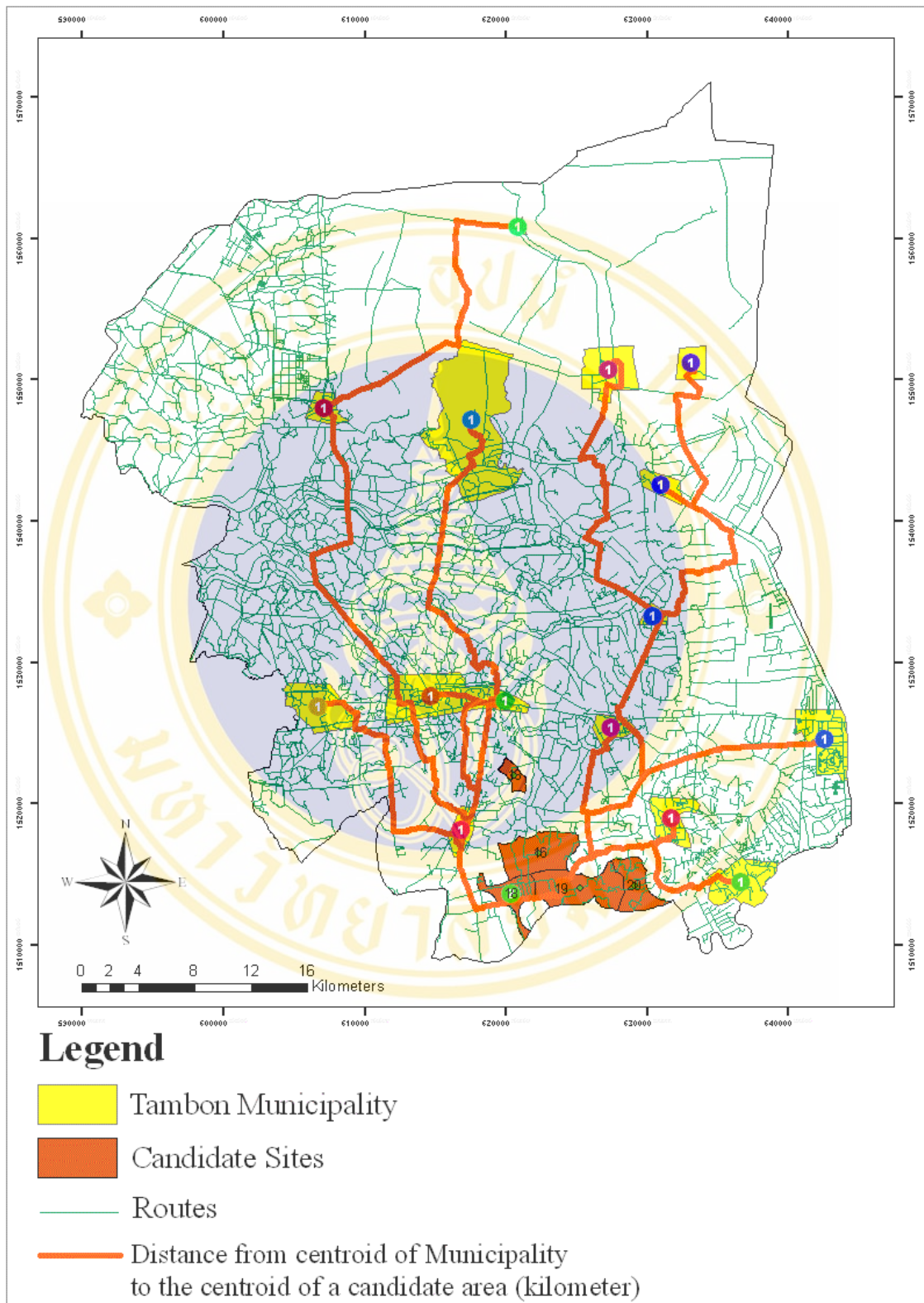
Creating the best route from each municipality (15 in total) to the candidate site, the total distance of site 13 was 420.42 kilometers (see Figure 4.9). The total distance of site 16 was 486.53 kilometers (see Figure 4.10). The total distance of site 18 was 520.02 kilometers (see Figure 4.11). The total distance of site 19 was 497.81 kilometers (see Figure 4.12). The total distance of site 20 was 485.69 kilometers (see Figure 4.13). The total distance of the existing landfill site (Tambon Takong) was 400.89 kilometers (see Figure 4.14).



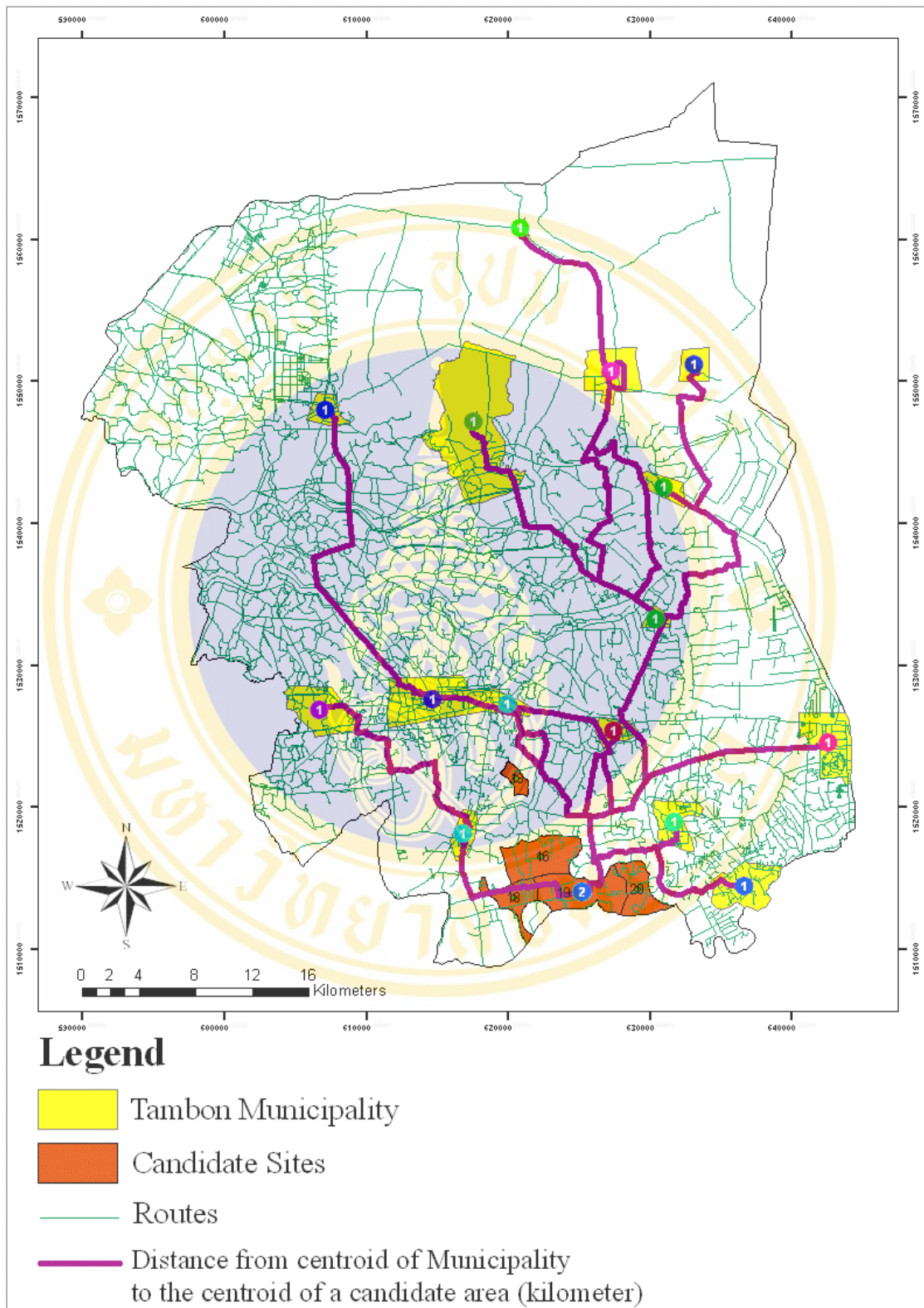
**Figure 4.9** Distance from centroid of each Municipality to the centroid of site 13



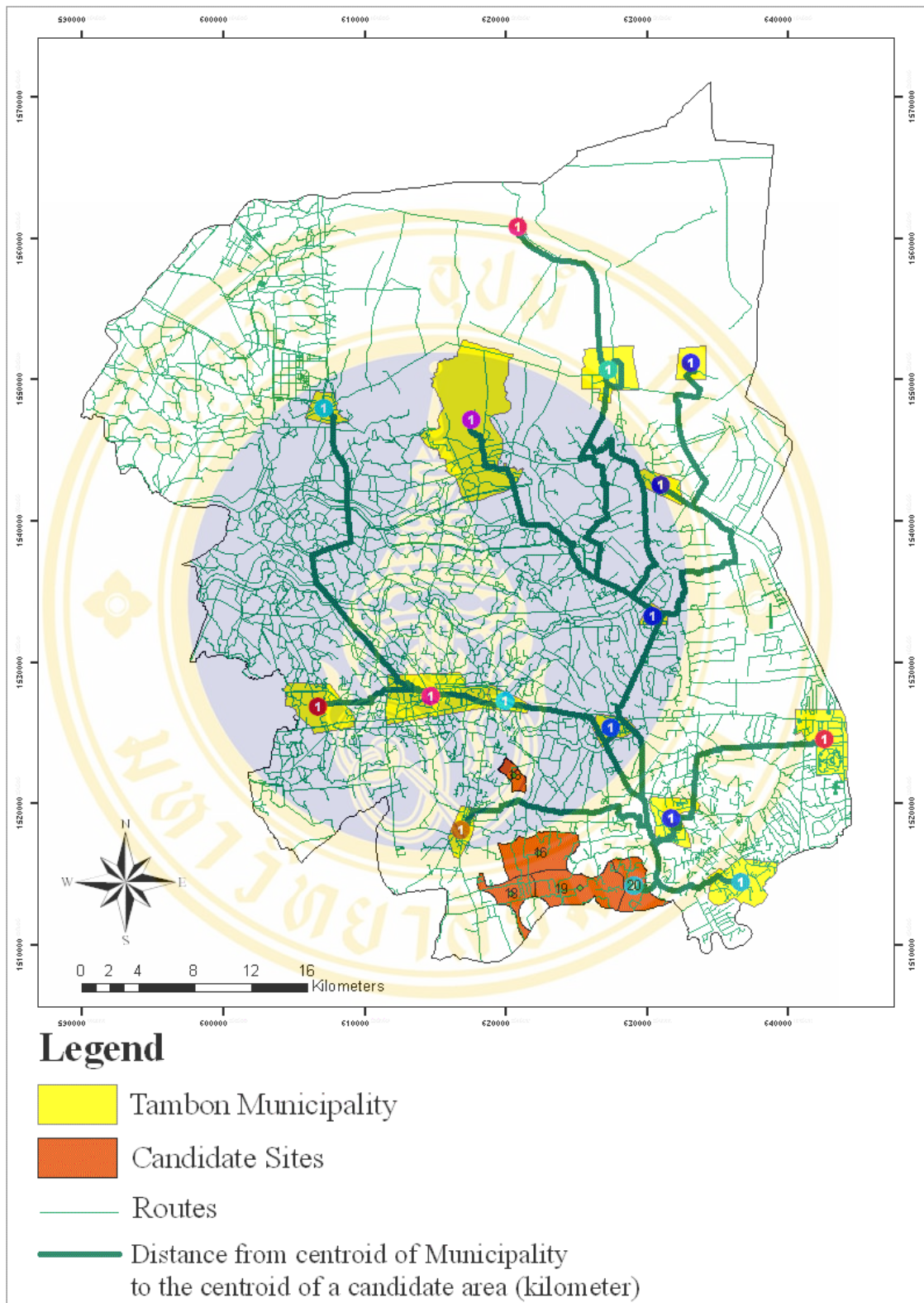
**Figure 4.10** Distance from centroid of each Municipality to the centroid of site 16



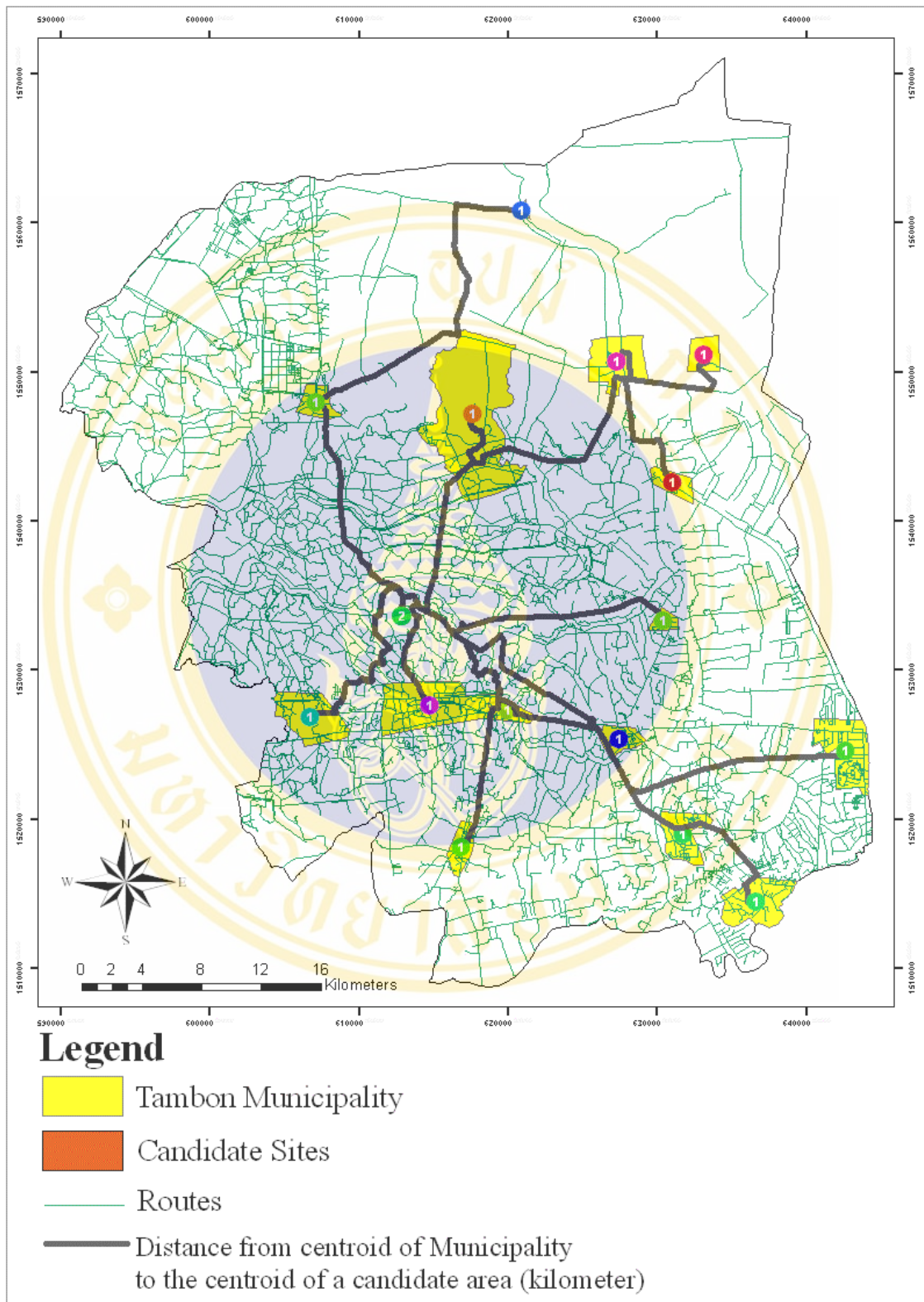
**Figure 4.11** Distance from centroid of each Municipality to the centroid of site 18



**Figure 4.12** Distance from centroid of each Municipality to the centroid of site 19



**Figure 4.13** Distance from centroid of each Municipality to the centroid of site 20



**Figure 4.14** Distance from centroid of each Municipality to the existing landfill site (Tambon Takong)

**Table 4.11** Comparison of the total fuel cost for transportation

Municipality	Amount of Solid waste (ton/d)	Total Fuel Cost for Transportation (Baht)																	
		The existing solid waste landfill (Tambon Takong)			Site 13			Site 16			Site 18			Site 19			Site 20		
		Distance (km)	Fuel Cost (baht)*	Distance (km)	Fuel Cost (baht)*	Distance (km)	Fuel Cost (baht)*	Distance (km)	Fuel Cost (baht)*	Distance (km)	Fuel Cost (baht)*	Distance (km)	Fuel Cost (baht)*	Distance (km)	Fuel Cost (baht)*	Distance (km)	Fuel Cost (baht)*	Distance (km)	Fuel Cost (baht)*
1	Bang Luang Municipality	2.20	41.36	199.37	58.16	280.34	62.48	301.14	71.54	344.80	62.42	300.84	60.15	289.93					
2	Kamphaeng Saen Municipality	4.00	16.71	146.21	39.79	348.13	47.05	411.71	46.88	410.22	54.29	475.08	53.89	471.51					
3	Sam Ngam Municipality	7.32	18.54	297.17	38.09	610.69	47.46	760.82	46.90	751.92	47.39	759.81	45.13	723.53					
4	Bang Len Municipality	7.01	32.25	495.33	47.78	734.03	52.10	800.34	56.25	864.08	52.04	799.38	49.78	764.62					
5	Rangra Thum Municipality	2.18	37.31	178.36	48.42	231.52	52.74	252.16	56.89	271.99	52.68	251.85	50.41	241.04					
6	Lum Phraya Municipality	1.00	37.96	82.75	38.28	83.43	42.60	92.84	46.75	101.89	42.33	92.70	40.27	87.77					
7	Huai Phlu Municipality	1.20	21.12	55.65	22.03	58.04	26.35	69.42	30.50	80.35	26.29	69.25	24.02	63.29					
8	Phrong Madusa Municipality	6.07	16.61	220.66	20.49	272.27	27.11	360.18	26.43	351.25	32.61	433.35	35.79	475.56					
9	Nakhon Pathom Municipality	196.46	10.80	4,647.34	12.90	5,551.78	19.52	8,398.40	22.19	9,546.03	25.11	10,804.58	26.97	11,604.24					
10	Thammasala Municipality	5.03	14.33	157.88	8.19	90.22	14.86	163.76	19.68	216.83	19.37	213.45	21.57	237.70					
11	Nakhon Chai Si Municipality	6.98	22.16	338.75	11.31	172.85	15.62	238.86	19.18	293.20	14.97	228.80	15.00	229.32					
12	Salaya Municipality	4.66	39.92	407.36	26.27	268.00	28.07	286.40	29.96	305.72	25.75	262.74	23.13	236.00					
13	Don Yai Hom Municipality	6.47	23.68	335.66	7.23	102.45	9.84	139.53	8.72	113.67	13.49	191.28	22.62	320.65					
14	Sam Phran Municipality	15.65	29.62	1,015.31	16.29	558.35	16.85	577.44	15.84	543.04	11.20	383.94	8.05	276.05					
15	Om Yai Municipality	18.93	38.53	1,597.31	25.19	1,044.55	23.89	990.41	22.31	925.13	17.67	732.67	8.91	369.47					
<b>Total (Baht)</b>				10,175.10		10,406.63		13,843.41		15,130.12		15,999.73		16,390.67					

\*2.19 Baht/Ton/Kilometer (Aungkana, 2007; Chodchai, 2007)

As a result, the total fuel cost for transportation from all municipalities to a candidate area can be computed simply by the summation of the product between the weight of solid waste in each zone and distance to the candidate area. The total fuel cost for transportation was computed six times, each for the existing solid waste landfill, candidate sites 13, 16, 18, 19 and 20 respectively. Table 4.11 shows the results.

From all of the five candidate sites, candidate site 13 gives the minimum total fuel cost for transportation of 4751.89 ton/kilometer or 10,406.63 baht. When site 13 was compared fuel cost for transportation with the existing solid waste landfill location (Tambon Takong) founded that the existing solid waste landfill had a slim advantage over than candidate site 13. Surprisingly, the existing solid waste landfill and candidate site 13 was compared on different criteria. It's founded that candidate site 13 had some advantages over the existing solid waste landfill some aspects according to the comparison in table 4.12. This was because the existing landfill was not selected by considering not enough factors. This is why it was located near the community where soil type, land price and groundwater depth were not favorable as compared to site 13.

**Table 4.12** Comparison of the existing solid waste landfill with new landfill sites

Factors	The existing solid waste landfill (Tambon Takong)	Candidate site 13
		Nakhon Chai Si District, Tambon Bangrakam
Size of area	280,000 m <sup>2</sup>	2,613,993 m <sup>2</sup>
Flood area	Suitable	Suitable
Buffer of urban area	Unsuitable	Suitable
Buffer of road	Suitable	Suitable
Buffer of river	Suitable	Suitable
Soil type	Good	Excellence
Land price	Very Expensive	Good
Groundwater depth	Fair	Excellence
Total fuel cost for transportation	10,175.10 Baht	10,406.63 Baht

Eventually, the most preferred site was identified at Nakhon Chai Si District, Tambon Bangrakam. The size was sufficiently large enough to accommodate solid waste during the next 20 years.

## CHAPTER V

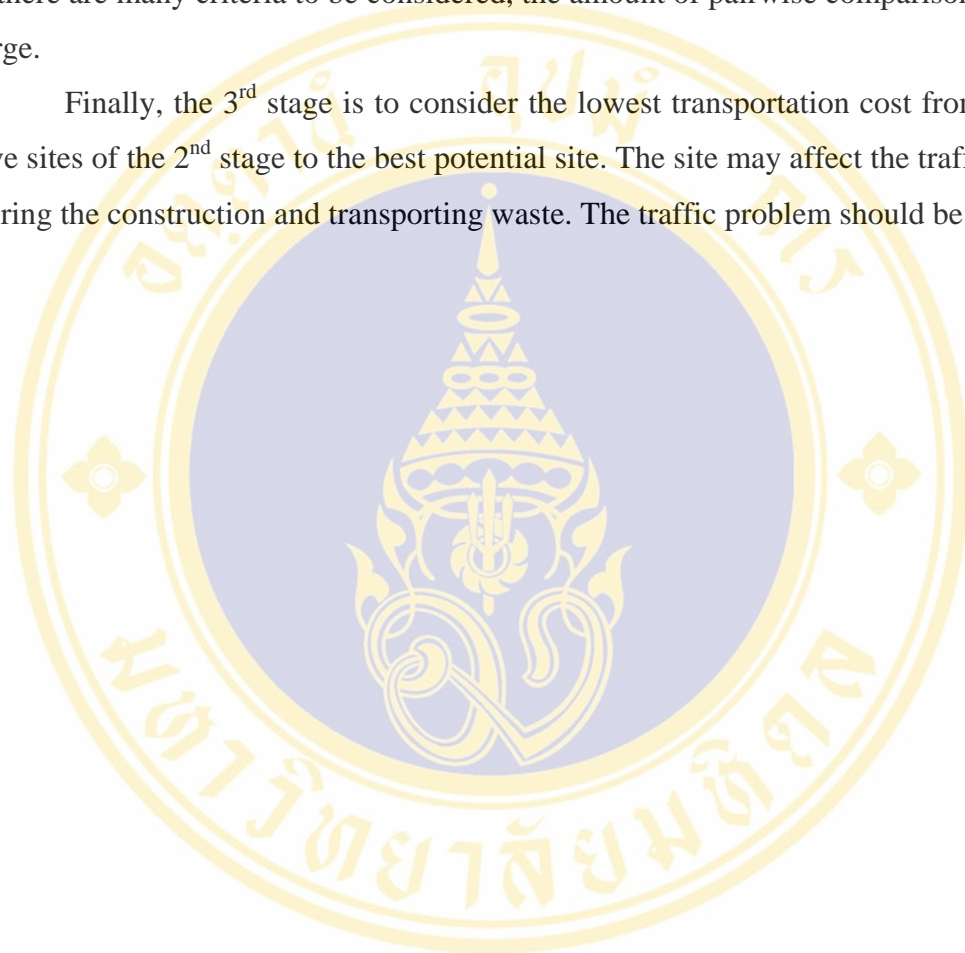
### DISCUSSION

The method proposed in this research differs from the conventional methods of landfill selection in term of factors and steps used. In the first stage, unsuitable landfill sites were screened out from the base map by considering the following factors: flood areas, urban areas and buffer of roads and rivers. This selection takes into account the environment of an area, such as distance from historic sites or important places, potential flood areas, water bodies and urban residential areas in order to prevent odour, noise and nuisance. Another important factor is the slope but because of the flat areas in most part of the province therefore slope wasn't taken into account. After implementing this stage, areas outside the environmental sensitive areas were selected.

The 2<sup>nd</sup> stage was to rank candidate sites obtained from the first stage. Factors used in this stage consist of; soil types land prices and groundwater depth. Landfill has directly impacts on groundwater quality. The landfill sites should be properly constructed in order to avoid polluted water from leaking to as groundwater. There should be observation holes to monitor the leaking so that measure could be made if the leaking is observed. So the chances leachate will be limited. This stage used an Analytical Hierarchy Process (AHP model) to present priority landfill objectives. The advantages of this method are that only two factors of the criteria have to be considered at the same time; it can be implemented on a spreadsheet environment and exported to GIS based decision making procedures. A further advantage of AHP is its stability and flexibility regarding changes within and additions to the hierarchy. On the other hand, the relative importance of evaluation criteria is determined without considering the scales on which the criteria are measured. The AHP method has a consistency ratio (CR) for evaluating the performance. After evaluating all criteria was accepted excepting evaluating of table 4.2. Because of consistency ratio which is fully 100 % is difficult to happen in real life because the situation in real life which influences to satisfaction changes all times (Witoon, 1999). For example, if candidate

site 1 is suitable more than candidate site 2 and also suitable more than candidate site 3. According to continuous principle, candidate site 1 should suitable more than candidate site 3 but the candidate site 3 may suitable more than the candidate site 1 sometimes. It depends on other outside situations etc. Moreover, a disadvantage is that if there are many criteria to be considered, the amount of pairwise comparisons will be large.

Finally, the 3<sup>rd</sup> stage is to consider the lowest transportation cost from the top five sites of the 2<sup>nd</sup> stage to the best potential site. The site may affect the traffic nearby during the construction and transporting waste. The traffic problem should be aware.



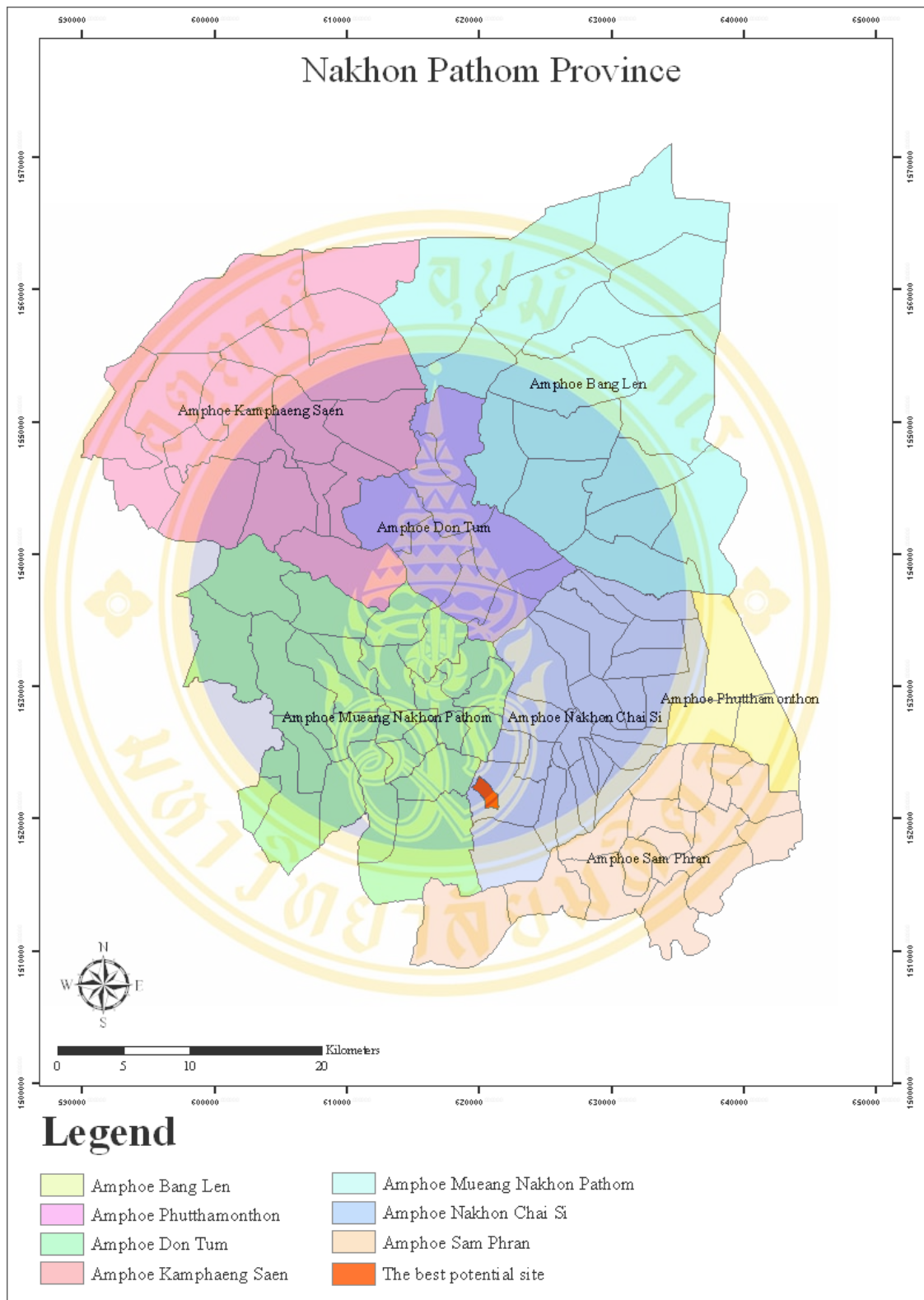
## CHAPTER VI

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Conclusions

The results of the selection for a potential solid waste landfill site for Nakhon Pathom Province, using GIS technique can be concluded as follows.

Realizing that solid waste management is a big issue in Nakhon Pathom Province and that preparation should be taken seriously, this paper had initiated research to analyze the situations. This paper described the methodology and was a case study for identifying the best site for solid waste landfill. Specifically, this paper performed multi-criteria analysis within the GIS environment. The considered criteria included flooded areas, water bodies, urban areas, road and river buffers as well as groundwater depth. The first task was to estimate the amount of solid waste generated over the next 20 years and the required size of landfill to accommodate it. The calculation determined the size of the landfill site is a minimum of 1,328,374 m<sup>2</sup> while the size of the best potential site covers 2,613,993 m<sup>2</sup> or about 1,633.74 Rai. It can be seen that site 13 is sufficiently large enough to store the estimated solid waste over the next 20 years. After this, a proposed three-stage procedure was used where the 1<sup>st</sup> stage is to eliminate flooded areas, water resource, urban, road and river buffers. It can be seen that site 13 wasn't located on an unsuitable area. The 2<sup>nd</sup> stage was to rate the resulting candidate sites using an Analytical Hierarchy Process (AHP model). The final stage was to calculate transportation costs of the top five sites from the 2<sup>nd</sup> stage for the best potential site. As a result, the best potential site has been identified which was located in Nakhon Chai Si District, Tambon Bangrakam as shown in Figure 6. In summary, GIS was proven to be an effective analytical tool to select the most preferable area for solid waste landfill.



**Figure 6** The Best Potential Site

## 6.2 Recommendations for Future Study

6.2.1 The best potential landfill site should have transfer points for Tambon (sub-districts) located far from the best potential landfill site. It is possible that those sites are inconvenient for transport to the landfill site. Consequently, the best potential landfill site should have transfer points to support the volume of solid waste volume from those Tambon.

6.2.2 The committee of the governmental administrators and community representatives is very importance. The final decision should also take into consideration the social aspect in order to reduce negative impacts on the community near the candidate site.

6.2.3 The landfill sites proposed here, will not last for ever and continued studies into possible new sites and more inadvertently on how to reduce waste are vital. Also other methods of dealing with solid waste management suitable for Nakhon Pathom Province should be investigated.

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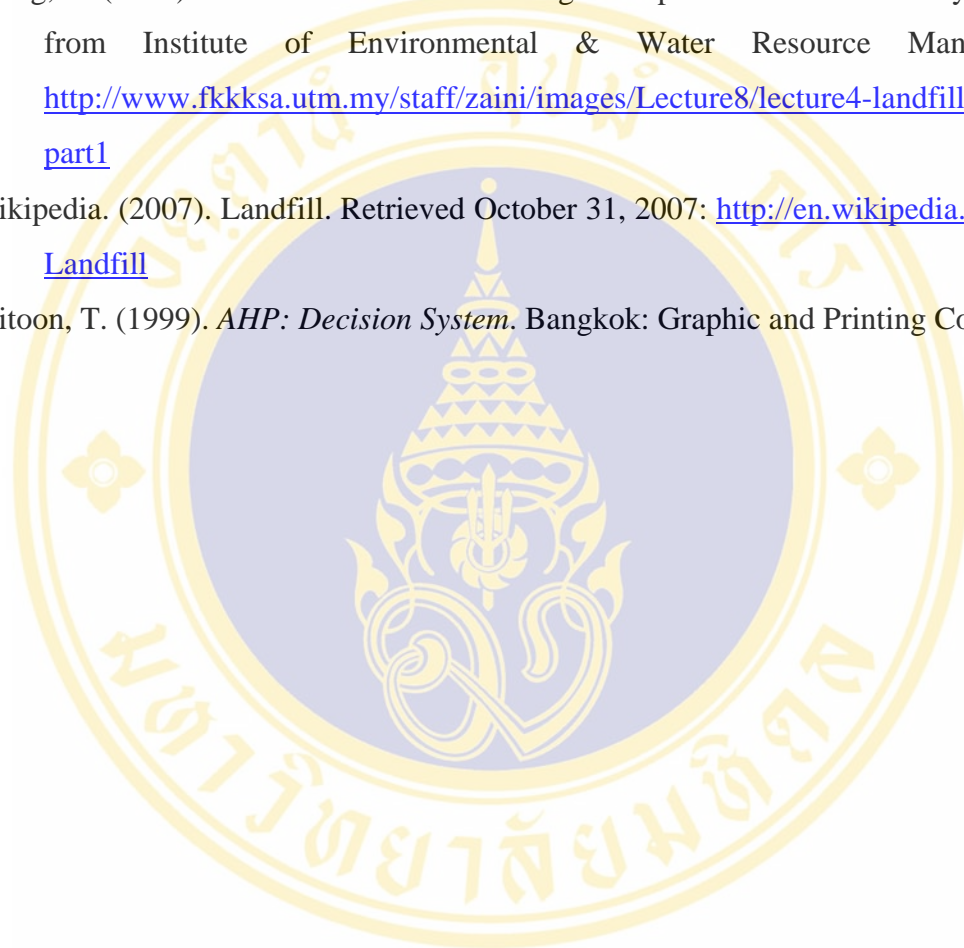
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## APPENDIX A

Table A Result from Screening of Potential Areas for Landfill Sites

ID	AMPHOE	TAMBON	AREA (m <sup>2</sup> )	
1	Amphoe Bang Len	Bua Pak Tha	5074791.32	Acceptable
2		Bua Pak Tha	167657.34	Unacceptable
3		Bua Pak Tha	128790.58	Unacceptable
4		Bang Luang	56913.61	Unacceptable
5		Bang Luang	1045709.10	Unacceptable
6		Don Toom	338.83	Unacceptable
7		Don Toom	259.63	Unacceptable
8		Don Toom	908.82	Unacceptable
9		Don Toom	926.51	Unacceptable
10		Krong Nok Kra Tung	763188.11	Unacceptable
11		Krong Nok Kra Tung	162079.04	Unacceptable
12		Krong Nok Kra Tung	5803.51	Unacceptable
13		Krong Nok Kra Tung	201726.66	Unacceptable
14		Krong Nok Kra Tung	664326.80	Unacceptable
15		Narapirom	148924.55	Unacceptable
16		Narapirom	1748.86	Unacceptable
17		Narapirom	3803.73	Unacceptable
18		Narapirom	19198.03	Unacceptable
19		Narapirom	277832.69	Unacceptable
20		Bang Pla	202.60	Unacceptable
21		Bang Pla	11039.89	Unacceptable
22		Lam Pa Ya	7.07	Unacceptable
23		Lam Pa Ya	1861384.72	Acceptable
24		Lam Pa Ya	8137.14	Unacceptable
25		Lam Pa Ya	381.63	Unacceptable
26		Lam Pa Ya	391945.18	Unacceptable
27		Lam Pa Ya	43585.25	Unacceptable
28		Lam Pa Ya	15323.66	Unacceptable
29		Lam Pa Ya	1680.54	Unacceptable
30		Bangrakam	83.04	Unacceptable
31		Bangrakam	7827.67	Unacceptable
32		Bangrakam	1119521.22	Unacceptable
33		Bangrakam	192.58	Unacceptable
34		Bangrakam	5936.35	Unacceptable
35		Bangrakam	80228.42	Unacceptable
36		Bangrakam	1292.18	Unacceptable
37		Bangrakam	1749.98	Unacceptable
38	Amphoe Don Tum	Lam Look Bua	71888.80	Unacceptable
39		Lam Huy	830024.06	Unacceptable
40		Don Puttha	97041.52	Unacceptable

ID	AMPHOE	TAMBON	AREA (m <sup>2</sup> )	
41	Amphoe Don Tum	Don Puttha	22.40	Unacceptable
42		Huay Pra	21793.09	Unacceptable
43		Huay Pra	5466.89	Unacceptable
44		Huay Pra	15143.31	Unacceptable
45		Huay Pra	37281.66	Unacceptable
46		Huay Pra	4260.65	Unacceptable
47		Amphoe Kamphaeng Saen	Kam Peang San	50502.10
48	Don Koi		220843.38	Unacceptable
49	Tung Kwang		28.08	Unacceptable
50	Huay Mong Thong		3844385.80	Acceptable
51	Huay Kwang		844330.03	Unacceptable
52	Huay Muang		505264.71	Unacceptable
53	Huay Muang		92.63	Unacceptable
54	Huay Muang		31.84	Unacceptable
55	Huay Muang		94.61	Unacceptable
56	Huay Muang		51.70	Unacceptable
57	Kra Tub		1732468.81	Acceptable
58	Kra Tub		291345.76	Unacceptable
59	Kra Tub		3536.87	Unacceptable
60	Kra Tub		3108464.08	Acceptable
61	Srapattana		21361.77	Unacceptable
62	Srapattana		22992.34	Unacceptable
63	Srapattana		255651.79	Unacceptable
64	Srapattana		335.70	Unacceptable
65	Srapattana		116904.76	Unacceptable
66	Sra Si Mum		708047.19	Unacceptable
67	Sra Si Mum		628038.19	Unacceptable
68	Sra Si Mum		645.04	Unacceptable
69	Sra Si Mum		64048.37	Unacceptable
70	Sra Si Mum		197005.58	Unacceptable
71	Nong Kra Tum		624797.47	Unacceptable
72	Nong Kra Tum		22544.84	Unacceptable
73	Nong Kra Tum		691113.01	Unacceptable
74	Nong Kra Tum		159597.91	Unacceptable
75	Nong Kra Tum		17497.41	Unacceptable
76	Tung Look Nok		885499.24	Unacceptable
77	Tung Look Nok		155.86	Unacceptable
78	Tung Look Nok		796993.89	Unacceptable
79	Tung Look Nok		895440.94	Unacceptable
80	Tung Look Nok		1897407.77	Acceptable
81	Tung Bua		228364.63	Unacceptable
82	Tung Bua		615.31	Unacceptable
83	Rangpikul		107060.51	Unacceptable
84	Rangpikul		210789.73	Unacceptable

ID	AMPHOE	TAMBON	AREA (m <sup>2</sup> )	
85	Amphoe Muang	Mab Kae	319714.05	Unacceptable
86		Tanonkad	1712902.92	Acceptable
87		Wang Yen	515873.98	Unacceptable
88		Nong Ngu Learn	1410.89	Unacceptable
89		Nong Ngu Learn	1822206.58	Acceptable
90		Nong Ngu Learn	1276801.52	Unacceptable
91		Nong Ngu Learn	36708.04	Unacceptable
92		Nong Ngu Learn	272.92	Unacceptable
93		Nong Ngu Learn	454880.99	Unacceptable
94		Nong Ngu Learn	17394.90	Unacceptable
95		Tub Luang	50660.52	Unacceptable
96		Tub Luang	1817331.67	Acceptable
97		Ban Yang	903666.83	Unacceptable
98		Ban Yang	342738.60	Unacceptable
99		Ban Yang	118476.82	Unacceptable
100		Ban Yang	6458.23	Unacceptable
101		Ban Yang	99712.58	Unacceptable
102		Ban Yang	6976.51	Unacceptable
103		Ban Yang	1308.66	Unacceptable
104		Ban Yang	135184.77	Unacceptable
105		Ban Yang	8569.18	Unacceptable
106		Sra Ka Tiam	1462.58	Unacceptable
107		Sra Ka Tiam	2931012.94	Acceptable
108		Sra Ka Tiam	31.43	Unacceptable
109		Bang Kaem	4272163.83	Acceptable
110	Bang Kaem	419546.66	Unacceptable	
111	Don Yai Hom	1332342.18	Acceptable	
112	Don Yai Hom	106561.56	Unacceptable	
113	Don Yai Hom	10424.31	Unacceptable	
114	Don Yai Hom	4716876.47	Acceptable	
115	Don Yai Hom	4715315.15	Acceptable	
116	Amphoe Nakorn Chai si	Bang Pra	382.20	Unacceptable
117		Sam Pa Tuan	144116.52	Unacceptable
118		Tai Ya Was	487975.92	Unacceptable
119		Bang Kaew	894662.87	Unacceptable
120		Bang Kaew Fa	3.87	Unacceptable
121		Bang Kaew Fa	4730.69	Unacceptable
122		Bang Kaew Fa	4248.08	Unacceptable
123		Watlamud	126286.95	Unacceptable
124		Watlamud	432912.83	Unacceptable
125		Srimahapho	368755.05	Unacceptable
126		Srimahapho	292720.59	Unacceptable
127		Srimahapho	423963.24	Unacceptable
128		Srimahapho	10069.05	Unacceptable
129		Srimahapho	8627.24	Unacceptable
130		Srimahapho	31.07	Unacceptable
131		Huay Plu	11063.34	Unacceptable
132		Huay Plu	5.96	Unacceptable
133		Huay Plu	1166.75	Unacceptable
134		Lam Bua	16261.42	Unacceptable
135		Lam Bua	83591.02	Unacceptable

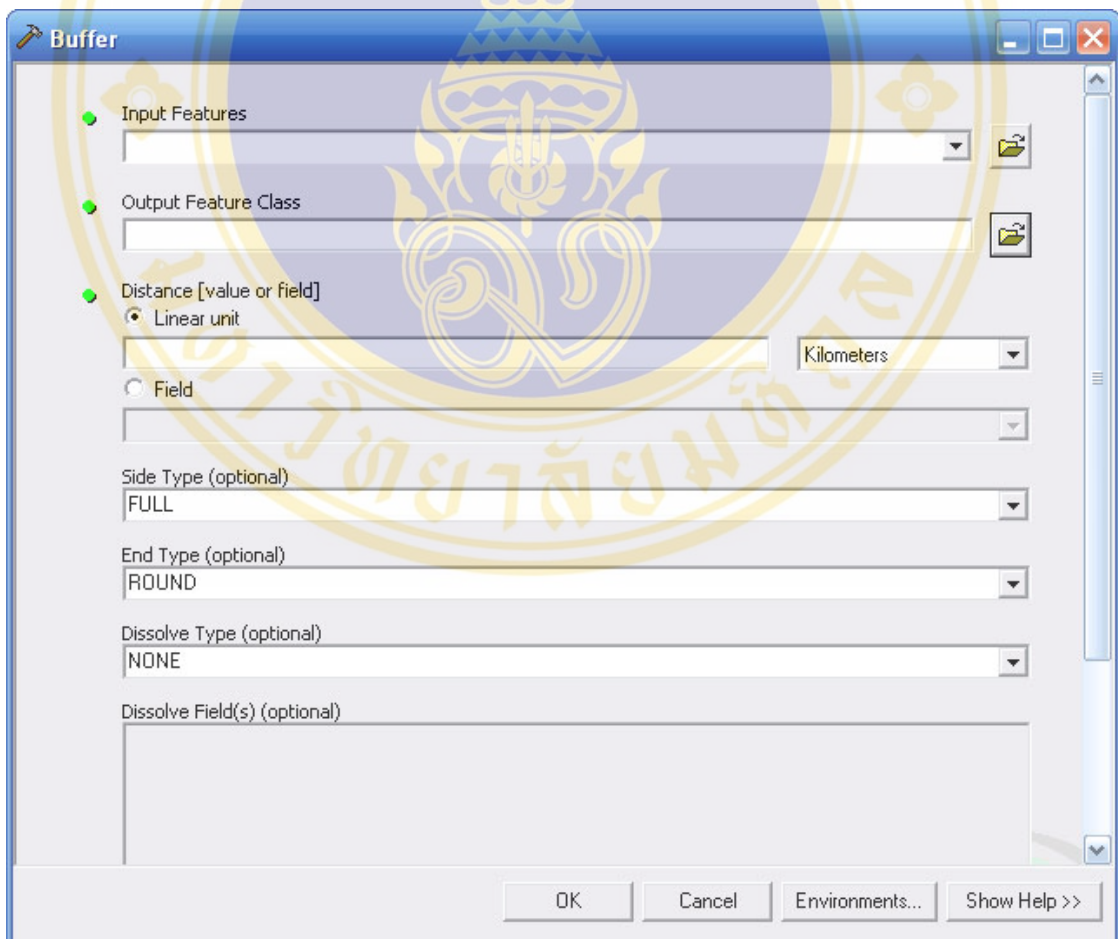
	AMPHOE	TAMBON	AREA (m <sup>2</sup> )	
136	Amphoe Nakorn Chai si	Lam Bua	257851.27	Unacceptable
137		Lan Tak Fa	1257230.21	Unacceptable
138		Lan Tak Fa	8.57	Unacceptable
139		Lan Tak Fa	49471.68	Unacceptable
140		Lan Tak Fa	1710.79	Unacceptable
141		Lan Tak Fa	127333.39	Unacceptable
142		Lan Tak Fa	4.24	Unacceptable
143		Don Fak	14234.93	Unacceptable
144		Don Fak	2587.37	Unacceptable
145		Don Fak	87063.72	Unacceptable
146		Don Fak	1078.91	Unacceptable
147		Don Fak	1575.19	Unacceptable
148		Don Fak	30998.98	Unacceptable
149		Don Fak	27026.03	Unacceptable
150		Don Fak	10784.55	Unacceptable
151		Don Fak	765.37	Unacceptable
152		Don Fak	1062.67	Unacceptable
153		Wat Sam Rong	3284.66	Unacceptable
154		Wat Sam Rong	57248.32	Unacceptable
155		Ta Kra Chup	183606.46	Unacceptable
156	Ta Kra Chup	11621.48	Unacceptable	
157	Bangrakam	2613993.76	Acceptable	
158	Bangrakam	349433.96	Unacceptable	
159	Kok Pra J-Dee	4985.81	Unacceptable	
160	Kok Pra J-Dee	13196181.79	Acceptable	
161	Amphoe Phutthamonthon	Salava	31688.16	Unacceptable
162		Mahasawad	529662.27	Unacceptable
163		Mahasawad	35208.24	Unacceptable
164		Mahasawad	27432.38	Unacceptable
165		Mahasawad	43529.49	Unacceptable
166		Mahasawad	1602.95	Unacceptable
167		Hom Kred	481152.60	Unacceptable
168		Bang Terv	465994.17	Unacceptable
169		Klong Mai	1635315.92	Acceptable
170		Raiking	277550.51	Unacceptable
171	Sampran	213962.47	Unacceptable	
172	Klong Jin Da	14374436.75	Acceptable	
173	Amphoe Sam Pharn	Song Ka Nong	915649.68	Unacceptable
174		Song Ka Nong	68520.07	Unacceptable
175		Song Ka Nong	248773.59	Unacceptable
176		Tha Talad	2772.40	Unacceptable
177		Tha Talad	66290.58	Unacceptable
178		Bang Chang	8204598.60	Acceptable
179		Bang Chang	90335.92	Unacceptable
180		Ban Mai	1004270.05	Unacceptable
181		Ban Mai	180114.08	Unacceptable
182		Ban Mai	8923.40	Unacceptable
183		Taladjinda	6670537.17	Acceptable
184	Taladjinda	279184.59	Unacceptable	

## APPENDIX B

### CREATE BUFFER POLYGON

To create a new feature class of buffer polygon around specified Input Features. Features can be polygons (Land-Use, Water Resources), lines (Roads, Rivers), or points. Creating buffer polygon can be described as follow:

Click Analysis tool on ArcToolbox then click Proximity, choose Buffer. You can see Buffer Window.



**Figure B.1** Buffer Window

**Input Features:** The feature layer or feature class to be buffered.

**Output Feature Class:** The feature class to contain the resulting polygons.

**Distance:** Choose linear unit, the distance used to create buffer zones around Input Features. Either a value or a numeric field can be used to provide buffer distances. Distance unit is kilometers.

**Side Type:** Choose “FULL”, a buffer will be generated on both sides of the line. This is the default.

**End Type:** Choose “ROUND”, end will be in the shape of a half circle. This is the default.

**Dissolve Type:** Choose “NONE”, individual buffer for each feature is maintained, regardless of overlap. This is the default.

Then, Click OK.

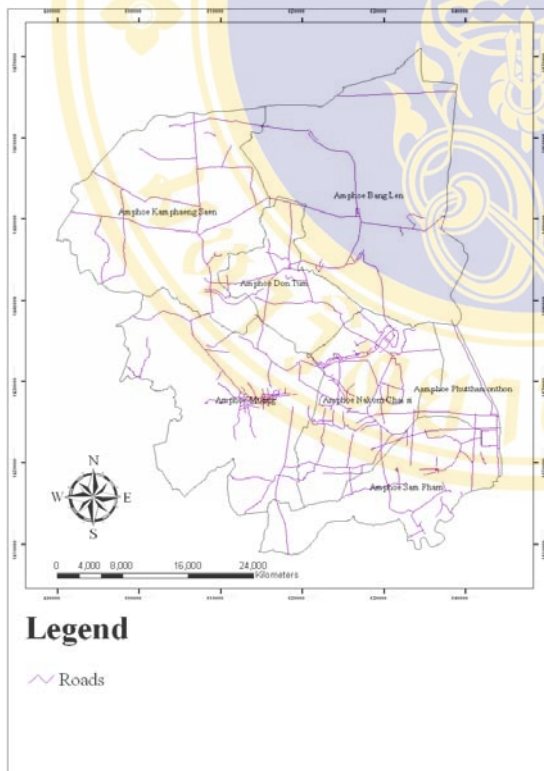


Figure B.2 Input

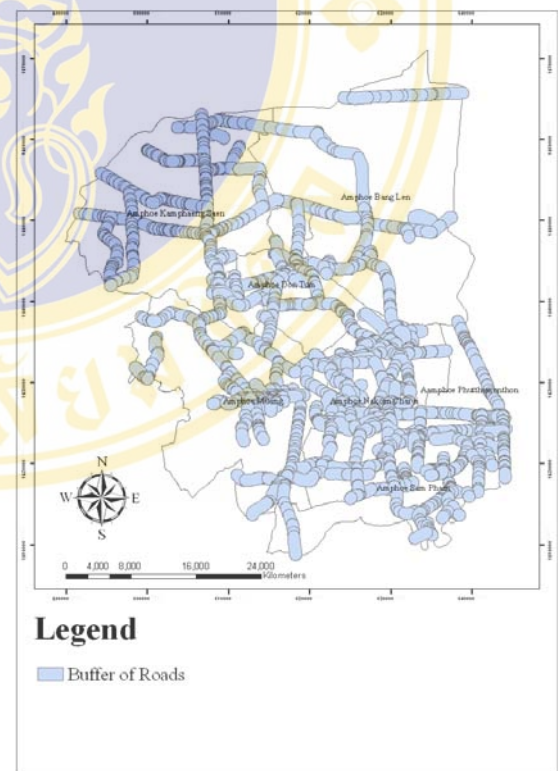


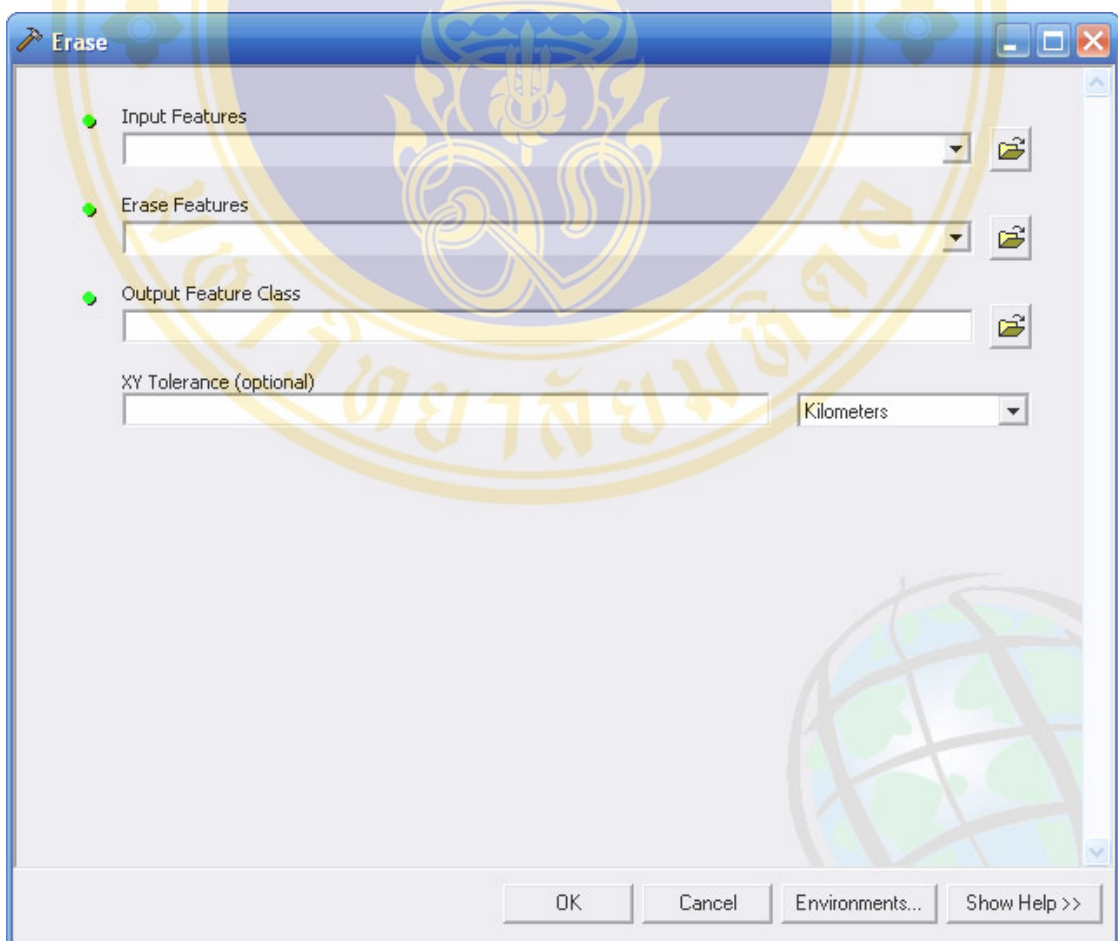
Figure B.3 Output

## APPENDIX C

### ERASING

To create a feature class by overlaying the Input Features with the polygons of the Erase Features. Only those portions of the Input Features falling outside the Erase Features outside boundaries are copied to the Output Feature Class. Erasing polygon can be described as follow:

Click Analysis tool on ArcToolbox then click Overlay, choose Erase. You can see Erase Window.

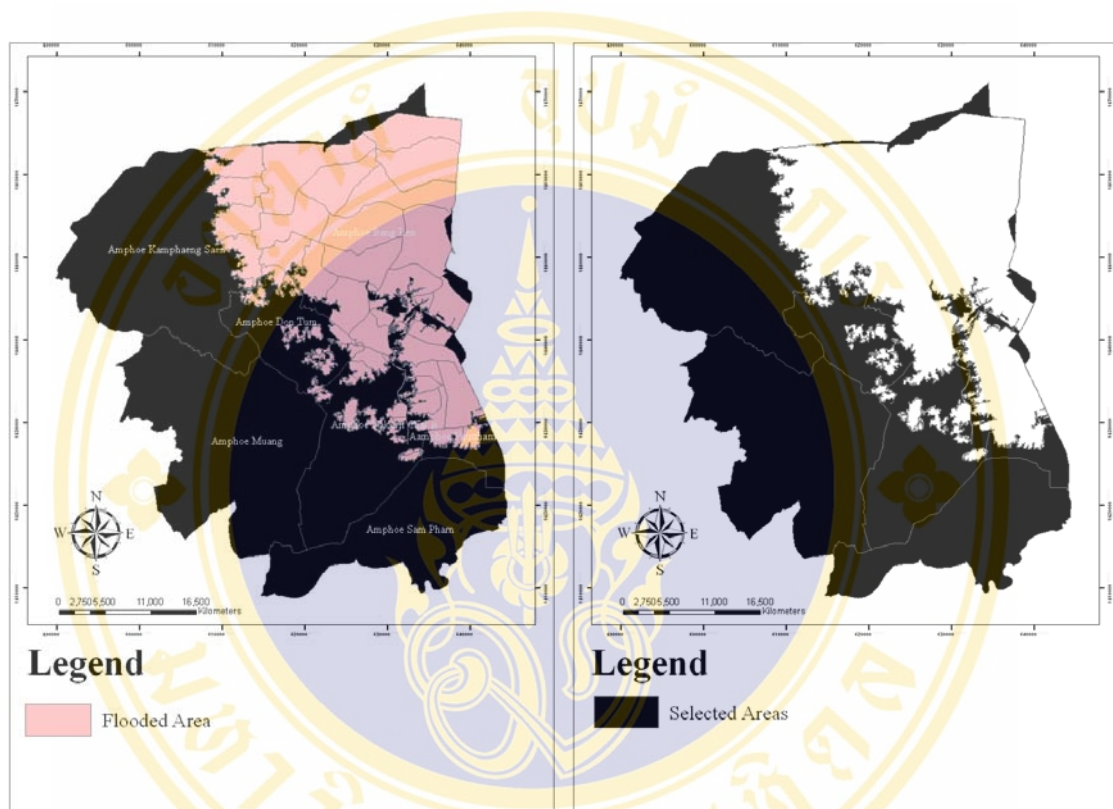


**Figure C.1** Erase Window

**Input Features:** The input feature class or layer.

**Erase Features:** The features whose outer polygon defines the erasing area.

**Output Features Class:** The feature class that will contain only those input features that lie outside the erase features area.



**Figure C.2** Before Erasing

**Figure C.2** After area is erased

## APPENDIX D

### FINDING THE BEST ROUTE

Creating a route can mean finding the quickest, shortest, or most scenic route, depending on the impedance chosen. This research chose to find the quickest base on hierarchy route. The first should manage with attribute of route's shapefile. At least, shapefile's attribute should have speed, meters and minutes attribute as shown in Figure D.1. The time that was used in this stage can calculate from equation below.

$$\text{Minutes} = \frac{60(\text{Meters})}{1000(\text{Speed})}$$

Where

*Minutes* attribute is time of an edge, *Meters* attribute is length of an edge, *Speed* attribute is assumed to be 80, 70, 60 kilometers/hour require for 1) main roads 2) sub roads and 3) others respectively.

So 80, 70 and 60 kilometers/hour were obtained from the Traffic Land Act 2522 B.E., It defined that Trucks which totally weigh over 1,200 kilograms or buses are driven in Bangkok, Pattaya or municipality district. The truck cannot be driven over 60 kilometers/hour in these districts. Moreover, the trucks cannot be driven over 80 kilometers/hour in outside these districts.

TRANS_	TRANS_ID	TRANS	TRANS_TYP	SPEED	Meters	Minutes
17	4965	9999	2	60	2287.59127	2.287591
19	4966	9999	2	60	1501.65179	1.501652
20	4967	9999	2	60	192.164724	.192165
21	4968	9999	2	60	1065.36192	1.065362
23	4969	9999	2	60	1326.63470	1.326635
24	4970	9999	2	60	1127.24289	1.127243
26	4971	9999	2	60	549.443359	.549443
27	4972	9999	2	60	1530.62852	1.530629
30	4973	9999	2	60	1265.87379	1.265874
32	4974	9999	2	60	928.701126	.928701
34	4976	9999	2	60	1107.94238	1.107942

**Figure D.1** Minimum attribute for finding the best route

Then, create a network dataset from wizard in ArcCatalog. The ArcCatalog can manage geographic data type for example; line, shapefile and geodatabase. The methodology to find the best route is as follow:

1. Start ArcCatalog and go to the folder where you will create a new dataset. Right mouse click at shapefile and choose “New Network Dataset...” as shown in Figure D.2.

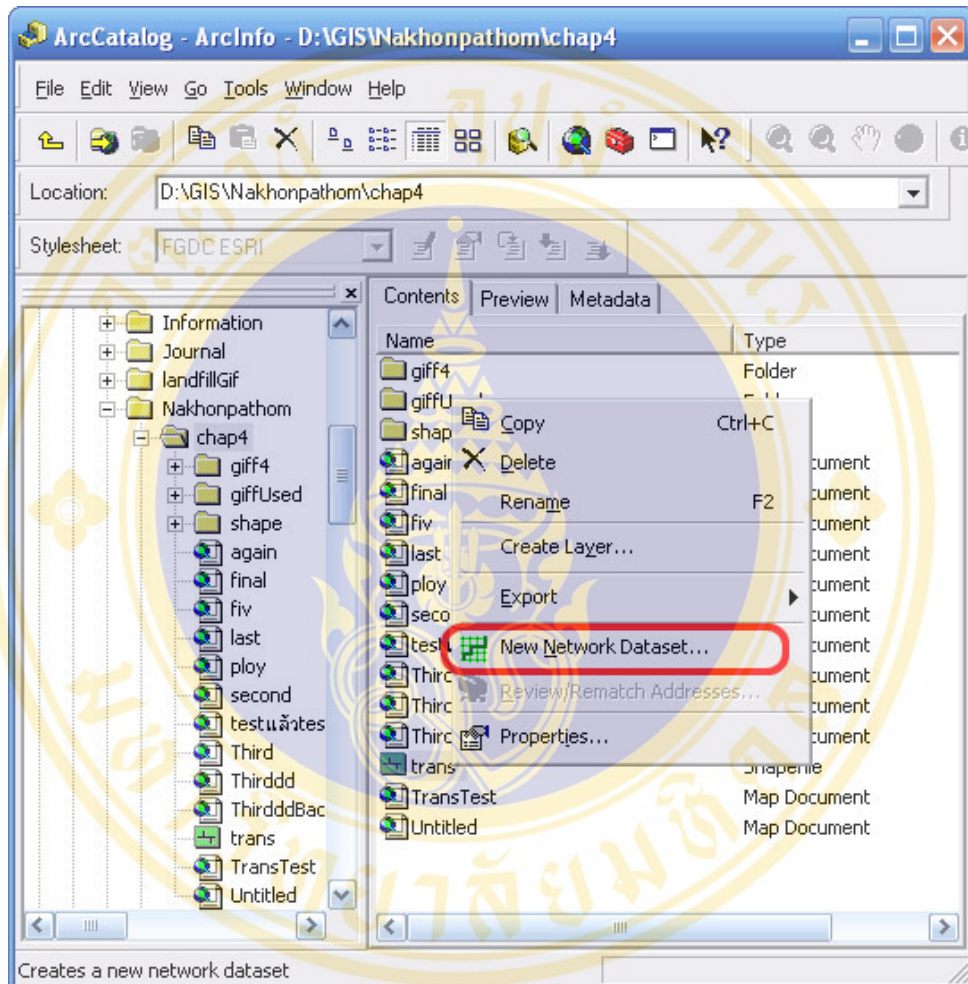
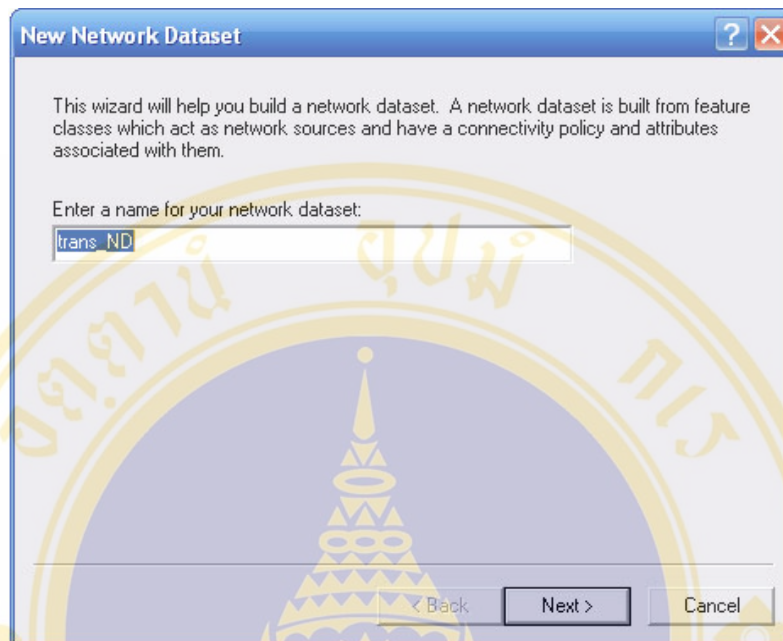


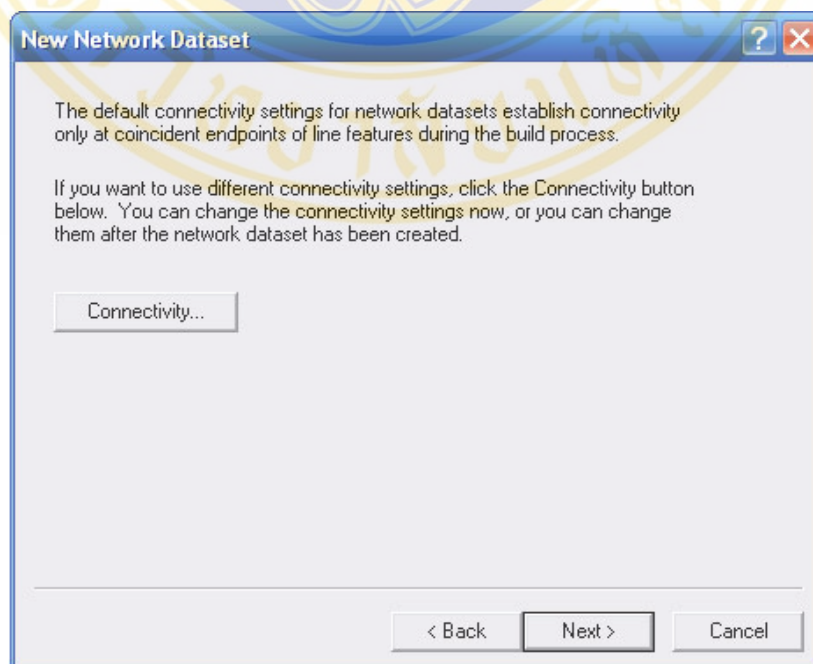
Figure D.2 New Network Dataset

2. Enter a name for your network dataset.



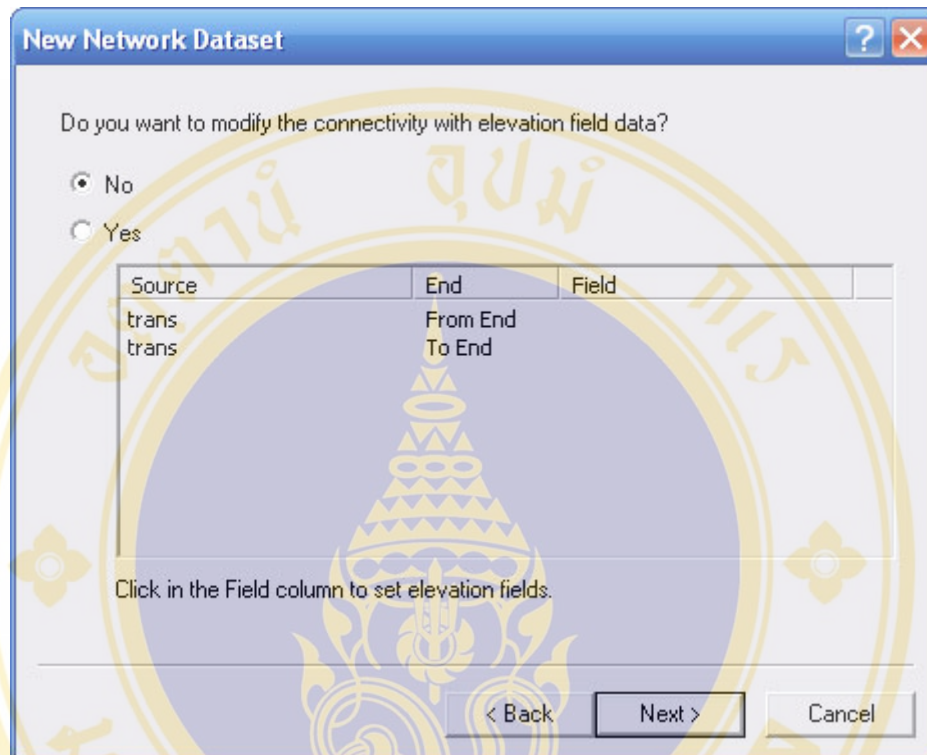
**Figure D.3** Network Dataset Wizard Mode

3. Click “Next”



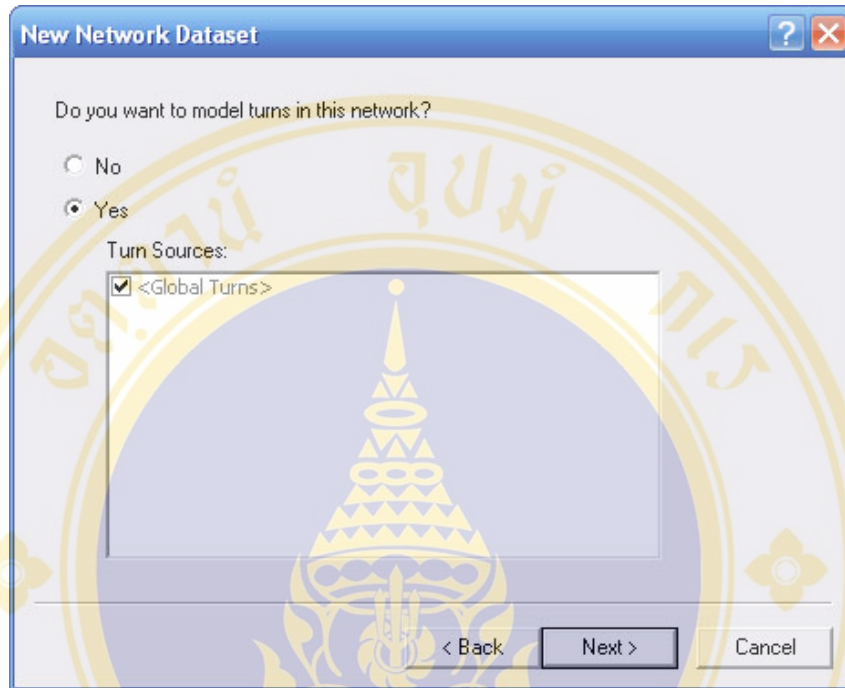
**Figure D.4** Connectivity

4. Choose “No” then click “Next”. “Yes”, defines route’s height such as bridge or express way where they connect together.

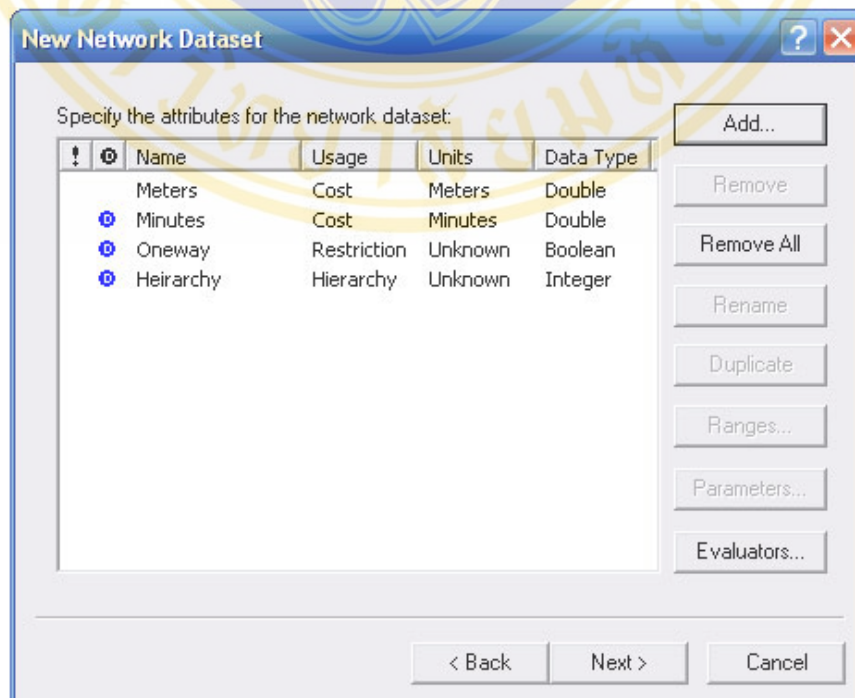


**Figure D.5** Set elevation fields

5. Choose “Yes”, global turns function is used to define several turn types then click Next button to define properties of Network Dataset (see Figure D.7).



**Figure D.6** To define Turn Sources



**Figure D.7** Definition of New Network Dataset’s properties

The field evaluator assigns values to a network attribute from a field for each network source. The four types of evaluators are described below.

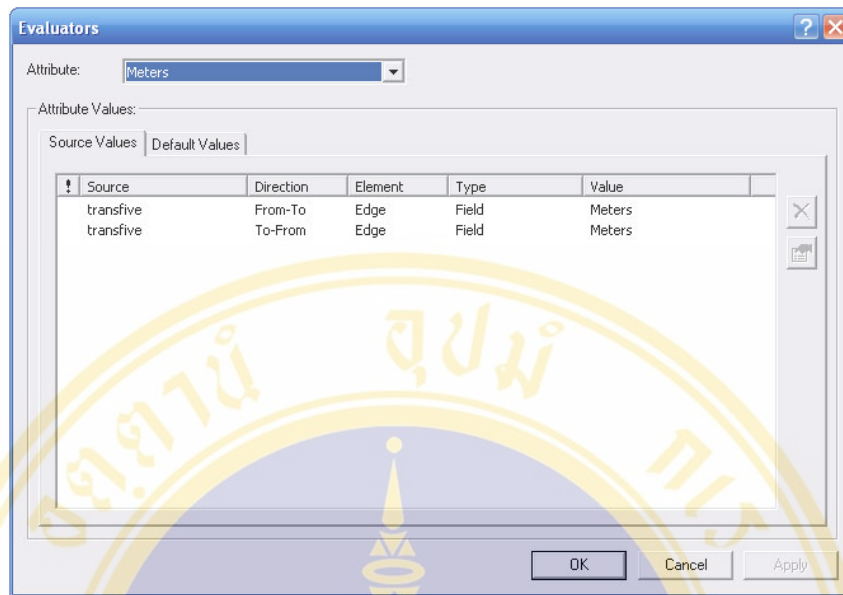
**1. Cost:** Certain attributes are used to measure and model impedances, such as travel time (transit time on a street) or demand (the volume of garbage picked up on a street). These attributes are apportioned along an edge; that is, they are divided proportionately along the length of an edge.

**2. Descriptors:** Descriptors are attributes that describe characteristics of the network or its elements. Unlike costs, descriptors are not apportioned. This means that the value does not depend on the length of the edge element. For example, the number of lanes is an example of a descriptor on a street network. Speed limit of streets is another descriptor attribute for a street network. Although it is not a cost attribute and cannot be used as impedance, it can be used in conjunction with distance to create a cost attribute (for example, drive time) that can be used as impedance.

**3. Restrictions:** Restrictions can be identified for particular elements, such that during an analysis, restricted elements cannot be traversed. For example, one-way streets can be modeled with a restriction attribute, so they can only be traversed from one end to another and not in the reverse direction. In all cases, a restriction attribute is defined using a Boolean data type.

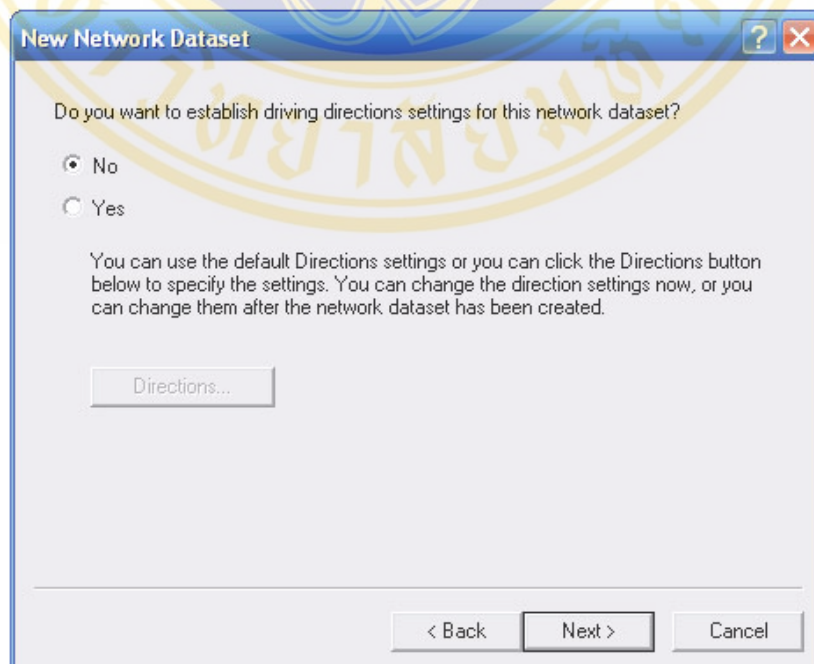
**4. Hierarchy:** Hierarchy is the order or grade assigned to network elements. A street network might have a road class hierarchy for separating interstates from local roads. In finding a shortest path from one point to another, the user preference to take or avoid interstates can be modeled through a hierarchy.

Definition of network 'dataset' properties can be defined by clicking Evaluators button as shown in Figure D.8.



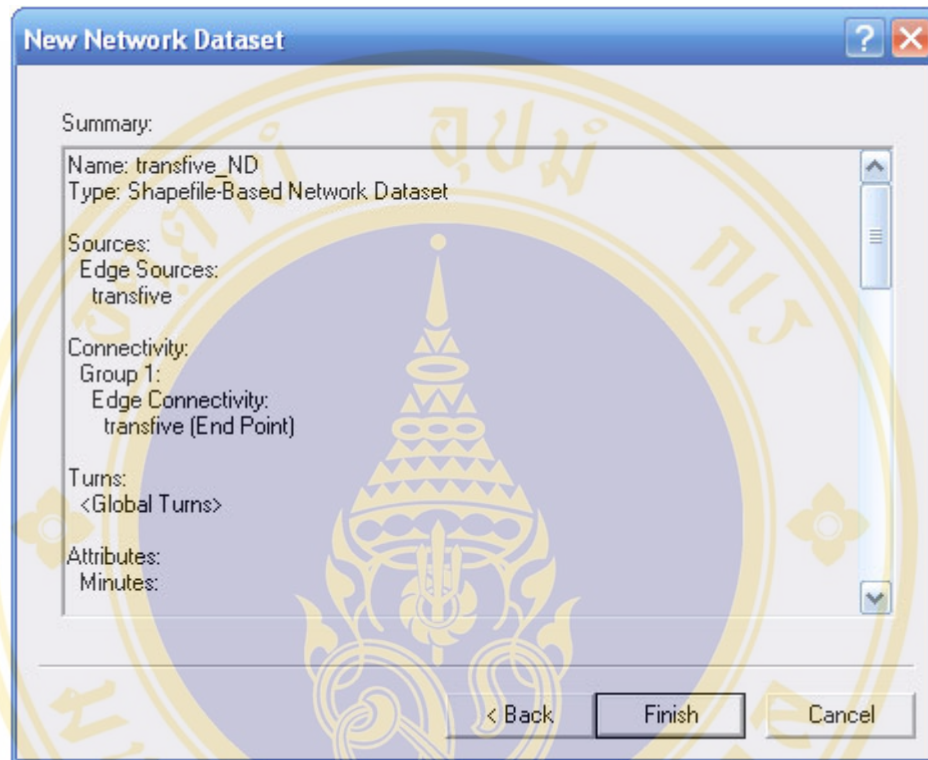
**Figure D.8** Evaluators

You can see meters attribute is defined from “Meters” field name. Meters attribute store length. Unit is meters. When we customize all attributes finish. We can see “establish driving direction setting” window (see Figure D.9).





**Figure D.9** Establish Driving Directions Setting

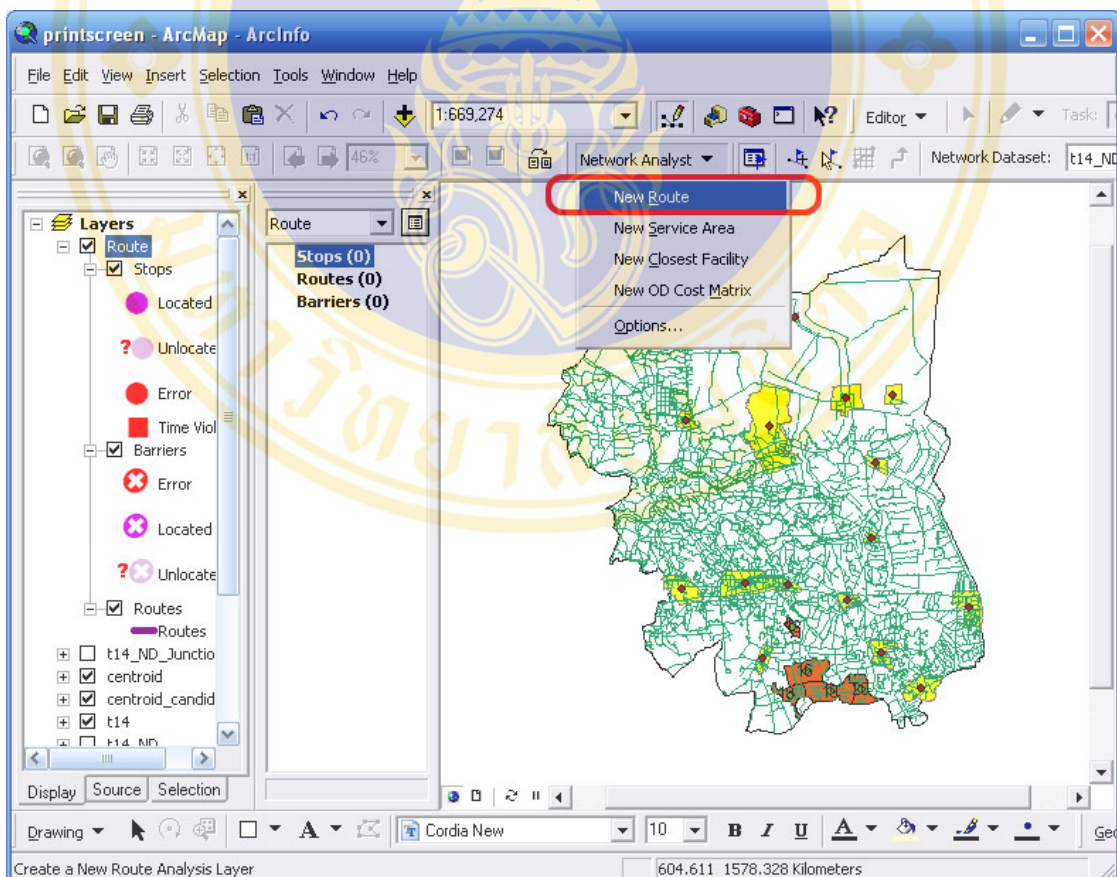
7. When we define value in Network dataset finished. You can see review the network dataset summary output (as shown in Figure D.10) before create Network Dataset. Click Finish. Click Yes to build the network dataset.



**Figure D.10** Summary

## Network Analysis in ArcMap

1. Start ArcMap.
2. Click the Add Data button .
3. Navigate to the network dataset location.
4. Click the network dataset and click Add.
5. If the Network Analyst Window is not already open, on the Network Analyst toolbar, click the Network Analyst Window button .
6. On the Network Analyst toolbar, click the Network Analyst dropdown menu and click New Route. The Network Analyst Window now contains empty lists of stops, routes, and barriers categories. Additionally, the table of contents contains a new route analysis layer.



**Figure D.11** New Route

7. Route Layer will appear as shown in Figure D.12.

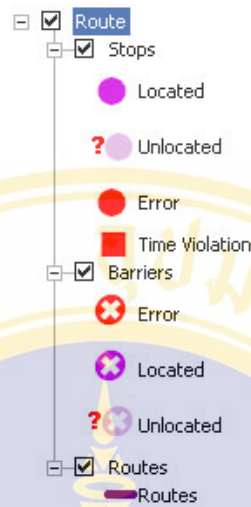



Figure D.12 Route Layer

8. In the Network Analyst Window, click Stops. On the Network Analyst toolbar, click the Create Network Location tool . Click the locations on the display where you want to add stop locations. For example Transportation from Sam-Ngam to Site 13 (see Figure D.13).

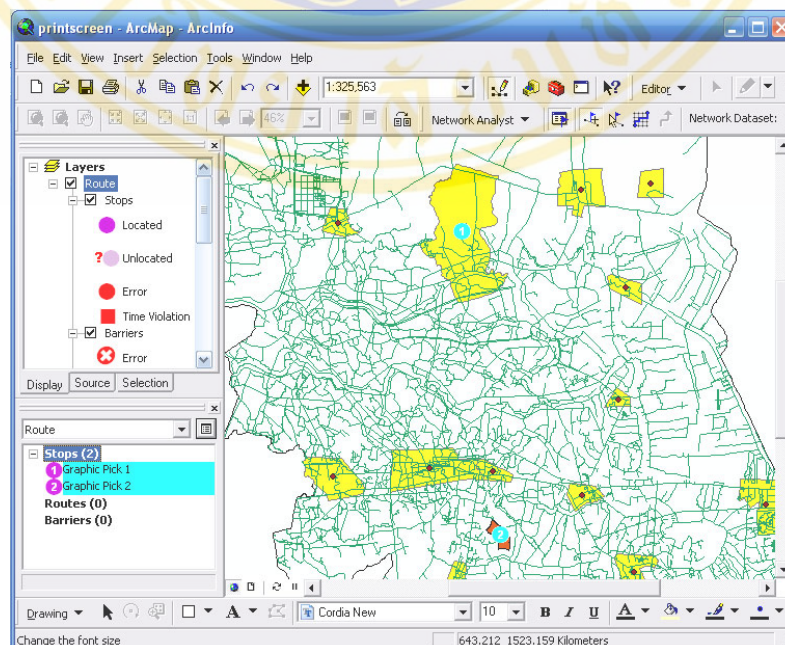
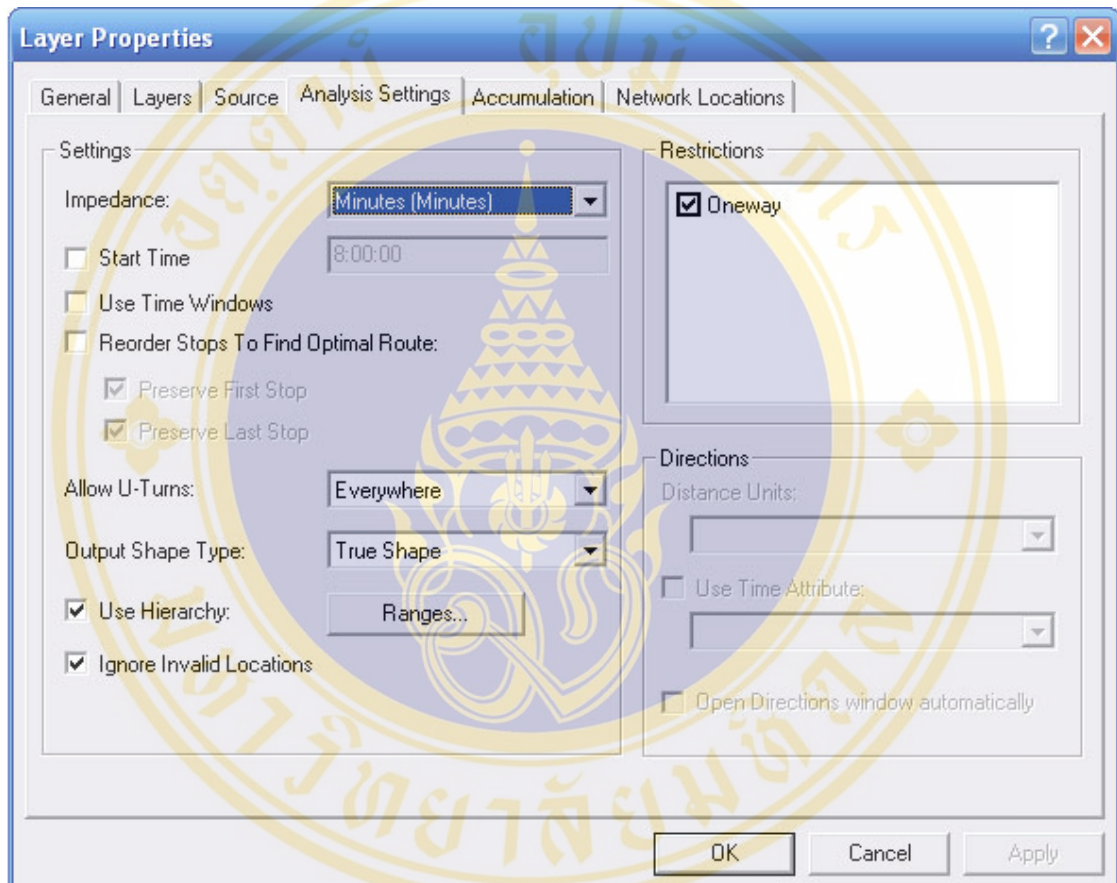


Figure D.13 Transportation from Sam-Ngam to Site 13

9. If you need to adjust a stop location, on the Network Analyst toolbar, click the Select/Move Network Location tool .

10. In the table of contents, right-click the Route layer and click Properties (or click at  button).

11. Click the Analysis Settings tab.



**Figure D.14** Analysis Setting

12. Set the route properties to be used in the analysis. We can define other value as follow:

**Impedance:** Any cost attribute can be chosen as the impedance, which is minimized while determining the route. For instance, choosing the Minutes attribute results in the quickest route.

**Allow U-Turns:** While calculating a route, Network Analyst can allow U-turns everywhere, nowhere, or only at dead ends. In this case choose everywhere

**Output Shape Type:** The results of route analysis can be represented by the true shape, a straight line, or none.

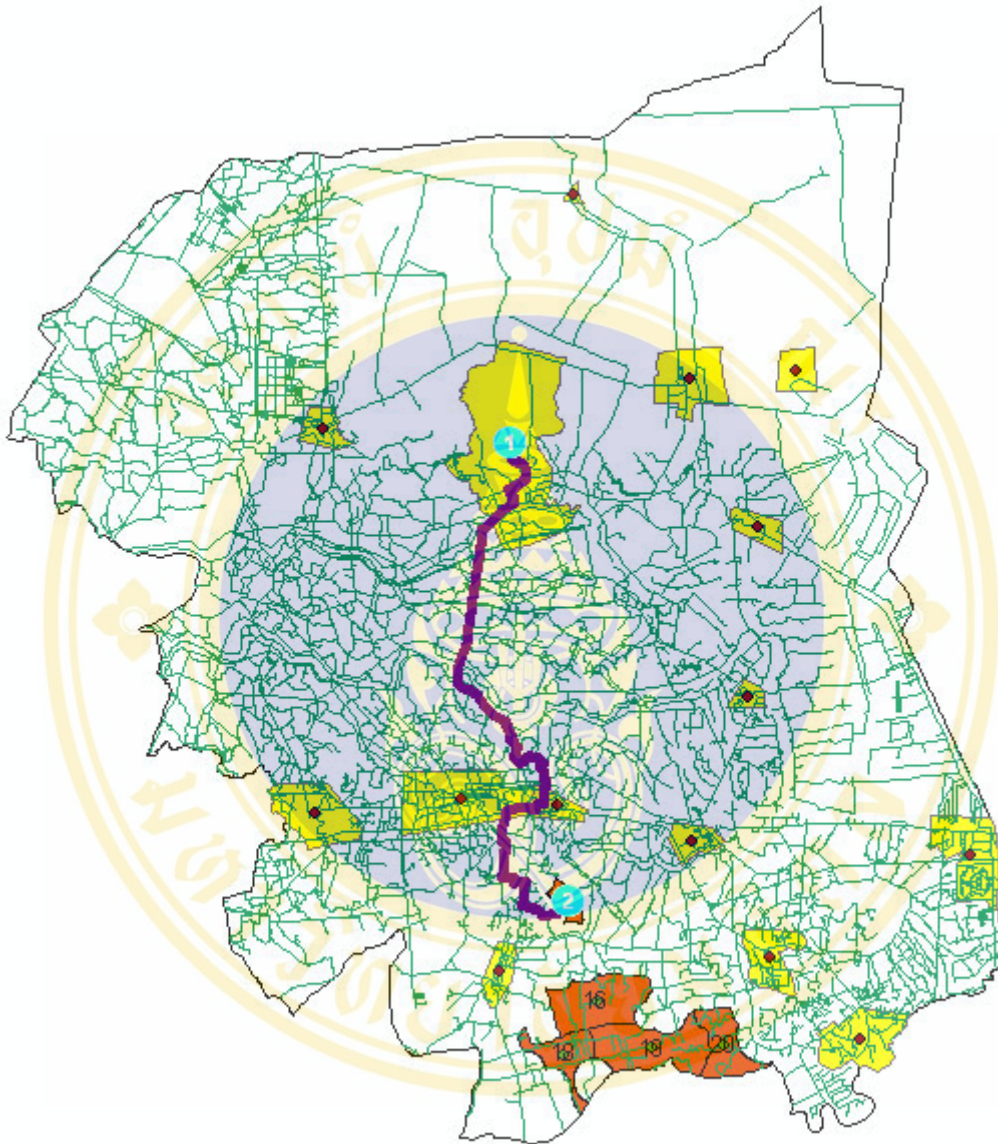
**Use Hierarchy:** We can create a route that favors the hierarchy of the network. The first step to creating a route using a hierarchy is to have a network dataset that has a hierarchy. This hierarchy is stored as a network attribute. The hierarchy attribute reclassifies the hierarchy classes of edge sources to three ranks:

- Primary roads, which have the highest rank—for example, freeways and limited access highways.
- Secondary roads, which have the middle rank—for example, major roads and arterial roads.
- Local roads, which have the lowest rank—for example, collectors and local streets.

**Ignore Invalid Locations:** This allows you to ignore unlocated stops and find the route between located stops only. If this option is not used, you cannot find the best route until all stops are located.

**Restrictions:** You can choose which restriction attributes should be respected for calculating the route. Restrictions, such as Oneway, should be used while finding the quickest route on streets. If your network dataset contains additional restriction attributes, such as weight limit or height limit, those could be used as well.

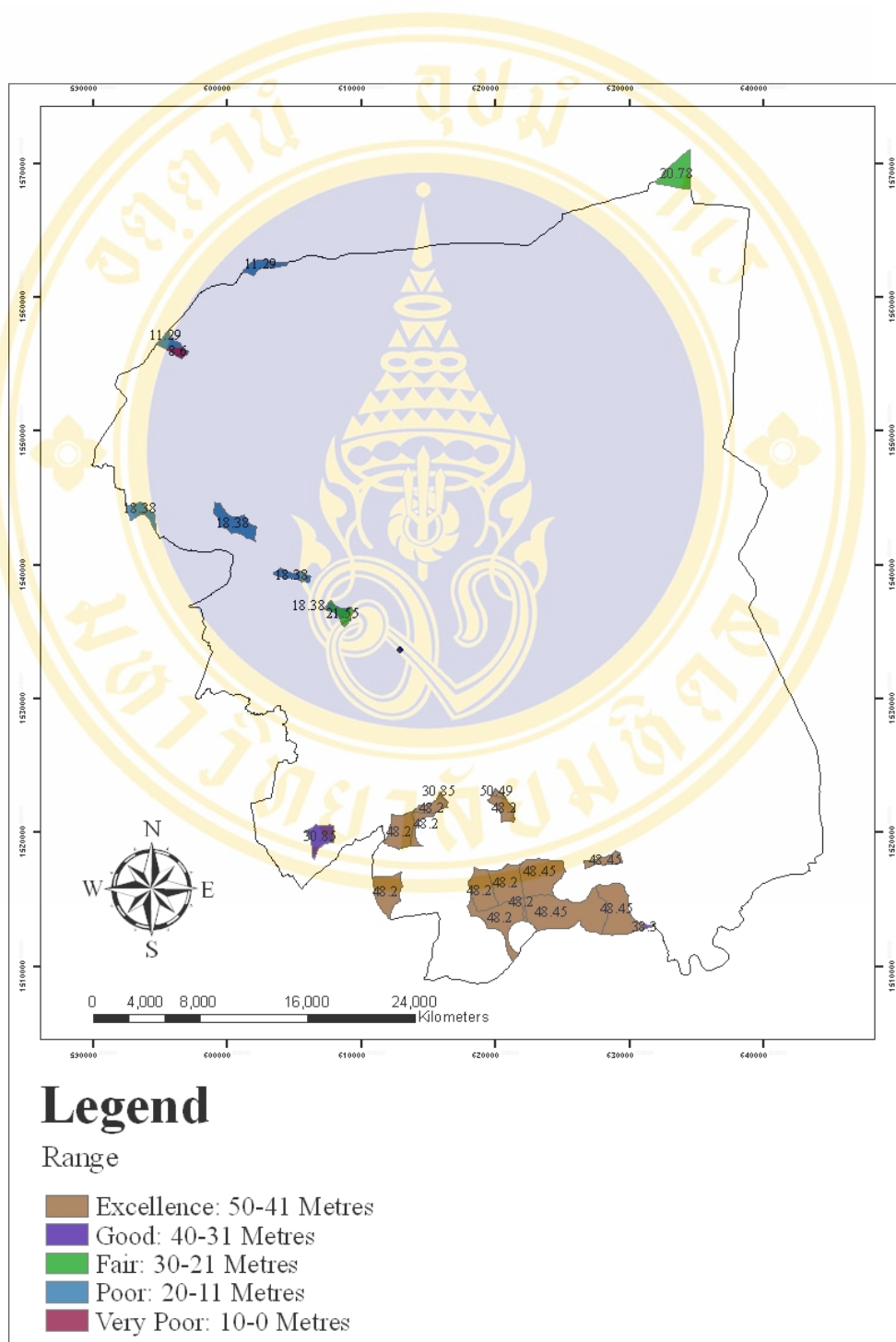
13. Click the Solve button  on the Network Analyst toolbar.



**Figure D.15** Best Route

## APPENDIX E

### RANGE OF EACH FACTOR



**Figure E.1** Range of Groundwater depth

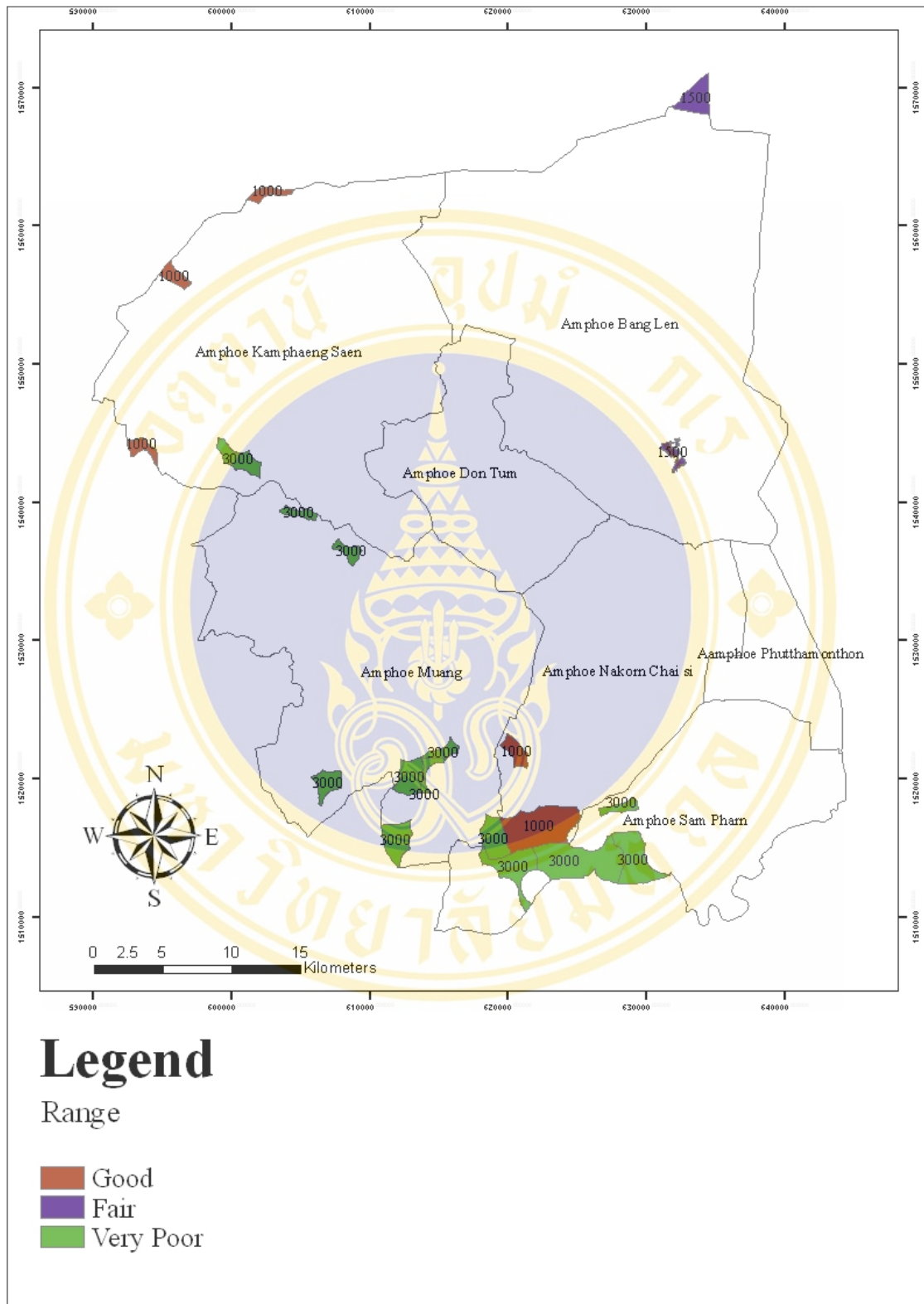
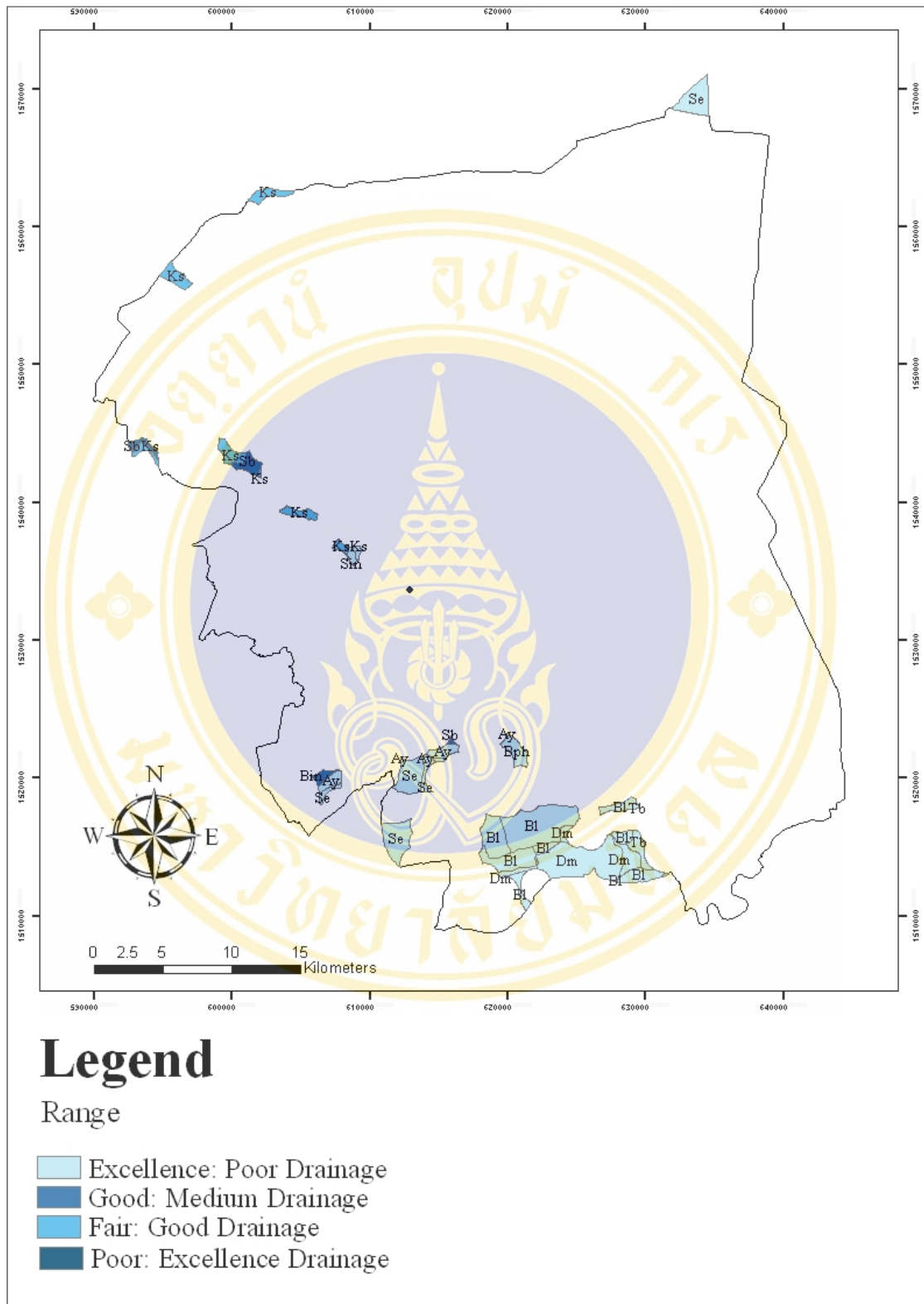


Figure E.2 Range of Land Price



**Figure E.3** Range of Soil Types

**Table E** Soil's Profile (Kasetsart U., 2007)

Soil's Profile	
Soil Type Name	Drainage
Kamphaeng Saen(Ks)	Good Drainage
Saraburi(Sb)	Medium Drainage
Ayutthaya(Ay)	Medium Drainage
Sena(Se)	Poor Drainage
Thon Buri(Tb)	Poor Drainage
Bang Len(Bl)	Poor Drainage
Damnoen Saduak(Dm)	Poor Drainage
Sing Buri(Sin)	Poor Drainage
Bang Pa-in(Bin)	Medium Drainage
Bang Phae(Bph)	Poor Drainage

## APPENDIX F

### PUBLICATION I

455

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### Multi-Criteria Consideration for the Candidate Sites of Solid Waste Landfill by Using Geographic Information Systems (GIS) Technology

Janjira Jamjan<sup>1\*</sup> Bunlur Emaruchi, PhD.<sup>2</sup> Somchai Pathomsiri, PhD.<sup>3</sup>

<sup>1</sup>Technology of Information System Management, Faculty of Engineering, Mahidol University  
Salaya, Nakornpathom 73170

<sup>2,3</sup>Department of Civil Engineering, Faculty of Engineering, Mahidol University  
Salaya, Nakornpathom 73170

E-mail: som\_prettygirl@hotmail.com\*

**Abstract**

Amid the rapid growth of economy and urban development, there are concerns regarding the proportional increment of solid waste and environmental problems. This study aims to analyze the current situation in Nakornpathom province. In particular, estimating generated solid waste during the next 20 years, and perform multi-criteria analysis by using the Geographic Information Systems (GIS) technology to identify a list of some strong candidate sites. The considered criteria include flooded area, buffer of roads, buffer of rivers, buffer of urban areas, buffer of water resource, land price, soil type as well as groundwater depth. This study proposes two-stage procedures where the 1<sup>st</sup> stage is to eliminate the unsuitable land and the 2<sup>nd</sup> stage is to rate and identify the best candidate sites. Finally, the two new sites have been identified and compared with the existing landfill at Kamphaengsaen district. The comparison indicates that both sites have several advantages over the existing one.

**Keywords:** GIS, Solid Waste, Landfill, Environment, Nakornpathom

**1. Introduction**

Environmental problem is now becoming one of the serious problems of urban areas as a result of population growth, human activities, city development, industrial expansion, and so on. One of the major environmental problems encountered in many cities is solid waste management, particularly the solid waste disposal system. The role of urban planning should be able to solve this problem. The paper deals with a very important side of such planning, namely, the selection of the most suitable site for landfill. Naturally, it is the multi-criteria decision making process by considering relevant rules, regulations, guidelines, recommendations and technical aspects before the final candidate site can be listed. This study shows that this can be done by using the Geographic Information Systems technology and illustrate in the case of study of landfill site selection in Nakornpathom province.

**2. Literature Review**

To identify the most suitable site for the location of solid waste landfill, inevitably, there are several criteria to fulfill. These may be from the Department of Pollution Control, international and local standards. Reviewing suggests that the following criteria are usually relevant.

**2.1 Land Size and Characteristics**

It is desirable to locate the landfill site that can accommodate solid waste for as long as 20 years [1]. As a result, the amount of waste has to be estimated for during such period and then the required land size can be determined. In addition, the geological conditions need to be sufficiently firm and stable to support the weight of solid waste. Furthermore, within the vicinity area, there should be no watershed area classes 1 and 2 as defined under the Cabinet Resolution [2].

**2.2 Distance**

There is always transportation cost involved in the solid waste disposal system. In general, the distance prefers to locate the site near the sources of waste generators in order to save as much as transportation costs. It is suggested for the efficient collection, the site should not be more than 30 kilometers farther away from the source [1], [2].

**2.3 Land Use**

Landfill site should avoid the areas which are still in use or can be more valuable to the community than being the solid waste landfill. For examples, landfill site should not consider acquiring residential area, agricultural zone, and industrial area. Instead one may consider unused and undeveloped land, for examples, deserted mine, acid soil area, and alkaline soil areas [1].

**2.4 Environmental Consideration**

The candidate site should not be near the historic site, temple, school, ditch, and watercourse. Neither the site with good view should be selected. Landfill site should be kept out of sight.

The general guideline is not to locate a site within one kilometer from the historic site, antique boundary and international museum. Neither should be located within one kilometer from the water-well or water supply manufacturer for the obvious reason

that the solid waste may contaminate the water resource [2]. If there is a nearby river, the site should be at least one kilometer away from it [3]. To keep the landfill out of sufficient far from sight, the site perhaps should be no less than 750 meters further away from the road.

Moreover, the selected area should not be often flooded because it would cost a lot of money to construct the flood protection system. In addition, the landfill should be situated at a significant distance away from urban residential areas due to public concerns, such as aesthetics, odor [4], noise, decreases in property value. One may consider a buffer of one kilometer around the urban area [5].

### 2.5 Geographical Features

From the geographical aspect, the selected site should not be a either too low or too high land. The site should not be steep otherwise the access will be limited [1].

### 2.6 Soil Type

The characteristic of soil type is determined by drainage. The suitable soil should have poor drainage in order to prevent the leakage of leachate. The ideal soil is perhaps the clay which can form the appropriate buffer from water source [1].

### 2.7 Groundwater Depth

In case of deep landfill, one needs to consider the level of groundwater depth. The main issue is the fear of contamination. Therefore, the site with deeper groundwater depth is more preferable because the risk of contamination is low [1].

Obviously, all of the above considerations make the selection of landfill site a multi-criteria decision making whereas several criteria should or need be satisfied simultaneously. Naturally, the end results may be a set of candidate sites with equally qualified for the final say by the decision maker. It is the main objective of this paper to assist the decision maker in identifying a short list of candidate sites in the timely and efficient manner by using the Geographic Information Systems (GIS) technology. Next, final stage will briefly describe the study area – Nakornpathom province.

## 3. Study Area

This paper chose Nakhonpathom province as the case study because of its seriousness of the current situation and availability of the data. At present, Nakornpathom is receiving not only solid waste from within its own community, but also accepting additional amount from Bangkok and vicinity provinces. It is anticipated that the existing solid waste landfill at Kamphaengsaen district (see Figure 1 for the location) may be reaching its capacity in the near future. Preparedness should now be taken seriously.

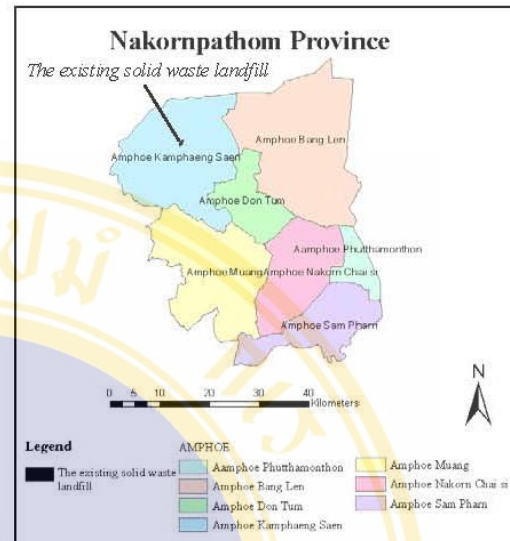


Figure 1. The existing solid waste landfill and Boundary of Nakornpathom Province

Nakornpathom covers the area of 2,168.327 square kilometers [6]. Its boundary is as follows:

- North bounded by Suphanburi and Ayuthaya provinces
- South bounded by Samutsakorn and Ratchaburi provinces
- East bounded by Nonthaburi, Bangkok and Ayuthaya provinces
- West bounded by Ratchaburi and Khanchanaburi provinces

Nakornpathom's administration is divided into seven administrative districts or Amphoe, i.e., Muang, Phuthamonthon, Sam Phran, Nakhon Chaisi, Bang Len, Kamphaeng Saen, and Don Toom. The district boundary is displayed in Figure 1.

Geographically speaking, Nakornpathom province consists of a flat plain. The main flat low land occupies greater parts of the province, with no hill and forest. The altitude is between 2 - 10 meters above the mean sea level. By average, the area is around six meters above the mean sea level. The geographical location is slope from the north to the south and from the west to the east. The area in the north and northeast mostly consist of highland with its height around 6 - 10 meters [7].

## 4. Data

To accomplish the multi-criteria analysis in Geographic Information Systems (GIS) environment, GIS shapefiles collection, consisting of land-use, river, soil type, land price, road, flood area and ground water depth. These are input data sets that will be analyzed by GIS software. The version use is ArcGIS Version 9.2. Table 1 summarizes the input factors used in the subsequent analysis.

Table 1 Summary of the input factors used in the analysis

Factors	Scale and Source	Buffer Zone	Ranking and Description
Flood Area	1:50,000 from Royal Irrigation Department	Not suitable	-
Urban Area	1:50,000 Land-use Map	1 km.	-
Road	1:50,000 from Land Development Department	750 m.	-
River	1:50,000	1 km.	-
Soil Type	1:50,000 from Land Development Department	-	1) Poor Drainage (2) 2) Medium Drainage (3) 3) Good Drainage (5) 4) Excellence Drainage (9)
Land Price	1:50,000	-	1) 0 – 600 Bath 2) 601 – 1200 Bath 3) 1201 – 1800 Bath 4) 1801 – 2400 Bath 5) 2401 – 3000 Bath
Groundwater Depth	1:50,000 from Department of Groundwater Resources	-	1) 50-41 2) 40-31 3) 30-21 4) 20-11 5) 10-0

**5. Analysis**

The second stage analyzes the positive area. Considered factors includes soil type, land price and groundwater depth. Each factor is digitized for subsequent overlay. The result from this stage is the list of candidate sites with their associated ranking.

**5.1 Estimation of the Landfill Size**

The first need to know how much solid waste need to be disposed so the size of land can be determined. The volume of solid waste may be estimated from the following equation [8].

$$V = \frac{N \times W}{D} \tag{1}$$

Where  $V$  is volume of solid wastes to use landfill,  $N$  is the number of years = 20,  $W$  is the amount of solid wastes to use landfill per year (ton/year) and  $D$  is the compressed density of solid wastes (ton/m<sup>3</sup>). In short, the quantity of solid waste is 500 ton/day.

Based on the computed volume by Equation (2), the required size of area for building landfill can be determined by the following equation:

$$A = \left( \frac{V}{H} \right) \times k \tag{2}$$

Where  $A$  is the required size of total area for landfill system (m<sup>2</sup>),  $V$  is volume of solid wastes to use landfill (m<sup>3</sup>),  $H$  is height of landfill's class (not including the covering soil),  $k$  is a constant in order to reserve some more space as buffer zone for constructing a building, liquid waste system, and plantation around the landfill. In this study,  $k$  is equal to 1.5. The calculation suggests the size of 1,659,090 m<sup>2</sup>.

**5.2 Application of GIS to Identify the Candidate Sites**

Landfill siting is a complicated job. This paper considered multiple criterion corresponding to the guidelines and recommendations provided by the Department of Pollution Control and international standards. Fortunately, GIS technology offers the spatial analysis capabilities to quickly eliminate parcels of land unsuitable for being the landfill site. Thus, the analysis is divided into two stages.

**5.2.1 The 1<sup>st</sup> Stage: Preliminary Locations**

The first stage analyzes the negative area, in other words, it is to eliminate the undesirable area. During this stage does the elimination layer-by-layer. The first stage starts with the base map of the whole Nakornpathom province. Then, the flooded areas are eliminated from the based map and eliminated the 1-km buffer of urban area. The process is displayed in Figure 2.

Next, more factors are considered i.e., 1-km buffers of roads, rivers, and water resources as shown in Figure 3. The result from this stage is the shapefile showing the scattered suitable land for subsequent analysis in the 2<sup>nd</sup> stage as show in Figure 4. Totally, there are 10 suitable areas.

**5.2.2 The 2<sup>nd</sup> Stage: Secondary Locations**

This stage aims to identify the candidate sites out of the shapefile resulted from the 1<sup>st</sup> stage. This stage analyzed several important factors, namely:

**Soil type:** The characteristic of soil type were determined by drainage. The suitable soil should have poor drainage ability such as clay [8]. Soil type can categorize the quality of drainage ability into five classes, varying from 1 (excellence), 2 (good), 3

(fair), 4 (poor), and 5 (very poor). The rating of each candidate site is shown in Table 2.

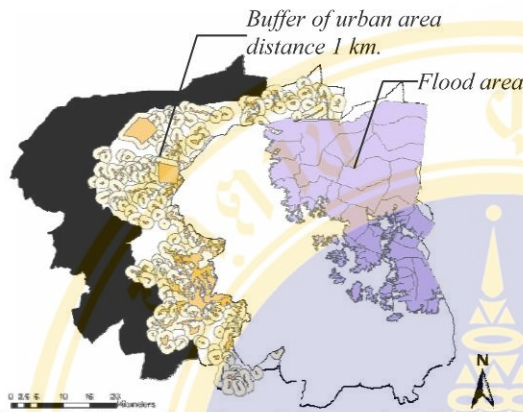


Figure 2. Elimination of unsuitable area from the base map

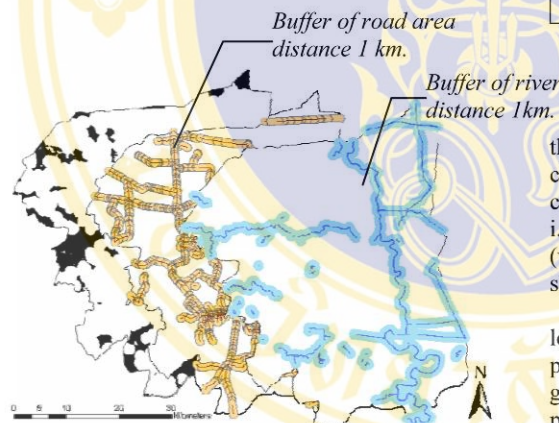


Figure 3. Elimination of road and river buffers

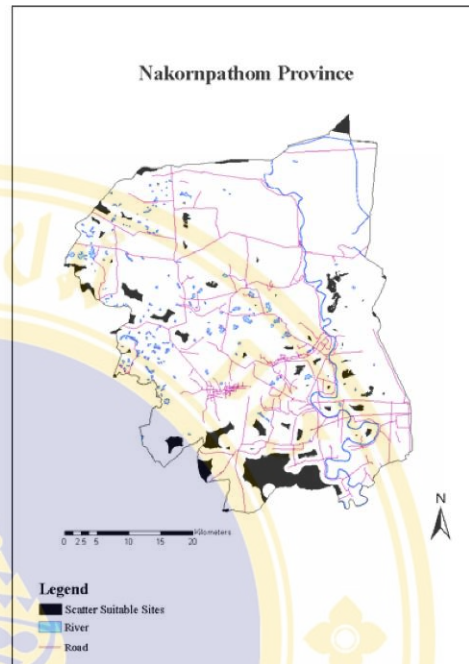


Figure 4. Scatter suitable lands in Nakornpathom Province

**Land price:** Intuitively, the best site should be the cheapest piece of land, given that all other characteristics being the same. Land price can categorize the rating of land price into five classes, i.e., 1 (excellence), 2 (good), 3 (fair), 4 (poor), and 5 (very poor). The rating of each candidate site is shown in Table 2.

**Groundwater depth:** The area should be located on the area with deep groundwater depth to prevent the contamination by leach ate [8]. Again, groundwater depth can categorize the rating of land price into five classes, i.e., 1 (excellence), 2 (good), 3 (fair), 4 (poor), and 5 (very poor). The rating of each candidate site is shown in Table 2.

Each factor is digitized and then overlaid, as displayed in Figure 4. Output from this stage is the shapefile showing candidate sites with their associated ratings. Recall that the lower number indicates the more suitable land. As a result, this stage can rank all pieces of lands by the resulting ratings. The sites with the minimum ratings are the strongest candidate site for being the landfill.

Figure 5 shows the locations of 13 candidate sites. Table 2 summarizes rating of all 13 candidate sites. Sites 6 and 9 are the strongest candidate sites with the total rating of 4. Both of them are in the southern part of Nakornpathom. These two sites will be discussed in depth in the next section.

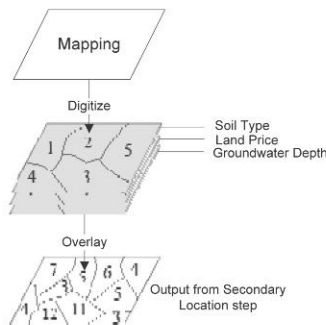


Figure 5. Overlaying for determine the secondary locations

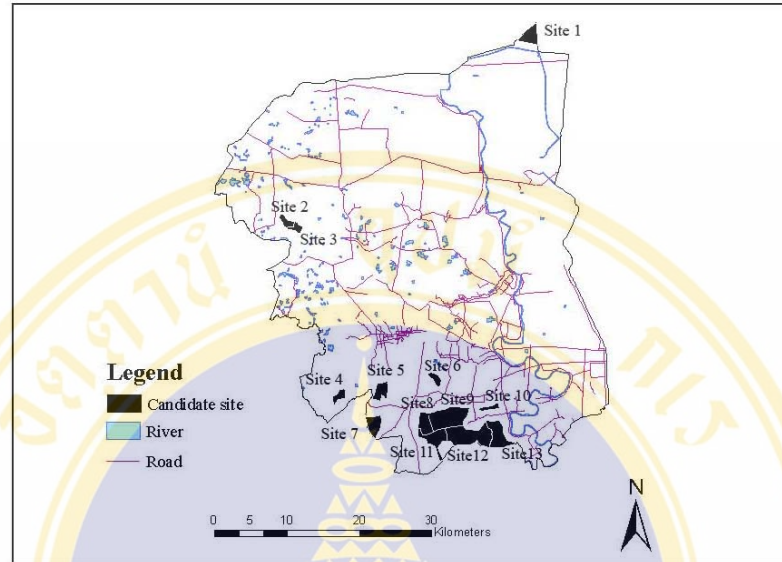


Figure 5. Map showing the 13 candidate sites for landfill

Table 2 Ratings for 13 candidate sites

	Site												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Soil Types*	1	3	2	1	1	1	1	1	1	1	1	1	1
Land Price*	3	2	2	5	5	2	5	5	2	5	5	5	5
Groundwater Depth*	3	4	4	2	1	1	1	1	1	1	1	1	1
<b>Total</b>	<b>7</b>	<b>9</b>	<b>8</b>	<b>8</b>	<b>7</b>	<b>4</b>	<b>7</b>	<b>7</b>	<b>4</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>

Remark on ratings: 1 = Excellence, 2 = Good, 3 = Fair, 4 = Poor, 5 = Very poor

**6. Discussion**

The two strongest candidate sites identified in the 2<sup>nd</sup> stage are:

**Site 6:** this site covers the area in Tambon Bangrakam and Amphoe Nakornchaisri. The total size is 2,161,980 m<sup>2</sup> or about 1,351 Rai.

**Site 9:** this site covers the area in Tambon Kokprajaedee and Amphoe Nakornchaisri. The total size is 13,260,549 m<sup>2</sup> or about 8,288 Rai.

Either of these two sites is sufficient to

accommodate solid waste in the next 20 years. Surprisingly, both sites have advantages over the existing solid waste landfill at Kamphaengsaen district according to the comparison in Table 3. Out of nine criteria, both sites are as good as the existing landfill at worst. Possibly, the existing landfill was not selected by considering as many relevant factors. That may explain well why it seems to be located near the community and not far enough from the river, as compared to candidate sites.

Table 3 Comparison of the existing solid waste landfill with new landfill sites

Factors	The existing solid waste landfill (Kamphaengsaen)	New sites	
		Amphoe Nakornchaisri Tambon Bangrakam	Amphoe Nakornchaisri Tambon Kokprajaedee
Size of area	699,274 m <sup>2</sup>	2,161,980 m <sup>2</sup>	13,260,549 m <sup>2</sup>
Flood area	Suitable	Suitable	Suitable
Buffer of urban area	Unsuitable	Suitable	Suitable
Buffer of road	Suitable	Suitable	Suitable
Buffer of river	Unsuitable	Suitable	Suitable
Airport	Suitable	Suitable	Suitable
Soil type	Fair	Excellence	Excellence
Land price	Good	Good	Good
Groundwater depth	Excellence	Excellence	Excellence

## 7. Conclusion

Realizing that solid waste management is a big issue in Nakornpathom province and preparedness should be taken seriously, this paper initiated this research to analyze the situations. This paper describe the methodology and a case study for identification of the candidate sites of solid waste landfill in this paper. Specifically, this paper performed multi-criteria analysis within the GIS environment. The considered criteria include flooded area, urban buffer, road buffer, river buffer, water resource buffer, soil type, land price, as well as groundwater depth. The first estimate the amount of generated solid waste during the next 20 years and required size of landfill to accommodate it. Then propose the two-stage procedure where the 1<sup>st</sup> stage is to eliminate the unsuitable land and the 2<sup>nd</sup> stage is to rate the resulting candidate sites. As a result, the two strongest candidate sites are identified. One covers 1,351 rai of Tambon Bangrakam and Amphoe Nakornchaisri. The other covers 8,288 rai of Tambon Kokprajaedee and Amphoe Nakornchaisri. The comparison has been made between these two new sites and the existing landfill at Kamphaengsaen district. Evidently, the last has identified two new sites which have several advantages over the existing site.

## Acknowledgements

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## APPENDIX G

### PUBLICATION II



การประชุมวิชาการวิศวกรรมโยธาแห่งชาติครั้งที่ 13  
14-16 พฤษภาคม 2551  
ณ โรงแรมอมรินทร์ ป่าอม บีช พัทยา

**SELECTION OF THE MOST PREFERABLE AREA FOR SOLID WASTE  
LANDFILL BY USING GEOGRAPHIC INFORMATION SYSTEMS (GIS)  
A CASE STUDY OF NAKORNPATTHOM PROVINCE**

Janjira Jamjan<sup>1</sup>  
Bunlur Emaruchi, PhD.<sup>2</sup>  
Somchai Pathomsiri, PhD.<sup>3</sup>  
Pet Techarat<sup>4</sup>

<sup>1</sup>Graduate Student, Technology of Information System Management E-mail: [som\\_prettygirl@hotmail.com](mailto:som_prettygirl@hotmail.com)  
<sup>2</sup>Lecturer E-mail: [egbem@mahidol.ac.th](mailto:egbem@mahidol.ac.th)  
<sup>3</sup>Lecturer E-mail: [egspt@mahidol.ac.th](mailto:egspt@mahidol.ac.th)  
<sup>4</sup>Graduate Student, Technology of Information System Management E-mail: [n\\_ploy555@hotmail.com](mailto:n_ploy555@hotmail.com)  
 Faculty of Engineering, Mahidol University, Phuthamonthon 4 Rd., Salaya, Nakornpathom 73170

**ABSTRACT:** During the past decade, Nakornpathom province experienced relatively fast growth due to several reasons including the expansion of economic activities from Bangkok, the construction of more residences and governmental offices, as well as increasing investment in the agricultural industry. Inevitably, this results in the proportional increment of solid wastes and burden to dispose them. Effective solid waste management is therefore an important countermeasure. It is anticipated that the existing solid waste landfill at Kamphaengsaen district may be reaching its capacity in the near future since it is receiving not only solid waste from within Nakornpathom, but also accepting additional amount from Bangkok and vicinity provinces. Preparedness should now be taken seriously. This research sets the main objective to study the whole area of Nakornpathom and choose the most preferable area for a future landfill that can accommodate solid waste during the next 20 years. To accomplish the objective, we estimated the future generated waste based on the number of population and the rate of waste generation then utilized ArcGIS - the Geographic Information System (GIS) technology. Within the GIS environment, we considered multiple criterion corresponding to the guidelines and recommendations provided by the Department of Pollution Control and international standards. These consist of land-use compatibility, appropriate soil type, right topography, inexpensive land price, convenient transportation, distant from river and water resources, non flooded area, low ground water level, and size suitability. Our results suggest a set of preliminary candidate areas of which the one at Nakornchaisri district shows the least total transportation cost. When compared to the existing landfill site, GIS's selection clearly shows several advantages. Nevertheless, the final decision should also take into consideration the social aspect in order to reduce the negative impacts on the community near the candidate area.

**KEYWORDS :** GIS, Solid Waste, Landfill, Environment, Nakornpathom

**1. Introduction**

One of the major environmental problems facing many cities is excessive solid waste generated from daily activities either by households or industry. One way to manage this issue is dispose it in landfills. However, finding the appropriate site for obnoxious facilities such as landfill site is always difficult because there are many technical and social criteria to be satisfied. Often times, these criteria create conflicts. On one hand, the preferred should be located near the community in order to reduce the cost of transporting the solid waste. On the other hand, being near or too near the community means unpleasant environment for the residents and raises the opposition. The use of Geographic Information Systems (GIS) may be useful for solving such multi-criteria

decision making. With its spatial database and analysis capabilities, the selection of the most preferable area for solid waste may be more convenient. This paper demonstrates the application of GIS-based decision making process for the case study of Nakornpathom province.

**2. Literature Review**

In general, siting the appropriate areas for landfill needs to meet two major criteria [1]. One is called *exclusionary criteria* and the other is *non-exclusionary criteria*.

The exclusionary criteria basically include the application of laws, rules, regulations, and technical requirements that screen unsuitable land out from further

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consideration. The common exclusionary criteria consist of the following list:

- *Size of land*, the candidate area should be contiguous and large enough to accommodate the amount of solid waste for the next 20 years [2]. Furthermore, the geological conditions need to be sufficiently firm and stable to support the weight of solid waste. There should be no watershed area as defined under the Cabinet Resolution, within its vicinity [3].
- *Land Use*, frequently conflicting with land use pattern prohibits certain areas from further consideration.
- *Environmental Issues*, the candidate area should not be near the historic site, temple, school, ditch, and watercourse due to the fear of contamination. If there is a nearby river, the site should be at least one kilometer away from it [4]. If possible, the landfill is preferably kept out of sight from public. The guideline is no less than 750 meters away from the major road. Flooded area should be screened out from the outset because it is not worth constructing flood protection system. In addition, the landfill should be situated at a significant distance away from urban residential areas due to public concerns, such as aesthetics, odor [5], noise, decreases in property value. One may consider a buffer of one kilometer around the urban area [6].
- *Geography*, the areas under consideration should not be either too low or too high land. The slope should not be steep otherwise the access will be limited [2].

The non-exclusionary criteria when applied are not to screen out certain areas, but rather rank them according to their characteristics. The following criteria are the examples:

- *Proximity*, a location with close proximity to the source of solid waste is usually preferred since it reduces the transportation cost significantly. However, too close is barely acceptable because it creates unpleasant neighborhood and may raise concerns even opposition from the community. The general guideline for siting a landfill is within 30 kilometers from the source [2], [3].

- *Type of soil*, the suitability of soil is determined by its drainage ability, with poor permeability is more preferable in order to prevent the leakage of leach ate. Therefore, the ideal soil is clay which can form the desirable buffer from water resource [2].
- *Land price*, inexpensive area is always preferred.
- *Groundwater depth*, the big concern here is water contamination. As a result, the area with deeper groundwater level is preferred [2].

As one may see some of the above mentioned criteria are conflicting with each other. This is a typical multi-criteria decision making process. In the subsequent section, the application of GIS for solving this problem will be illustrated. First, the study area of Nakhonpathom province is described next.

### 3. Study Area

Nakhonpathom's administration is divided into seven districts or Amphoe, i.e., Muang, Phutthamonthon, Sam Phran, Nakhon Chaisi, Bang Len, Kamphaeng Saen, and Don Toom. Geographically speaking, Nakhonpathom province is situated on a flat plain. The altitude is between 2 -10 meters above the mean sea level (MSL). By average, the area is around six meters above MSL. The geographical location inclines from the north to the south and from the west to the east. The area in the north and northeast mostly consist of highland with its height around 6 - 10 meters [7].

Beside its self-generated solid waste, one may not be aware that Nakhonpathom province has been accepting solid waste from Bangkok for years. It is anticipated that the existing solid waste landfill at Kamphaengsaen district may be reaching its capacity in the near future. Preparedness should now be taken seriously.

### 4. Data

GIS operations requires database in the form of digital map. The map may consist of different layers on top of each other. For this application, layers represent land-use, river, soil type, land price, road, flood area, and groundwater depth. These layers are basic input that will be manipulated and analyzed by GIS software. The version that is employed in this study is ArcGIS Version 9.2. Table 1 summarizes the digital map, scale and data source, buffer zone, and ranking description.

**Table 1 Description of digital maps**

Map layer	Scale	Data Source	Buffer Zone	Ranking and Description
Flood Area	1:50,000	Royal Irrigation Department	Not suitable	-
Urban Area/Land Use Map	1:50,000	Land Development Department	1 km.	-
Road	1:50,000		750 m.	-
River	1:50,000		1 km.	-
Soil Type	1:50,000	Land Development Department	-	1) Poor Drainage (2) 2) Medium Drainage (3) 3) Good Drainage (5) 4) Excellence Drainage (9)



Map layer	Scale	Data Source	Buffer Zone	Ranking and Description
Land Price	1:50,000	N.A.	-	1) 0 – 600 Bath 2) 601 – 1200 Bath 3) 1201 – 1800 Bath 4) 1801 – 2400 Bath 5) 2401 – 3000 Bath
Groundwater Depth	1:50,000	Department of Ground Water Resources	-	1) 50-41 2) 40-31 3) 30-21 4) 20-11 5) 10-0

**5. GIS Application for Landfill Siting**

The analyses are carried out in steps as follows. First the required size is estimated based on rate of solid waste generation per year. Second, the preliminary candidate areas are obtained by applying the exclusionary criteria described previously. This is done within GIS environment using spatial analysis features. Third, the secondary candidate areas are obtained by applying the three non-exclusionary criteria, i.e., soil price, land price and ground water depth. Last, the final candidate areas are decided by the total transportation cost. The details are given below.

**5.1 Determination of Landfill Size**

The estimated volume of solid waste may be calculated from the following equation [8].

$$V = \frac{N \times W}{D} \tag{1}$$

*V* is the volume of solid waste expected to be disposed in landfill (m<sup>3</sup>), *N* is the design period, say 20 years, *W* is the rate of solid waste generation per year (ton/year) and *D* is the compressed density of solid wastes (ton/m<sup>3</sup>). Nakornpathom had been defined medium cluster by clustering of Pollution Control Department. In short, the quantity of solid waste is about 500 ton/day in 2005.

The required size of area for constructing a landfill is then determined by:

$$A = \left( \frac{V}{H} \right) \times k \tag{2}$$

*A* is the required size of area for landfill system (m<sup>2</sup>), *H* is the height of landfill's class (not including the covering soil), *k* is a constant in order to reserve more space as buffer zone for constructing a building, liquid waste system, and plantation around the landfill. In this study, *k* is equal to 1.5. In all, this leads to the required size of 1,659,090 m<sup>2</sup>.

**5.2 Preliminary Candidate Areas**

At this step, unsuitable areas are screened out by imposing exclusionary criteria within the GIS environment. This is done layer-by-layer or criteria-by-

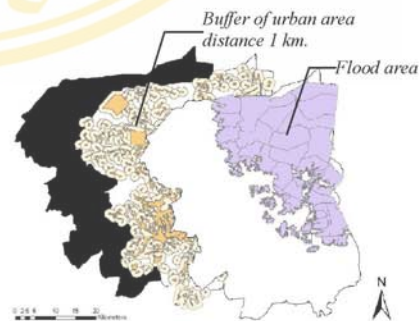
criteria, so to speak. Given the base digital map of Nakornpathom province, the screening is proceeded by:

- The flooded areas are eliminated from the based map.
- The 1-km buffer of urban area is eliminated. The process is displayed in Figure 1.
- The 1-km buffers of roads, rivers, and water resources are eliminated, as shown in Figure 2.

The result from this step is the shapefile showing the scattered suitable land areas for subsequent analysis in the next step – determination of secondary candidate areas. In all, there are totally 13 preliminary candidate areas, as shown in Figure 3.

**5.3 Secondary Candidate Areas**

This step applies three non-exclusionary criteria to the 13 preliminary candidate areas, i.e., soil type, land price and groundwater depth. Their rating scores are given in Table 2. Each criterion is digitized and then overlaid on top of each other. Output from this stage is the shapefile showing 13 preliminary candidate areas with their corresponding rating scores. The lower score indicates the more suitable land. As a result, the rating scores can be used to rank the suitability of the candidate areas.



**Figure 1** Elimination of flooded areas and urbanized buffer

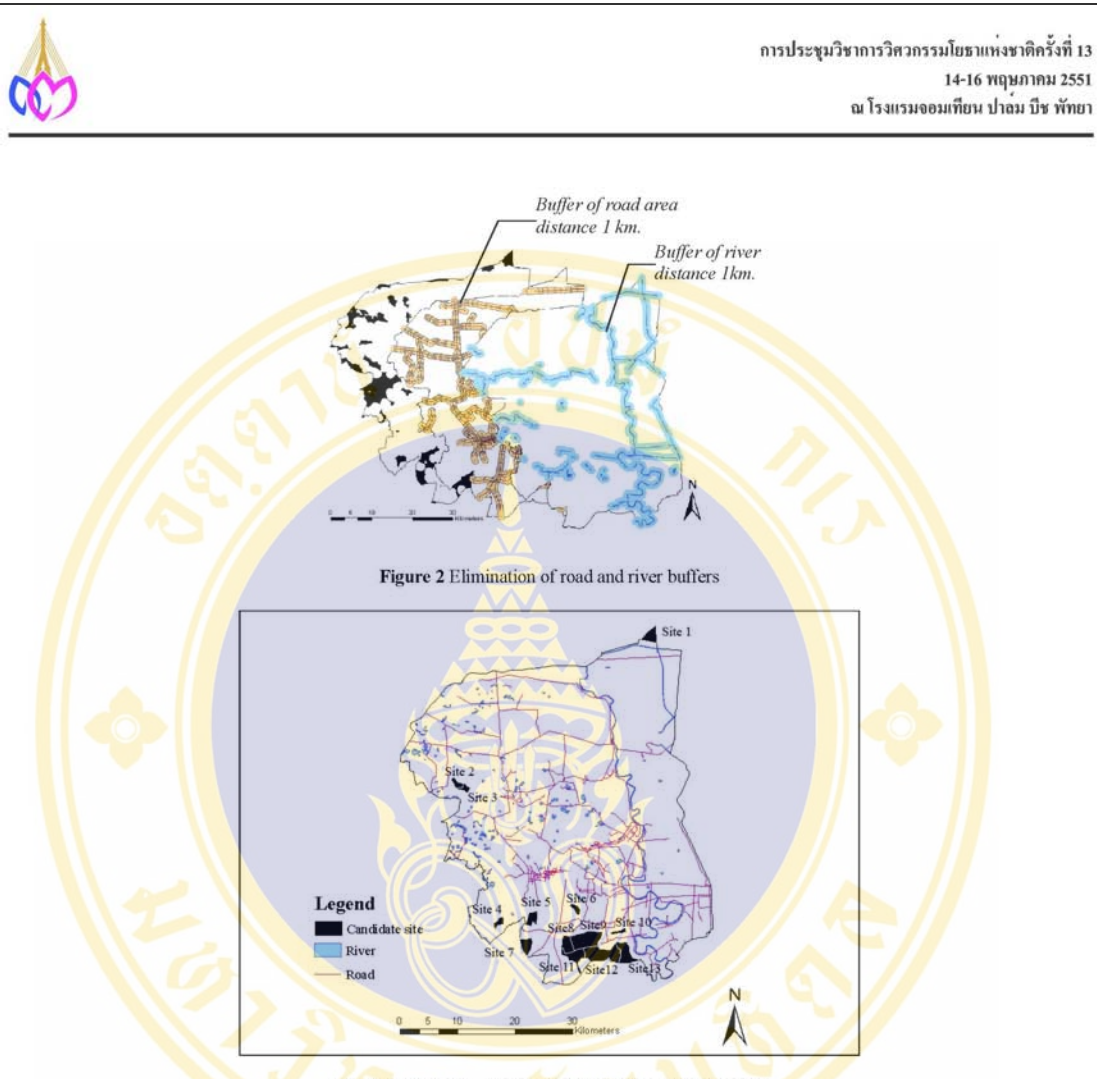


Figure 2 Elimination of road and river buffers

Figure 3 Map showing the 13 preliminary candidate areas

In Table 2, the total rating scores are reported at the bottom line. Areas 6 and 9 seem to be the strongest candidate areas with the total rating scores of 4. Both of them are in the southern part of Nakornpathom province.

On the contrary, the weakest candidate is area 2 with the rating score of 9. In the next step, the top five candidate areas will make the cut for the final consideration.

Table 2 Ratings of non-exclusionary criteria for 13 preliminary candidate areas

	Area												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Soil types*	1	3	2	1	1	1	1	1	1	1	1	1	1
Land price*	3	2	2	5	5	2	5	5	2	5	5	5	5
Groundwater depth*	3	4	4	2	1	1	1	1	1	1	1	1	1
Total	7	9	8	8	7	4	7	7	4	7	7	7	7

Note on ratings: 1 = Excellence, 2 = Good, 3 = Fair, 4 = Poor, 5 = Very poor

**5.3 Final Candidate Areas**

The criterion used in this step is still non-exclusionary, i.e., the total transportation cost. Top five of candidate sites from the secondary candidate areas singled out for consideration here, i.e., 6, 9, 11, 12, and 13. It is assumed that the unit transportation cost (ton/kilometer) is identical for any zone to any candidate

area. As a result, the total transportation cost from all zones to a candidate area can be simply computed by the summation of the product between the weight of solid waste in each zone and distance to the candidate area. This is shown in equation (3) below. In the GIS database, a zone represents a sub-district or Tambon.



$$\sum_{i=1}^n (Weight_i)(D_{i-Area}) \tag{3}$$

Where  $i$  is the index of Tambon,  $n$  is number of Tambon in Nakornpathom province (106 totally).  $Weight_i$  is amount of solid waste (ton) generated in Tambon  $i$ ,  $D_{i-Area}$  is the Euclidean distance from centroid of Tambon  $i$  to the centroid of a candidate area (kilometer). The total transportation cost is computed five

times, each for candidate areas 6, 9, 11, 12 and 13 respectively. Table 3 shows the results.

Candidate area 6 gives the minimum total transportation cost of 12,542 ton-kilometer. Note that this calculation is based on the amount of solid waste generated from population in 2000. Area 6 size is 2,161,980 m<sup>2</sup> or about 1,351 Rai. This size is sufficiently large to accommodate solid waste during the next 20 years.

**Table 3 Comparison of the total transportation costs**

Amphoe	Population	Amount of Solid Waste (ton)	Total transportation cost (Ton - kilometer)				
			Area 6	Area 9	Area 11	Area 12	Area 13
Mueang	267,525	455.85	4,170.11	6,691.94	7,402.28	8,336.64	9,477.22
Kamphaengsan	118,802	72.47	2,349.15	2,755.31	2,887.01	3,011.41	3,150.57
Dontoom	45,743	26.53	528.89	677.58	748.33	756.71	784.74
Nakornchaisri	104,310	81.78	799.60	992.46	1,267.35	1,105.29	1,092.03
Banglen	89,512	69.82	2,197.34	2,538.70	2,762.02	2,680.76	2,661.40
Sampran	166,536	138.59	2,155.03	1,812.58	2,095.75	1,517.65	1,167.94
Puttamontol	29,477	16.51	341.92	353.20	405.71	339.92	294.92
<b>Total</b>	<b>821,905</b>	<b>861.55</b>	<b>12,542.05</b>	<b>15,821.77</b>	<b>17,568.46</b>	<b>17,748.39</b>	<b>18,628.82</b>

If compared area 6 with the existing landfill at Kamphaengsan district on nine criteria, it is found that the candidate area 6 has several advantages. As can be seen from Table 4, the selected area is at worst as good as the existing one. Possibly, the existing landfill was not

selected by considering as many relevant criteria as in this study. That may explain well why it seems to be located near the community and not far enough from the river, as compared to candidate area 6.

**Table 4 Comparison between candidate area 6 and the existing solid waste landfill**

Criteria	The existing solid waste landfill (Kamphaengsan)	Candidate area 6 Amphoe Nakornchaisri Tambon Bangrakam
Size of area	699,274 m <sup>2</sup>	2,161,980 m <sup>2</sup>
Flood area	Suitable	Suitable
Buffer of urban area	Unsuitable	Suitable
Buffer of road	Suitable	Suitable
Buffer of river	Unsuitable	Suitable
Airport	Suitable	Suitable
Soil type	Fair	Excellence
Land price	Good	Good
Groundwater depth	Excellence	Excellence

**6. Concluding Remark**

The paper presents an application of GIS to select the most preferable area for landfill. The process is carried out in three steps. First, the preliminary candidate areas are singled out from the whole study area (Nakornpathom province) by imposing a set of exclusionary criteria. This results in 13 areas. Second, non-exclusionary criteria, i.e., soil type, land price and groundwater depth are used to the rate the 13 areas. The top five areas make the cut for the final consideration. Last, the final candidate area is selected out of the top five based on the total transportation cost. Eventually, the most preferable area is identified at Tambon Bangrakam. When compared to the existing landfill at

Kamphaengsaen district, the selected area is superior to the existing landfill on most criteria. In summary, GIS was proved to be an effective analytical tool to select the most preferable area for landfill.

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Dr. Somchai Pathomsiri is a senior member of the Engineering Institute of Thailand under H.M. the King's Patronage and registered professional engineer. He earned his B.Eng in Civil Engineering (Honors) from King Mongkut's University of Technology Thonburi, M.Eng (Transportation and Traffic Engineering) from Chulalongkorn University, MBA (Executive Program) from Thammasat University and Ph.D. (Transportation Systems Engineering and Planning) from University of Maryland, USA

Miss Pet Techarat earned her B.Eng. (Civil Engineering) from Mahidol University. Presently, she is a graduate student in Technology of Information System Management at the Faculty of Engineering, Mahidol University and working as a research assistant at the Department of Civil Engineering. Her research focus is the application of Geographic Information Systems (GIS) Technology in environmental system engineering.



If interested in Geographic Information Systems (GIS) Applications Contact:  
Department of Civil Engineering, Faculty of Engineering, Mahidol University, 25/25 Phutthamonthon 4 road, Salaya, Phutthamonthon, Nakompathom 73170  
Tel. 02-889-2138 Ext. 6396-7, Fax. 02-889-2138 Ext. 6388  
E-mail: [espspt@mahidol.ac.th](mailto:espspt@mahidol.ac.th)

About the Authors



Miss Janjira Jamjan is a graduate student in Technology of Information System Management at the Faculty of Engineering, Mahidol University. She earned BBA. in Computer Business (2<sup>nd</sup> class honor) from Ratchabhat Suansunantha University. Currently, she is working for Power Telco Col., Ltd as a system analyst freelance.

Dr. Bunlur Emaruchi earned his B.Eng. (Civil Engineering) from Chiangmai University, M.Sc (Geomorphological Surveys) from International Institute for Aerospace Surveys and Earth Science, Netherlands, M.Sc. (Forest Engineering) from University of New Brunswick, Canada, and Ph.D. (Environmental Systems Engineering) from University of Regina, Canada



## BIOGRAPHY



<b>NAME</b>	Miss Janjira Jamjan
<b>DATE OF BIRTH</b>	28 July 1983
<b>PLACE OF BIRTH</b>	Bangkok, Thailand
<b>INSTITUTIONS ATTENDED</b>	Suan Sunandha RajaBhat University 2001-2005 (4 academic year ) Bachelor of Business Administration (Business Computer) Mahidol University, 2006-2009 (3 academic year ) Master of Science (Technology of Information System Management)
<b>HOME ADDRESS</b>	36/21 M.1 Petkasaem Rd. Nongkangplu Nongkaem Bangkok 10160
<b>E-MAIL ADDRESS</b>	<a href="mailto:jamjaruss@hotmail.com">jamjaruss@hotmail.com</a> , <a href="mailto:jamjan.janjira@gmail.com">jamjan.janjira@gmail.com</a>
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