

การเลือกพื้นที่สำหรับฝังกลบขยะอันตรายและการวิเคราะห์เส้นทางขนส่งขยะอันตรายด้วยระบบ
สารสนเทศภูมิศาสตร์ในจังหวัดขอนแก่น

นายจรัญ ราชสมบัติ

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SITE SELECTION FOR HAZARDOUS WASTE LANDFILL AND ROUTING
ANALYSIS FOR HAZARDOUS WASTE TRANSPORT USING GEOGRAPHIC
INFORMATION SYSTEMS AT KHON KAEN PROVINCE

Mr. Jongruk Rachsombut

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Environmental Management
(Interdisciplinary Program)
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การศึกษานี้มีวัตถุประสงค์เพื่อคัดเลือกพื้นที่ที่เหมาะสมในการจัดตั้งหลุมฝังกลบของ
 เสียอันตรายในจังหวัดขอนแก่น โดยระบบสารสนเทศภูมิศาสตร์ ได้ถูกนำมาใช้ในการวิเคราะห์ข้อมูลจาก
 หลายๆแหล่งข้อมูลเพื่อระบุพื้นที่ที่มีศักยภาพ และคัดเลือกพื้นที่ที่เหมาะสมสำหรับจัดตั้งหลุมฝังกลบของ
 เสียอันตราย การระบุพื้นที่ที่มีศักยภาพ ได้วิเคราะห์โดยใช้ ข้อกำหนดที่ดัดแปลงมาจากกรมควบคุมมลพิษ
 ซึ่งประกอบไปด้วยหลายปัจจัย ได้แก่ แหล่งน้ำ สภาพทางธรณีวิทยา พื้นที่อ่อนไหวทางสิ่งแวดล้อมและ
 ปัจจัยอื่นๆที่เกี่ยวข้อง โดยการคัดเลือกพื้นที่ที่เหมาะสมเฉพาะ พื้นที่ที่สามารถรองรับของเสียอันตรายเป็น
 เวลา 20 ปีและเส้นทางที่สั้นที่สุด ที่ใช้ในการขนส่งของเสียอันตราย จากแหล่งกำเนิดถึงพื้นที่ ที่มีศักยภาพ
 เป็นหลุมฝังกลบ เท่านั้นถูกนำมาพิจารณา ผลจากการศึกษาพบว่า ภายในจังหวัด ขอนแก่นมีพื้นที่ที่มี
 ศักยภาพอยู่ 18 แห่ง โดยมีระยะทางในการขนส่ง ของเสียอันตราย สั้นที่สุดห้าอันดับแรกคือ พื้นที่ที่ 6 ซึ่ง
 ตั้งอยู่ที่ตำบลม่วงหวาน อำเภอน้ำพอง พื้นที่ที่ 7 พื้นที่ที่ 9 พื้นที่ที่ 8 และพื้นที่ที่ 10 ซึ่งตั้งอยู่ที่ตำบลโคกสูง
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 TRANSPORT USING GEOGRAPHIC INFORMATION SYSTEMS AT KHON
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The aim of this study is to identify a suitable site for constructing a hazardous waste landfill within Khon Kaen Province. A geographic information systems (GIS) software package was used to analyze various data sources in identifying and selecting a suitable landfill site. To identify potential areas, several factors including water resources, geology, sensitive area, community area, and other related factors were analyzed based on modified criteria for hazardous waste landfill from the Pollution Control Department (PCD), Thailand. To select a suitable landfill site, only potential areas having size large enough to be used for 20 years and a shortest distance for transporting hazardous waste from generators to the potential areas were considered. Results from the study revealed that eighteen potential areas were found within Khon Kaen Province. While, the first five least transport distances between generators and potential site were at site 6 in Tambon Muang Wan, Amphoe Nam Phong, site 7, site 9, site 8, and site 10 in Tambon Khok Song, Amphoe Ubonrat which the distance of 1223.52, 1225.99, 1245.12, 1288.35, and 1350.90 kilometers, respectively.

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CONTENTS

| | Page |
|---|-------------|
| ABSTRACT IN THAI..... | iv |
| ABSTRACT IN ENGLISH..... | v |
| ACKNOWLEDGEMENTS..... | vi |
| CONTENTS..... | vii |
| LIST OF TABLES..... | ix |
| LIST OF FIGURES..... | x |
| | |
| CHAPTER I INTRODUCTION..... | 1 |
| 1.1 Theoretical background..... | 1 |
| 1.2 Objectives..... | 5 |
| 1.3 Hypothesis..... | 5 |
| 1.4 Scope of study..... | 5 |
| 1.5 Expected result..... | 6 |
| | |
| CHAPTER II LITERATURE REVIEWS..... | 7 |
| 2.1 Hazardous waste | 7 |
| 2.1.1 Characterizes of waste..... | 7 |
| 2.1.2 Listed hazardous waste..... | 8 |
| 2.2 Hazardous waste sources..... | 8 |
| 2.3 Transportation..... | 10 |
| 2.4 Generator categories..... | 11 |
| 2.5 Landfill..... | 12 |
| 2.6 GIS..... | 16 |
| 2.6.1 Definition of GIS | 16 |
| 2.6.2 Components of GIS..... | 16 |
| 2.6.3 GIS for landfill site selection | 18 |
| 2.6.4 GIS network analysis..... | 19 |
| | |
| CHAPTER III MATERIALS AND METHODOLOGY..... | 21 |
| 3.1 Materials..... | 21 |
| 3.2 Methodology..... | 21 |
| 3.2.1 Screening potential areas | 23 |
| 3.2.2 Selection potential site | 25 |
| 3.2.3 Selection the most suitable site..... | 26 |
| 3.2.3.1 Data preparation | 28 |
| 3.2.3.2 Determining the best route | 28 |
| 3.2.3.3 Dijkstra's algorithm..... | 28 |
| 3.2.3.4 Performing ArcGIS Network analysis..... | 29 |
| 3.2.3.5 Study scenarios | 30 |
| | |
| CHAPTER IV RESULTS AND DISCUSSION..... | 34 |
| 4.1 Identification of potential area..... | 34 |
| 4.2 Selected of potential site..... | 51 |
| 4.3 Selection of the most suitable site..... | 55 |
| 4.3.1 Finding shortest distance by straight line method | 56 |

| | Page |
|--|-------------|
| 4.3.2 Finding the shortest route based on road network method... | 56 |
| 4.3.3 Finding the shortest route based on road type method | 57 |
| CHAPTER V CONCLUSION..... | 66 |
| 5.1 Conclusion..... | 66 |
| 5.3 Recommendations..... | 67 |
| REFERENCES..... | 69 |
| APPENDICES..... | 73 |
| APPENDIX A..... | 74 |
| APPENDIX B..... | 89 |
| APPENDIX C..... | 108 |
| BIOGRAPHY..... | 113 |

LIST OF TABLES

| Table | | Page |
|--------------|---|-------------|
| 2.1 | Standard guideline for generator..... | 11 |
| 3.1 | Modification criteria..... | 22 |
| 3.2 | Hazardous waste generators | 27 |
| 4.1 | Summary of the potential areas | 50 |
| 4.2 | Summary of the potential sites | 54 |
| 4.3 | Generator data | 55 |
| 4.4 | Finding shortest distance by straight line result | 56 |
| 4.5 | Finding the shortest route based on road network result | 57 |
| 4.6 | Finding the shortest route based on road type result | 58 |
| 5.1 | The first five least fuel cost and transport distance of generator to potential site | 67 |

LIST OF FIGURES

| Figure | | Page |
|---------------|---|-------------|
| 1.1 | Khon Kaen Province | 4 |
| 3.1 | Flowchart of methodology | 23 |
| 3.2 | Concept to find the distance | 30 |
| 4.1 | Map of positive soil group, aquifer, and groundwater table | 37 |
| 4.2 | Map of positive major road buffer areas | 38 |
| 4.3 | Map of positive recharge areas | 39 |
| 4.4 | Map of negative watershed areas | 40 |
| 4.5 | Map of forest conservation areas | 41 |
| 4.6 | Map of national park areas | 42 |
| 4.7 | Map of high floodrisk areas | 43 |
| 4.8 | Map of well buffer areas | 44 |
| 4.9 | Map of stream buffer areas | 45 |
| 4.10 | Map of lake buffer areas | 46 |
| 4.11 | Map of village buffer areas | 47 |
| 4.12 | Map of mining, airport, heritage, and wastewater treatment plant buffer areas..... | 48 |
| 4.13 | Map of potential areas | 49 |
| 4.14 | Potential sites | 53 |
| 4.15 | The suitable route for transport hazardous waste of generators to potential site 6..... | 60 |
| 4.16 | The suitable route for transport hazardous waste of generators to potential site 7..... | 61 |
| 4.17 | The suitable route for transport hazardous waste of generators to potential site 8..... | 62 |
| 4.18 | The suitable route for transport hazardous waste of generators to potential site 9..... | 63 |
| 4.19 | The suitable route for transport hazardous waste of generators to potential site 10..... | 64 |
| 4.10 | The suitable route for transport hazardous waste of generators to potential site 18..... | 65 |

CHAPTER I

INTRODUCTION

1.1 Theoretical background

During the past decade, the amount of hazardous waste produced in local communities has rapidly increased due to rapid economic and industrial growth. The Pollution Control Department (PCD) in Thailand reported a summary of the pollution situation in 2008 of around 1.849 million tons (an increase from 2006 of about 16,500 tons); 1.44 million tons was produced by industries and 0.409 million tons produced by households. (PCD, 2008) However, the management of hazardous waste is still inappropriate, such as co-disposal with solid waste at municipality disposal sites and illegal dumping. Therefore, such wastes are potentially hazardous to the environment, human health, living organisms, and also can cause contamination to surface soil and groundwater. Furthermore, the Department of Industrial Works (DIW) Industrial Waste Management master plan and feasibility study for transfer stations project 2008 found that most of the industrial hazardous waste recycling, treatment and disposal facilities are located in the eastern and central parts of Thailand. In other parts of the country there are mostly small scale factories, especially in the south and the northeast, far away from waste processing facilities. This inhibits the factories from sending their waste to be processed outside the factory. In some cases they cannot afford the expense of disposal. Thus, hazardous wastes are stored in the factories. (DIW, 2008) To minimize the malpractices of hazardous waste management from the factories, new treatment and disposal facilities should be established within these regions.

A typical hazardous waste management system consists of components for the collection, transportation, treatment and disposal of waste. Normally, the treatment process for hazardous wastes includes incineration, neutralization, precipitation, various separation processes, and secured landfills. (Beer, 1984) The treatment technologies convert the waste into harmless forms, or immobilize toxic components, or reduce the quantity of the waste. There are several methods used for

ultimate disposal of hazardous waste, such as incineration, immobilization, landfill, offshore, and underground storage. Landfill is a common method for final waste disposal which has been used in many countries, since it can decrease the harmful effects on humans and the surrounding environment caused by improper management. However, creating landfill sites is an extremely difficult task to accomplish, especially for hazardous waste, because it involves diverse environmental, economic, social and political factors. To find suitable landfill sites, therefore, site selection plays an important role in the hazardous waste management processes. In order to assure that the proposed location of the waste facility is based on sound environmental, social, economic, and political concerns, the goals of site selection should minimize health risk, environment impact and cost, and maximize public acceptability (Batstone et al., 1989). Several agencies have published criteria to assist in the selection of suitable landfill sites, for example the United State Environmental Protection Agency (U.S.EPA) published a manual of sensitive environments and considerations for the siting of hazardous waste management facilities (U.S.EPA, 1997); the State Pollution Control Board / Pollution Control Committee (SPCB/PCC) published criteria for hazardous waste landfill sites (SPCB/PCC, 2010: online); and the PCD published guideline criteria for secure landfills in Thailand (PCD, 2010: online). The criteria of each agency may be different, since it depends on the country to establish criteria based on environmental, human health, living organism, and economic aspects. Although, site selection is an important part of landfill construction, the transportation of hazardous waste is necessary to consider with regards to safety and cost of transportation. The proper planning and management of hazardous waste transportation benefit the generator with regards to cost reduction and minimizing the threat to human health and the environment from an accident or improper practice.

Khon Kaen Province was selected as the study site, which is located in the Northeastern region of Thailand, a distance of 445 kilometers from Bangkok. The province covers an area of 10,886 square kilometers and lies between longitude 101° to 103° and latitude 15° to 17°. Khon Kaen Province is subdivided into 26 districts (Figure 1), they are: Ban Fang district, Phra Yuen district, Nong Ruea district, Chum Phae district, Si Chomphu district, Nam Phong district, Ubolratana district, Kranuan district, Ban Phai district, Pueai Noi district, Phon district, Waeng Yai district, Waeng Noi district, Nong Song Hong district, Phu Wiang district, Mancha Khiri district,

Chonnabot district, Khao Suan Kwang district, Phu Pha Man district, Sam Sung district, Khok Pho Chai district, Nong Na Kham district, Ban Haet district, Non Sila district, Wiang Kao district, and Mueang Khon Kaen district. The area is bound by the following provinces:

In the north: Udonrtani, Loei, and Nong Bua Lam Pu

In the south: Nakorn ratchasima, and Burirum

In the east: Kalasin, and Mahasarakam

In the west: Chaiyabhum, and Petchabun

The topography of the Khon Kean Province is characterized by highland plains and plateau. The western region is occupied by the Petchabun and Phu Kradung mountains. While to the east and west the area is covered with the plains area of the Chi and Phong river basin. The average sea level is about 200 meters. The weather conditions in the Khon Kaen Province is characterized by a pronounced seasonal variation including rains (May to October), winter (November to February), and summer (March to September). The temperature is generally about 27°C. The lowest and highest temperatures are 10.2 and 41.1°C, respectively. The average annual rainfall is about 1,467 millimeters.

Khon Kaen Province is the centre of development in the Northeastern region, especially in economic, social and education areas. The community and economy are growing rapidly, and this is causing an increase in the production of hazardous waste. The Public Information Center (PIC) reported in 2007 the total amount of hazardous waste produced in the Khon Kaen Province to be about 682 tons per year. The most hazardous waste comes from industrial waste. However, only a small part of the industrial hazardous waste is treated by licensed centralised treatment facilities. Most of the community hazardous waste is co-disposed with solid waste at the municipality disposal sites. Therefore, there is an urgent need not only for identifying suitable sites for new hazardous waste landfill for the treatment and disposal of hazardous waste, but also for finding suitable routes for the transfer of waste from factories to the landfill in the Khon Kaen Province.

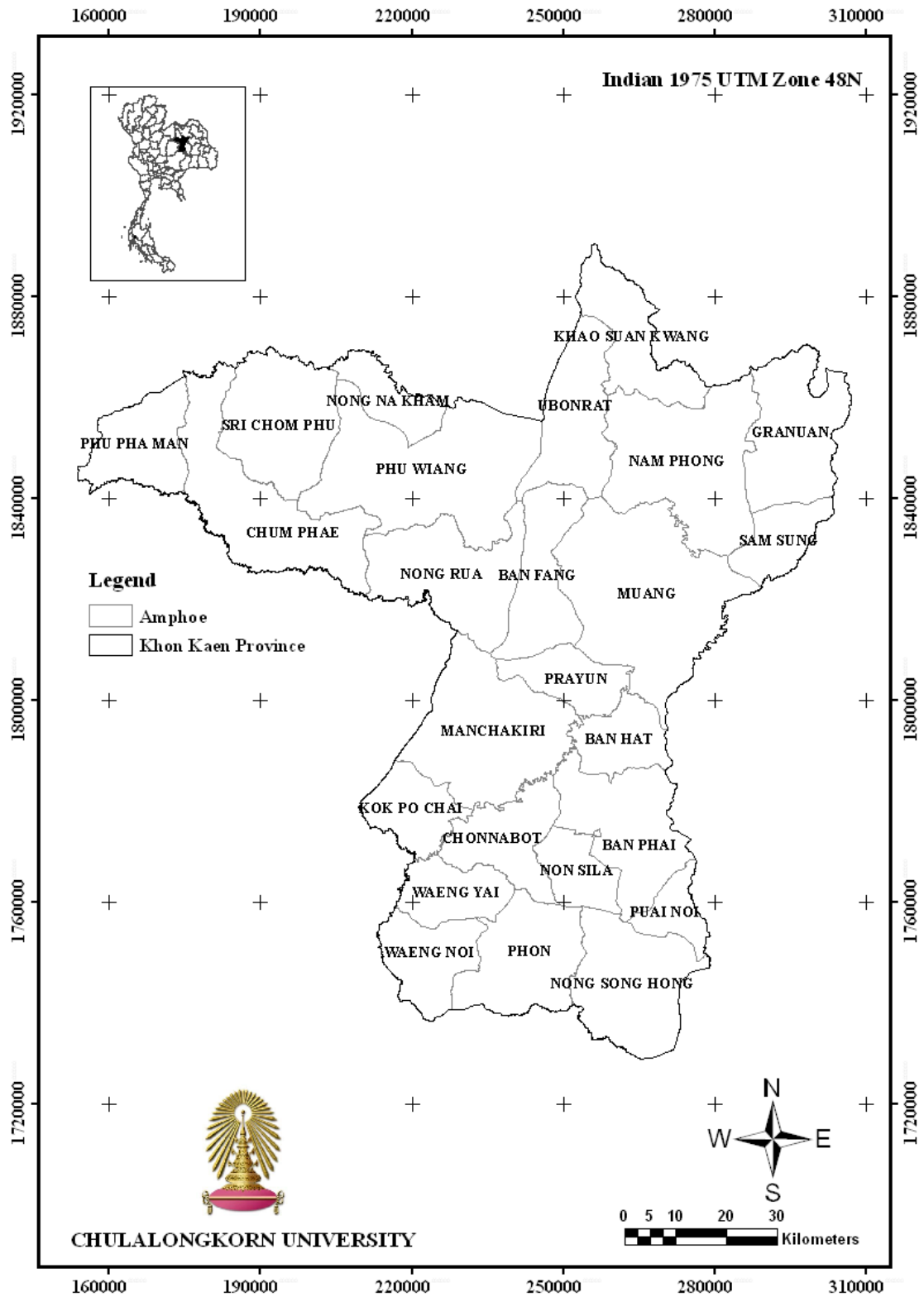


Figure 1 Khon Kaen Province

1.2 Objectives

The main objective of this study is to identify a suitable site for constructing a hazardous waste landfill within the Khon Kaen Province. The objective can be divided to four sub objectives as shown below:

1. To propose modified criteria for hazardous waste landfill from PCD Thailand.
2. To propose the process of identifying potential areas for hazardous waste landfill by using Geographic Information System (GIS).
3. To calculate and select the total area required for the next 20 years of hazardous waste landfill.
4. To propose a process of selecting a suitable transportation route for hazardous waste from the generator to disposal facilities by using GIS.

1.3 Hypothesis

Khon Kaen Province has a suitable site for constructing hazardous waste landfill with regards to environmental concerns and cost savings in the transportation of hazardous waste.

1.4 Scope of study

This study aims to select potential sites for hazardous waste landfill and is limited to the Khon Kaen Province. Only industrial hazardous waste is considered in the research. The application of the GIS technique is used in order to assist in identifying potential sites. The scope of the study included the following:

1. Integrating the criteria of hazardous waste landfills from U.S.EPA, PCD, and SPCB/PCC.
2. Selecting the potential areas according to the criteria for hazardous waste landfill sites in the study area using the application of GIS.
3. Selecting hazardous waste landfill sites to be used for the disposal hazardous waste for the next 20 years.

4. Analysing the selected hazardous waste sites based on the transportation costs of hazardous waste.
5. Discussing and providing conclusions on the findings.

1.5 Expected result

To be able to identify a suitable site for hazardous waste landfill and selecting suitable transport routes for hazardous waste from the generators to the disposal facilities within the Khon Kaen Province using GIS.

CHAPTER II

LITERATURE REVIEW

2.1 Hazardous waste

Hazardous wastes can be liquid, solid, or gas. It is potentially hazardous to the environment, human health, and living organisms if improperly managed (Batstone et al., 1989). According to the U.S.EPA., all hazardous waste generators must be identified their wastes in order to determine whether they are hazardous. Waste will be classified as a hazardous waste if it shows following characteristic: ignitability, corrosivity, reactivity or toxicity or in listed wastes (F-list, K-list, P-list, or U-list).

2.1.1 Characteristics of waste

1) *Ignitable hazardous waste*

- A liquid form of waste which has a flash point of lower than or equal to 140 degrees F (60 degrees C) as determined by an appropriate test method.
- A non-liquid form of waste which is capable of causing a fire through friction, absorption of moisture or a spontaneous chemical change, and when ignited the waste burns so vigorously and persistently that it creates a hazard.
- A gas form of waste that is ignitable when compressed or oxidizer.

2) *Corrosive hazardous waste*

- An aqueous waste with a pH of between 2 and 12.5.
- A liquid form of waste that corrodes steel at a minimum rate of 0.25 inch per year as determined by an appropriate test method.

3) *Reactive hazardous waste*

- A solid form of waste that is normally unstable, strongly reacts with water, or produces toxic gases when exposed to water or other materials.

- Capable of detonation or explosive reaction if subjected to a strong initiating source or heated under confinement.

4) Toxic hazardous waste

- A waste that contains certain substances (such as lead, arsenic, and mercury) determined to be harmful at or in excess of the maximum concentration.

2.1.2 Listed hazardous waste

1) F-list (waste codes F001 through F039)

The F-list contains hazardous wastes from non-specific sources which generated by various commercial or industrial processes. The list consists of solvents commonly used in degreasing, metal treatment baths and sludges, wastewaters from metal plating operations, dioxin containing chemicals or their precursors, and certain refinery wastes.

2) K-list (waste codes K001 through K136)

The K-list contains hazardous wastes generated by specific industrial processes. K-listed wastes include wood preservation, pigment production, chemical production, petroleum refining, iron and steel production, explosives manufacturing, and pesticides production.

3) P- and the U-list (waste codes P001-P123 and U001-U359)

The P- and U-lists contain discarded commercial chemical products, off-specification chemicals, container residues, and residues from the spillage of these chemicals. These lists include commercially pure grades of the chemical, any technical grades of the chemical that are produced or marketed, and all formulations in which the chemical is the sole active ingredient.

2.2 Hazardous waste sources

Generally, hazardous wastes are produced from many different chemical products and by many different types of business, industry, institution, and government agency. Large generators tend to be manufacturers of various products while small generators are most often in specific businesses. Below are examples of industries and processes that typically generate hazardous wastes (KDHE, 2006).

- Chemical Manufacturing
- Metal Fabrication
- Fiberglass Fabrication
- Chemical Formulation
- Wood Product Manufacturing
- Textile Manufacturing
- Metal Plating and Finishing
- Sandblasting Operations
- Pesticide Applicators
- Laboratories
- Vehicle Repair and Maintenance
- Furniture Refinishing
- Dry Cleaning
- Printing and Related Industries

In addition, sources of hazardous waste can be classified by human activities. It can come from several sources as follows.

1) Industrial hazardous waste

The major source of hazardous waste usually comes from industrial factories. Since most of production processes are generated waste, due to the material providing step, production step and after using the industrial product and provided that in the production process using chemicals, synthetic substances, metals and oil. The occasion of pelting away hazardous waste from production processes into the environment is increasing.

2) Household hazardous waste

Household was defined as a small section of hazardous waste generated in the world. The average household has varies items that fall under the category of hazardous waste. For example gasoline, batteries, antifreeze, and automobile oil are all considered as hazardous. Chemicals used to regulate and clean pools are normally toxic and hazardous. Even some cleaning products can be considered hazardous wastes. While the hazardous wastes that produced from homes is much less than that produced by industrial facilities, this waste must also be treated appropriately to decrease harmful effect to human and the environment.

3) Agricultural hazardous waste

Pesticides are often used in landscaping and agriculture. Many of the common chemicals in pesticides, such as diazanon, DDT, and malathion are toxic. The production of pesticides leads to hazardous waste. Currently, the EPA regulates the production of pesticides.

4) Hospital hazardous waste

Several of hospitals hazardous waste, such as tissue, infectious waste, and organs from patients, and from medical treatment including bodily fluids, and radioactive waste were leaved to environment to be contaminated with the municipal waste since inappropriate disposal.

2.3 Transportation

Due to rapid economic and industrial growth in local communities, the amount of hazardous waste has rapidly increased. The growth of the industrial and service sector without a proper management and planning system are key factors leading to potentially hazardous effects on the environment, human health, and living organisms. In addition, from the report by the DIW in 2008, most of the industrial hazardous waste recycling, treatment, and disposal facilities are located in the eastern and central parts of Thailand. In other parts of the country there are mostly small scale factories, especially in the south and the northeast, far away from waste processing facilities. This inhibits the factories from sending their waste to be processed outside the factory. In some cases they could not afford the disposal expenses. Thus, hazardous waste is stored in the factories (DIW, 2008).

The transportation of hazardous waste is an important issue. Due to the fact that the accidental release of hazardous waste occurring during transportation will often have further consequences. It is truly that the transport of hazardous waste will carry some risk to the public along the route. Thus the selection of the route for the transportation hazardous waste should be considered, based on minimizing the impact to the surroundings and being cost effective. It is important to note that the hazardous waste type and quantity, routing, and delivery time are not known by the public authorities, the highway companies, or by the population living in the territories traversed by these vehicles. In this respect, hazardous waste transportation on the road network actually represents a potentially high risk with regards to:

- The nature of the hazardous waste carried by the trucks and the physicochemical events associated with these materials (radioactivity, explosion, toxicity, corrosion, etc.);
- The nature, the localization and the density of the stakes (population, economic activities, buildings, networks, infrastructure, natural areas, etc.);
- The characteristics and state of the roads (topography, layout, presence of tunnels, etc.);
- The density of the traffic, and the environmental conditions (weather, natural events, etc.).

2.4 Generator categories

Any business or private that generates hazardous waste are defined as the word “generator” which can be categorized as three groups: Conditionally Exempt Small Quantity, Small Quantity, and Large Quantity as shown in the table 2.1 (Kentucky Division of Waste Management, 2009).

Table 2.1 Standard guideline for generator

| Conditionally Exempt Small Quantity | Small Quantity | Large Quantity |
|--|--|---|
| Not require for register and manifest | Require for register and manifest. | Require for register and manifest. |
| Their waste can be stored on-site if less than 100 kg/month but total accumulated not more than 1,000 kg | Their waste can be stored on-site for 90 days. | The waste can be stored on-site for 180 days. |
| Waste generated less than 100 kg/month | Waste generated more than 100 kg but less than 1,000 kg/month. | Waste generated more than 1,000 kg/month. |

Previous studies showed that the amount of hazardous waste in Thailand is increasing rapidly due to the expansion of its industrial base. The total

hazardous waste generated in 2001 was 1.65 million tons. Roughly, 300 million kg per year of hazardous waste is generated from non-industrial and community sources. However, there is a lack of a hazardous waste management system. To eliminate or minimize waste disposal problem, appropriate management practice is suggested (Ozaki et al., 2002). Several studies have suggested that certain technologies to reduce the waste quantity are put in place. The technologies include raw material alteration, in-plant minimization, equipment redesign, improved housekeeping and product substitution (Polprasert and Liyanage,

2.5 Landfill

Landfills are the physical facilities used for the disposal of residual solid waste within the surface soil of the earth. It is ultimately method to disposal waste. Normally, landfills are classified according to the kind of waste material disposed as;

Dumps refer to landfills that are not engineered with the special protection measures required by sanitary landfills,

Sanitary landfill refers to engineered facilities for the disposal of municipal solid waste. These usually have physical barriers such as liners and leachate collection systems. The landfill designs and operates to minimize impacts to human health and the environment,

Hazardous waste landfill refers to waste disposal units constructed to specific design criteria which receive waste meeting the local definition of hazardous waste. In general, these landfills are constructed to keep waste that indicates a serious hazard to human health, such as high-level radioactive waste. To be safe, double liner systems are the criterion for hazardous waste landfills. Locating sites for such landfill is a very difficult task to accomplish today. Due to the lack of ability to properly site, landfills has led to controversy and negative effects (Thoso, 2007). Hence, site selection plays an important role in hazardous waste management processes in order to ensure that the potential location for waste facilities consider environmental, social and economic concerns (Junggoth et al., 2008).

The U.S.EPA published a manual guideline for siting of hazardous waste disposal facilities as follows (U.S.EPA., 1997):

Flood plain: facilities should not being built on floodplains.

Wetlands: facilities should not be located in wetlands.

Ground water: facilities should be placed over low value groundwater or in areas where the underground conditions are not complex and clearly understood.

Earthquake zones: facilities are not allowed within 60 meters of a Holocene fault, a fault that has been active within the last 10,000 years.

Karst terrain: facilities should not be located in “active” karst areas.

Unstable terrain: it is possible to build a safe facility on unstable terrain; however, construction and operating costs would considerably high.

Unfavorable weather conditions: facilities that burn hazardous waste should not be placed where unsuitable weather conditions exist.

Incompatible land use: facilities not be placed near sensitive populations or in crowding areas.

The SPCB/PCC also published criteria for finding the location of hazardous waste landfill sites as follows (SPCB/PCC, 2010: online):

Physical site: The area of the site, which determines the lifetime of the landfill, depends on the site topography, the filling rate and method, and the availability of cover material. Most sites should have a capacity of at least 5 years.

Topography: Earth-moving and incompatible land use should be minimized. Site slope not more than 5% would be recommended in order to protect groundwater contamination which causing from site characteristic such as natural depression and valleys.

Soils: Highly permeable soil should not be recommended for the site with regard to daily cover, final cover, and liner system. And it should be located far away from sensitive erosion area and unstable soil/rock structure.

Public Parks: Landfill site should far away from public park area about 500 meters.

Highway: Landfill site should far away from highway about 500 meters.

Airport: Landfill site should far away from airports about 5,000 meters as notified by the regulatory authority or the aviation authority.

Habitation: Landfill site should far away from habitat area about 500 meters. The buffer zone area of landfill site about 500 meters must be declared a no-development area.

Critical Habitat Area: Landfill should far away from critical habitat areas and reserved forest zone. A critical habitat area means a sensitive endangered species area. If we cannot identify this area, the consultant from the SPCB/PCC would be required.

Ground Water Table Level: Landfill site should be located within low level of groundwater table in order to protect groundwater contamination problem. The recommend value is about 2 meters below the base of the landfill.

Water Supply: Landfill site should far away from water supply well about 500 meters.

River: Landfill site should far away from river and stream about 100 meters.

Lake or Pond: Landfill site should far away from lake and pond about 200 meters.

Flood Plain: Landfill site should not be located within a 100-year flood plain area, especially in the major rivers. However, in the secondary streams may be constructed if appropriate designed and embankment is constructed along the streamside.

Wetlands: Landfill site should not be located within wetland areas

Coastal Regulation Zone: Landfill site should not be located within a coastal regulation zone.

Air/Wind direction: Landfill site should not be located in windward, in order to minimize hazards effect to community area and environment sensitive area.

Aesthetics: Construction and operation of landfill sites should be considered visual impact from community area and road near the site. Buffer zone should be built to protect this impact.

In addition, if a landfill is located within a constrained area, then proper design measures are to be taken and prior permission from the SPCB/PCC should be obtained. If the other criteria are required, the planners should be consulted with the SPCB/PCC, commensurate with specific local requirements such as the presence of monuments, religious structures.

In Thailand, PCD is guideline criteria for hazardous waste disposal facilities as follows (PCD, 2010: online).

Topography: Site slope not more than 15 % would be recommended in order to protect groundwater contamination which causing from site characteristic such as natural depression and valleys.

Soils: Highly permeable soil should not be recommended for the site with regard to natural soil liner, daily cover, and final cover. (Suggested site hydraulic conductivity of not over 3×10^{-5}).

Geological: Avoid mineral resources and fault zones within a radius of 100 meters.

Groundwater table: Landfill site should be located within low level of groundwater table in order to protect groundwater contamination problem. The recommend is about 1.5 meters below the base of the landfill.

Flood Plain: Landfills do not locate in flood plain areas.

Major highway: Landfill should be located more than 100 meters but less than 10,000 meters from major highways.

Physical site: Typically, the area size of landfill should be at least 20 years. However, it should be regarded to site characteristic, generation rate of waste, and type of landfill.

Communities or residential areas: Landfill should be located more than 3,000 meters from such areas.

River or water resources: Landfill should be located more than 300 meters from such resources.

Water Supply: Landfill should far away from water supply well about 700 meters.

Religious, historic sites, conservation areas: Landfill should not be located in these areas.

Airport: Landfill should not be constructed within 5,000 meters of airports as notified by the regulatory authority or the aviation authority.

Watershed areas: Landfill should not be located within watershed class 1 and class 2 watershed areas.

2.6 GIS

2.6.1 Definition of GIS

There are many definitions of a geographic information system, each depending upon its perspective such as;

GIS is a computer system capable of collecting, storing, managing, manipulating, analyzing and representing geographic information (Aronoff, 1989).

A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information (ESRI, 2010: online).

From the definitions above, it can be concluded that the meaning of GIS is a system of hardware, software and a process to accommodate the management, manipulation, analysis, modeling, representation and display of geo referenced data to solve complex problems regarding the planning and management of resources.

2.6.2 Components of GIS

GIS consists of five key components: hardware, software, data, people, and methods.

1) Hardware

Hardware is the computer on which the GIS operates. Today, GIS runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations.

2) Software

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are:

- a database management system (DBMS)
- tools for the input and manipulation of geographic information
- tools that support geographic query, analysis, and visualization
- a graphical user interface (GUI) for easy access to tools.

3) Data

The most important component of a GIS is possibly the data. Geographic data and related tabular data can be collected in-house or bought from a commercial data provider. Most GISs employ a DBMS to create and maintain a database to help organize and manage data. A GIS database can be divided into 2 types: spatial data and non-spatial data. Each of these types has specific characteristics and different requirements for efficient data storage, processing and display.

- **Spatial data** is defined as the data component that is used for presenting the appearances of the spatial feature. Spatial data are divided into 3 types: point features, line features, and polygon features.
- **Non-spatial data** is defined as the data component that is used to describe the different characters of the non-spatial data in the study area. For example population number, types of street, and height above mean sea level.

4) People

Personnel, which are one of the important components within a GIS network, are often overlooked because they are not typically considered to be components within other types of information systems. However, users should not neglect the importance of trained personnel. Personnel within a GIS network can be defined as users who have been specifically trained in the use of GIS hardware, software, spatial data, and procedures. Using these components, trained personnel are

able to perform a variety of spatial analysis functions such as spatial data input, manipulation, analysis, and output.

5) Methods

In terms of GIS technology, procedures provide systematic instructions for achieving accurate results during spatial analysis, illustrate the order of the processes and relationships among inputs using “easy to read” diagrams, enable users to automate task that are performed repeatedly, and simplify the process of creating spatial databases that conform to standards.

2.6.3 GIS for landfill site selection

Lindquist (1991) identified the advantages of applying GIS in assisting the siting of landfill, such as screening out process based on a set of defined criteria, the capability of handling complicated geographic data, flexibility in implementing “what if” analysis, and the display and graphical representation of the results. It is also capable of transportation route analysis for hazardous waste from generators to disposal facilities in order to save management costs and reduce potential hazards to the environment, human health, and living organisms around the area. This tool plays an important role in regional screening for landfill sites. Since, software can define sites that fulfill all the requirements, and save a lot of costly fieldwork (BCRC, 2005).

Several previous studies have used GIS to identify potential sites for landfill, for example a study of integrated multi-criteria decision analysis and geographic information systems developed in order to find suitable hazardous waste landfill sites in Kurdistan Province, western Iran. GIS was utilized to perform an initial screening process to eliminate unsuitable areas. Afterward, multi-criteria decision analysis (MCDA) identified the most suitable sites using the information provided by the regional experts with reference to new chosen criteria (Mozafar et al., 2009). An integrated GIS, expert system (ES), and analytic hierarchy process (AHP) was developed find the most suitable hazardous waste landfill site in Khon Kaen Province, Thailand (Junggoth et al., 2008). GIS technology was used to find the most preferable site for a landfill in Nakhon Pathom Province, Thailand to accommodate solid waste for the next 20 years (Jamjan, 2009). GIS was used to find the potential areas for disposal sites and assess the selected disposal sites based on soil characteristics and groundwater levels (Thanasate-angkool, 2006). GIS was applied

for the selection of potential areas to be used as landfill sites in the Pathumthani Province, and an area of 1,500 square kilometers was selected by considering the relevant environmental factors using Arcinfo and ArcView programs (Kerdput, 1999). The result was classified into 5 classes of suitable areas; most suitable, suitable, moderately suitable, less suitable, and unsuitable. The most suitable areas are mainly located in Amphoes Nongsua, Lat Lum Kaeo, Lumlukka, Thanyaburi, Khlong Luang, and Muang Pathum Thani, respectively. The analysis of the preferred landfill sites in the Khon Kaen province used GIS and a Visual HELP computer program, where the criteria from the PCD and some additional criteria from the Changwat Action Plan for Environmental Quality Management project were input (Thaiyathum, 2005). Within this approach, 3 levels of sensitive areas were determined as highest, high, and medium to low environmental sensitive areas using GIS, then impacts of the sensitive areas in terms of the volume of leachate percolation were assessed using the Visual HELP computer program. The study explains a process in order to determine how to locate suitable sites for hazardous waste landfill by using the site screening technique.

2.6.4 GIS network analysis

GIS network analysis is an appropriate tool to use for solving network problems, such as selecting of the best route for transportation based on travel time or distance. For the study, GIS network analysis was used to find the suitable transportation route for hazardous waste from generator to disposal facilities.

Many GIS applications in routing analysis were studied, for instance the researchers assessed the hazardous materials transport risk in a multicommodity, multiple origin-destinations setting by using GIS as a tool. A GIS-based system was developed for assessing the trucking of shipments of dangerous goods on the Quebec and Ontario highways in Canada. The proposal of a developed network was evaluated to minimize transport distance, population exposure, the expected number of people to be evacuated in the case of an incident, and the probability of an incident during transportation (Verter and Kara, 2001). In similar, a GIS based hazardous waste transport system was developed to reduce the impact of potential incidents regarding hazardous waste shipments through an urban area. The facilities most sensitive to the impact of accidents, such as schools, hospitals, and daycare centers were avoided where practical in the routing of hazardous material transport (Panwhar and Pitt,

2001). A GIS optimal routing model was also demonstrated to determine the minimum cost/distance efficient collection paths for transporting the solid waste to the disposal facilities for the Asansol Municipality Corporation (AMC) of West Bengal State in India. The information used in the model included population density, waste generation capacity, road network and the types of road, storage bins, and collection vehicles (Ghose, Dikshit, and Sharma, 2006). Furthermore, the framework based on an integrated Multi Criteria Decision Analysis (MCDA) and GIS approaches for making optimum hazardous waste route planning choices was developed by including environmental considerations. A framework has been tested for a regional hazardous waste transport system from the Map Ta Phut Industrial Estate, Rayong Province, eastern Thailand to an incinerator plant located in the Saraburi Province, central Thailand (Monprapussorn, 2009).

CHAPTER III

MATERIALS AND METHODOLOGY

This section describes the materials and methodology used in the selection of a suitable hazardous waste landfill site in the Khon Kaen Province using Geographic Information Systems (GIS). The details can be described as follows:

3.1 Materials

Materials used for analyzing data to find the potential sites include GIS data maps of the study area, computer hardware, and software. The GIS data maps for this study were obtained from:

- 1) Royal Thai Survey Department,
- 2) Natural Resources Conservation Office, Royal Forest Department,
- 3) Groundwater Research Center, Faculty of Technology, Khon Kaen University,
- 4) Office of the Environment Policy and Planning, Ministry of Science Technology and Environment,
- 5) Office of Archaeology and National Museum Khon Kaen, The Fine Arts Department,
- 6) Khon Kaen Regional Environmental Health Centre, Ministry of Public Health, and
- 7) Khon Kaen Regional Environment Office, Ministry of Environment and Natural Resources.

The computer hardware and software that were used in this study included a personal computer (AMD Turion (tm) 62x2 Mobile Technology TL-52, 1.61 GHz, 1 GB of RAM, Hard disk 120 GB) and an ArcGIS Desktop from the Environmental Systems Research Institute (ESRI).

3.2 Methodology

In the study, modified criteria from the Pollution Control Department of Thailand (PCD) were used in order to determine suitable criteria for use in this

study (Table 3.1). Due to the fact that each area in Thailand has different environmental characteristics with respect to their topography, hydrology, geology, etc., the siting criteria should therefore be used flexibly to help make better decisions. The criteria were selected by taking into account the environmental characteristic of the area.

Table 3.1 Modification criteria

| Factors | Buffer zone | Restriction zone |
|----------------------------|---|--|
| Watershed class | | Class 1, 2 [#] |
| Flood risk | | < 25 years [#] |
| Streams and lakes | 300 meters [#] | |
| Groundwater table | | < 1.5 meter from bottom of landfill [#] |
| Recharge | | Not located [@] |
| Wells | 700 meters [#] | |
| Wastewater treatment plant | 700 meters [#] | |
| Soil group | | High permeable soil [@] |
| National park | | Not located [*] |
| Forest zone | | Not located [*] |
| Major roads | > 100 meters and < 10,000 meters [#] | |
| Airport | 5, 000 meters [#] | |
| Communities | 3,000 meters [#] | |
| Heritage | 1,000 meters [#] | |
| Aquifer | | High yields and high quality of groundwater [@] |
| Mining | 100 meters [#] | |

Remark: Criteria from PCD ([#])

Criteria from U.S.EPA (^{*})

Criteria from SPCB/PCC ([@])

The methodology is divided into 3 main steps; screening potential areas, selection of potential sites, and selection of the suitable sites.

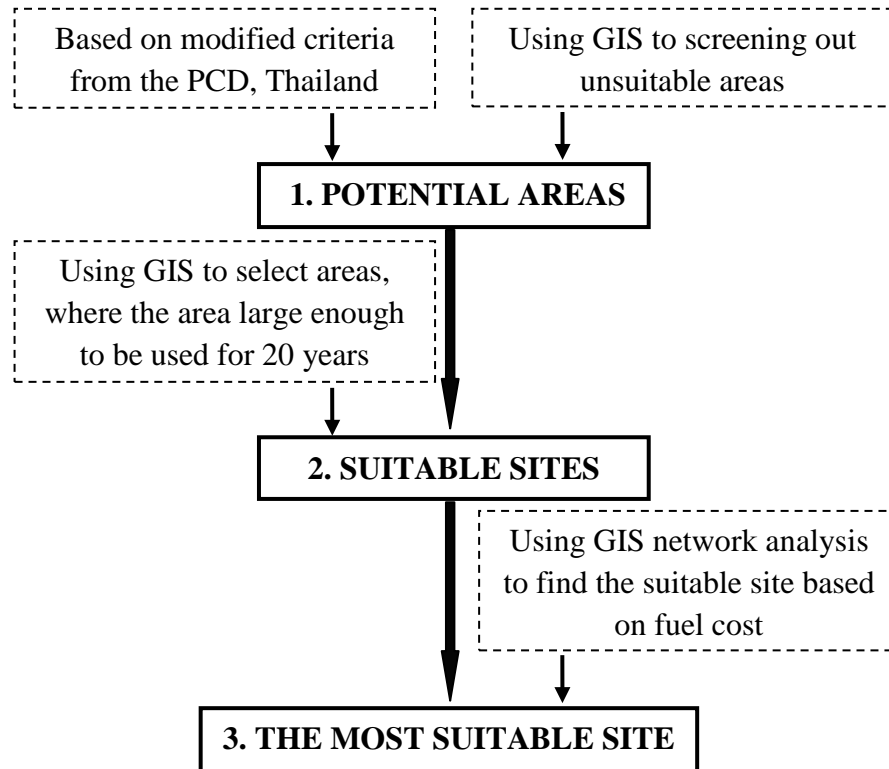


Figure 3.1 Flowchart of methodology

3.2.1 Screening potential areas

In the first step, using modified criteria from the PCD as described above, these factors were analyzed by using the overlay technique of the GIS software package. GIS data sets of watershed classes, flood risks, streams, lakes, groundwater tables, recharge areas, wells, wastewater treatment plants, soil groups, national parks, forest zones, major roads, airports, community areas, heritage, and mining areas were prepared and evaluated using ArcGIS software. The positive map and negative map were established by reclassification and constructing a buffer zone of the negative areas.

The positive area is defined as the area that is suitable for use as a hazardous waste landfill site, which is considered by the suitable characteristics of soil, major roads, groundwater table and aquifers. The overlay technique is described below:

- The map of the positive soil group is the map of permeable soil as selected from the soil group map.
- The map of the positive areas of the major highways within 100 meters and not more than 10 kilometers as selected from the major highways map.
- The map of positive groundwater table is the area of groundwater contours higher than 1.5 meters as selected from the groundwater contour map.
- The map of positive aquifer is the area of low yields and low quality of groundwater as selected from the aquifer map.

All positive areas will be grouped together by using the union tool in GIS software.

The negative area is defined as the environmental sensitive receptors to be impacted on by the hazardous waste landfill site. The negative map also consists of watershed class, flood risk, streams, lake, recharge, wells, wastewater treatment plant, national park, forest zone, airport, communities, heritage, and mining. The details are described below:

- Watershed areas class 1A, 2A and 2B were selected from the watershed map.
- High risk area of flood was selected from the flood risk map.
- A 300 meters buffer zone was created around the stream and lake maps.
- The areas allowing water to readily seep into the ground to replenish an aquifer were defined as negative areas.
- A 700 meter buffer zone was created around the wells map.
- A 700 meter buffer zone was created around the wastewater treatment plant map.
- Forest zone C was selected from the reservation forest map.
- All national parks was selected from national park map
- A 5,000 meter buffer zone was created around the airport map.
- A 3,000 meter buffer zone was created around the communities map.
- A 100 meter buffer zone was created around the historical site and mining map.

All negative areas were grouped together by using the union tool in GIS software.

After using overlay technique in the GIS software, positive maps and negative maps were intersected, and then non-intersected positive areas were the potential areas for hazardous waste landfill sites of Khon Kaen Province.

3.2.2 Selection potential site

Normally, when designing a hazardous waste landfill system the calculations should be based on a disposal period of 20 years, in order to cover the construction costs of the site (PCD, 2009). In addition, the amount and composition of hazardous waste, density of hazardous waste after compression, amount of daily cover, and height of landfill should be considered. The area required for constructing a landfill system can be calculated from the following equation (Chiangmai University, 2003):

$$A = \frac{V \times k}{H}$$

Where

- A = total area required for landfill system (m²).
- V = volume of waste in landfill (m³).
- H = height of landfill in class (not including soil to cover).
- k = constant of buffer zone around constructed buildings, liquid waste system and tree planting.

V value can be calculated from the following equation:

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

Where

- N = number of years for landfill operation (years)
- W = amount of waste in landfill per year (tons/year)
- D = density of waste compression (ton/m³)

After the area has been calculated, those areas insufficient were screened out from the potential areas. A sufficient area is defined as a potential site for constructing a hazardous waste landfill.

3.2.3 Selection the most suitable site

For the final step, to solve the routing problem in this study, GIS Network Analysis was used. Factors for consideration in this matter are amount of hazardous waste and route to transport waste. The study only considered hazardous waste that can be disposed of by hazardous waste landfill, hazardous waste that can be disposal of by other means were not considered. Only 17 of the 41 generators within the Khon Kaen province were considered in this study based on the permit requests for the release of hazardous waste with DIW. Therefore, data used for this study were grouped into the following consideration.

- **Spatial data** including:

- Road network data was obtained from the Royal Thai Survey Department. This data was digitized from 1:50000 scale maps.
- Political boundary data was obtained from the Office of National Statistics, Office of the Prime Minister (Tombon boundary) and the Royal Thai Survey Department (Amphoe and Province boundaries). These data were digitized from 1:50000 scale maps.
- Potential sites were obtained from the steps of screening and selecting potential sites as described previously.
- Generators location was obtained from DIW.

- **Non-spatial data:**

- Amount of hazardous waste produced by each generator (Table 3.2).

Table 3.2 Hazardous waste generators

| Generator | Generate (ton/years) | Longitude | Latitude |
|------------------|---------------------------------|------------------|-----------------|
| 1 | 13.00 | 16.48 | 102.42 |
| 2 | 1.39 | 16.34 | 102.80 |
| 3 | 176.50 | 16.68 | 102.73 |
| 4 | 10.30 | 16.07 | 102.72 |
| 5 | 22.00 | 16.67 | 102.75 |
| 6 | 41.50 | 16.48 | 102.83 |
| 7 | 22.50 | 16.72 | 102.84 |
| 8 | 3.00 | 16.17 | 102.75 |
| 9 | 52.60 | 16.70 | 102.75 |
| 10 | 0.57 | 16.23 | 102.76 |
| 11 | 5.00 | 16.55 | 102.82 |
| 12 | 0.50 | 16.73 | 102.84 |
| 13 | 3.80 | 16.84 | 102.85 |
| 14 | 50.00 | 16.42 | 102.71 |
| 15 | 6.60 | 16.70 | 102.74 |
| 16 | 0.70 | 15.78 | 102.60 |
| 17 | 5.00 | 16.12 | 102.74 |
| 18 | - | 16.73 | 102.84 |
| 19 | - | 15.81 | 102.64 |
| 20 | - | 16.37 | 102.80 |
| 21 | - | 16.33 | 102.44 |
| 22 | - | 16.70 | 103.05 |
| 23 | - | 16.02 | 102.70 |
| 24 | - | 16.53 | 102.11 |
| 25 | - | 16.52 | 102.14 |
| 26 | - | 16.38 | 102.81 |
| 27 | - | 16.67 | 101.83 |
| 28 | - | 16.44 | 102.71 |
| 29 | - | 16.18 | 102.75 |
| 31 | - | 16.05 | 102.77 |
| 32 | - | 16.73 | 102.81 |
| 33 | - | 16.44 | 102.81 |
| 34 | - | 16.46 | 102.83 |
| 35 | - | 16.44 | 102.66 |
| 36 | - | 16.70 | 102.93 |
| 37 | - | 16.30 | 102.88 |
| 38 | - | 16.43 | 102.89 |
| 39 | - | 16.43 | 102.84 |
| 40 | - | 16.39 | 102.81 |
| 41 | - | 16.33 | 102.82 |

Remark: The amounts of hazardous waste are the industrial waste that the generator generated and need to send it to landfill.

3.2.3.1 Data Preparation

Since these data were collected from various sources, thus, in order to carry out an analysis on the road network, all required data were rectified and a network dataset was created for use in the analysis phase. The road network was represented as a connection of nodes and links. The nodes represent the road intersections and the links represent the homogeneous road segments. A network dataset is built into GIS to construct and maintain connectivity with the road data in order to allow path finding analysis to be conducted. The data were prepared as follows:

1. The road networks from 26 Amphoes have been selected from the database, only road types 1 (highway), 2 (rural road), and 3 (rural road) were considered in the study. Four new fields have been added to the road attribute, namely kilometers per fuel used, fuel used, cost per liter, and total cost for the purposes of the network analysis phase.
2. After the potential sites have been selected from the previous step, they are then converted from a polygon feature class to a point feature using the feature to point (management tool in the GIS extension) in order to prepare the coordinates of each potential site.
3. Generator location has been added as a new field, namely the longitude, latitude, and amount of hazardous waste produced by each generator, for the purposes of the network analysis phase.

3.2.3.2 Determining the best route

The best route can mean different things in different situations. The best route can be the quickest, shortest, or most scenic route, depending on the impedance chosen. For instance, if the impedance is distance, then the best route is the shortest route. Hence, the best route can be defined as the route that has the lowest impedance. Any valid cost attribute can be used as the impedance when determining the best route.

3.2.3.3 Dijkstra's algorithm

Dijkstra's algorithm (Dijkstra, 1959) is an algorithm for finding the shortest path from a single source vertex to other vertex in a weighted, directed graph.

All weights must be non-negative (the Code Project, 2011). The concept of Dijkstra's algorithm works in the following way. Beginning at the target vertex, it checks for each vertex with an incoming edge to the current one; if the path over the current vertex is shorter than that previously found it replaces it. The same operation is then conducted for this vertex. The algorithm is aborted when all vertices have been scanned.

3.2.3.4 Performing ArcGIS Network analysis

The four basic steps for performing any type of network analysis in ArcGIS were:

1. Creating the analysis layer

New network locations for use in the network analysis were created with the create network location tool. Network analysis layers are composite layers in ArcMap used to store inputs, properties, and the results of the network analyses. The network analysis layers were used for the analysis based on various methods as following:

- If used for finding the shortest route based on the real road network, the input network locations (stops and barriers), properties, and the resultant of the shortest route were used as the analysis layer.
- If used for finding the shortest route based on road type, the input network locations (potential site, generator, and barriers), properties, and the results of the shortest route were used as the analysis layer.
- If used for finding vehicle routing problem method, the input network analysis locations (orders, depots, routes, depot visits, breaks, route zones, route seed points, route renewals, specialties, order pairs and barriers), properties, and the results of the vehicle routing problem were used as the analysis layer.

2. Adding network locations

Add locations to one or more network analysis classes (such as stops, barriers, routes, and route zones). Moreover, we can select or move network locations through the Select/Move Network Location tool.

3. Setting analysis properties

Each type of analysis has specific properties of its own which depend on usage. The properties that are used for the network analysis depend of the

impedance to be used, the restrictions to be obeyed, the U-turn policy, output shape type, accumulation attributes, and properties for finding network locations.

4. Performing the analysis and displaying the results

The result varies with the type of analysis performed and there was a new network analysis layer generating after analysis was performed.

3.2.3.5 Study scenarios

In this study, analysis was performing for finding the suitable sites by using the three methods with different scenarios: 1) finding shortest distance by straight line; 2) finding shortest route by road network; and 3) finding shortest route by real road type, with the purpose of comparing the distance and fuel costs for transportation from each analysis.

1. Finding shortest distance by straight line

In the first case, point distance analysis is a simple method to determine the distances from the input feature point (potential site) to all near feature points (generators) within a specified search radius, which is based on Pythagoras' Theorem (Sally, 2007). Figure 3.2 shows the concept of finding the distance by a straight line between an input feature point and near features points. Thus, the assumption of this case was shown as follow:

- a. amount of hazardous waste produced is the same for all generators.
- b. each generator transports waste separately and independently.
- c. a ten-wheel truck transport waste in a single trip.

Therefore, the output of this step is the most suitable site with the minimum distance for hazardous waste transportation. The equation for the minimum total distance is shown below.

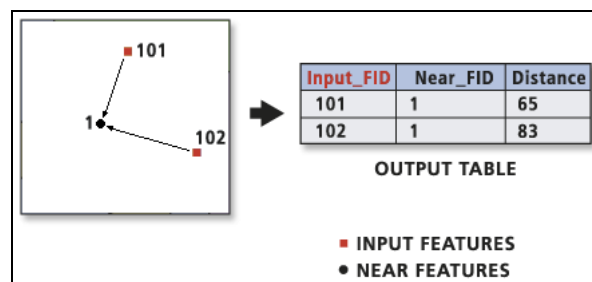


Figure 3.2 Concept to find the distance

Total fuel cost for transportation = $(D_t)(U)(F)$

$$D_t = \min \left\{ \sum_{i=1}^n (D_{i1} + D_{i2} + \dots + D_{in}) \right\}$$

Where

U = Unit fuel cost (baht/liter)

F = Fuel used (liter/kilometer)

D_t = minimum total distance of each generator to potential site (kilometer)

D_i = distance from generator to potential site (kilometer)

n = number of generators

i = index of generators

2. Finding shortest route based on road network

Finding the most suitable site which uses the minimum fuel cost and shortest route for transporting hazardous waste from each generator to potential sites is based on the following assumptions:

- a. amount of hazardous waste produced is the same for all generators
- b. each generator transports waste separately and independently.
- c. a ten-wheel truck transport waste in a single trip.

The distance affects the cost for transportation. Therefore, the only influencing factor was the distance from the generators to each potential site. GIS network analysis based on Dijkstra's algorithm was used in this step. A potential site (from the previous step), generator coordinates and road network were considered in order to create a network dataset for this analysis. Potential site and generator site were used as the stops and the distance was used as the impedance. The output of this step gives the suitable site with minimum distance of hazardous waste transportation. The equation of minimum total distance was shown below.

Total fuel cost for transportation = $(D_t)(U)(F)$

$$D_t = \min \left\{ \sum_{i=1}^n (D_{i1} + D_{i2} + \dots + D_{in}) \right\}$$

Where

U = Unit fuel cost (baht/liter)

F = Fuel used (liter/kilometer)

D_t = minimum total distance of each generator to potential site (kilometer)

D_i = distance from generator to potential site (kilometer)

n = number of generators

i = index of generators

3. Finding shortest route based on real road type

Finding the most suitable site which the minimum fuel cost and the shortest route for transporting hazardous waste from each generator to potential sites was based on the following assumptions:

- a. amount of hazardous waste produced is not the same for all generators
- b. each generator transports waste separately and independently
- c. road types to be considered in this study include road type 1, type 2, and type 3. Fuel used for road type 1 is defined as 0.25 liters per kilometer, while road type 2 and type 3 are defined as 0.33 liters per kilometer
- d. a ten-wheel truck has capacity of 10 tons.

For this analysis, the average fuel used of each road type and truck capacity was determined for the study only, which based on Nissan Diesel Company (Nissan Diesel, 2011: online). In fact, fuel consumption may be different, depending on many factors such as engine specifications, road type, speed used, and carrying weight. Thus, the distance, type of road, and truck capacity affect the cost of transportation. Therefore, the influencing factors were the distance of generators from each potential site, fuel used for each road type (type1, 2, and 3), amount of hazardous waste produced by each generator, and truck capacity. GIS network analysis based on the Dijkstra's algorithm was used in this step. A potential site (from the previous step), generator coordinates and road network were considered in order to create a network dataset for this analysis, while distance was used as the impedance. The output of this step gives the best suitable site with the lowest total fuel cost for

transportation. The equation for total fuel cost of transportation and minimum total distance is shown below.

Total fuel cost for transportation = $(F_t)(U)$

$$F_t = \min \left\{ \sum_{i=1}^n (F_{i1} + F_{i2} + \dots + F_{in}) \right\}$$

$$F_i = R_i \{ 0.25 (D_{iR1}) + 0.33 (D_{iR2} + D_{iR3}) \}$$

R_i = total waste from generator/truck capacity

Where

U = Unit fuel cost (baht/liter)

F_t = minimum total fuel used for transporting waste from each generator to potential site (liter)

F_i = fuel used for transporting waste from generator to potential site (liter)

$D_{R1, \text{ or } 2, \text{ or } 3}$ = distance of road type 1, or 2, or 3

n = number of generators

i = index of generators

CHAPTER IV

RESULTS AND DISCUSSION

Modified hazardous waste criteria from PCD were used to determine a suitable hazardous waste landfill site in the Khon Kaen Province. GIS was considered the appropriate tool for the study to identify the best suitable site and select the best route for hazardous waste transportation by using GIS network analysis. The process can be described as follows:

4.1 Identification of potential area

Modified hazardous waste criteria from PCD were used as a screening step. The screening of potential areas in the Khon Kaen Province for hazardous waste landfill sites were analyzed by using GIS techniques. All information was overlaid to find potential areas. The positive and the negative areas were overlaid and analyzed. This was done layer-by-layer or criteria-by criteria. The screening step was proceeded by:

1) The permeability of the subsoil of a landfill site has an important role to play in the development of the landfill as it acts like a barrier to leachate. In ideal situation, the permeability of the soil should be about 1×10^{-7} centimeter/second. Hence, the map of positive soil groups is the map of low permeability soil which is selected from the soil group map (Figure 4.1).

2) To minimize the visual impacts associated with a landfill from contiguous highways. The positive areas that were far away from the highways by more than 100 meters and less than 10 kilometers were selected from the major highways map (Figure 4.2).

3) To prevent contamination of groundwater from leachate, the positive areas of groundwater table which were deeper than 1.5 meters were selected from the groundwater contour map (Figure 4.1). The positive area of low yields and low quality of groundwater were selected from the aquifer map (Figure 4.1), and areas allowing water to readily seep into the ground to replenish an aquifer were defined as negative areas and were selected from the recharge map (Figure 4.3).

4) To minimize the threat posed by a landfill to:

a) cause destruction or adverse modification to critical habitats of endangered or threatened species

b) jeopardize the continued existence of endangered or threatened species, or

c) contribute to the taking of endangered or threatened species.

Therefore, the negative areas of the watershed (class 1A, 2A, and 2B), forest zone C, and all national parks were selected from the watershed area (Figure 4.4), reservation forest area (Figure 4.5), and national park area (Figure 4.6),

5) To minimize the potential of storm water flows associated with a 25-year flood event to;

a) disturb or erode the landfill cover,

b) disturb and wash out in-place waste,

c) impact on environmental monitoring systems, or

d) restrict the flows associated with the 25-year flood event or reduce the water storage capacity of the floodplain. Thus, high risk areas of flood were selected from the flood risk map (Figure 4.7).

6) To minimize the potential of surface water runoff from a landfill to impact on a perennial stream, lake, or pond with contaminated runoff, sediment load, and/or waste, a 700 meter buffer zone was created around the wells map (Figure 4.8) and wastewater treatment plant map (Figure 4.12), while a 300 meter buffer zone was created around the stream (Figure 4.9) and lake (Figure 4.10) maps.

7) A 3,000 meter buffer zone was created around the community areas map (Figure 4.11) in order to minimize the potential of the landfill sites to be located near or within populated areas, and minimize the visual impacts associated with a landfill from public parks and recreational areas.

8) A 5,000 meter buffer zone was created around the airport map (Figure 4.12) in order to minimize the potential of random bird strikes upon aircraft during departure and landing at airports.

9) To minimize the threat posed by a landfill to irreplaceable historic or archeological sites a 100 meter buffer zone was created around the historical sites map (Figure 4.12).

10) A 100 meter buffer zone was created around the mining map (Figure 4.12) to minimize the threat to them posed by a landfill site.

After using the overlaying technique in the GIS software, positive and negative maps were intersected and then non-intersected positive areas were identified as suitable areas for hazardous waste landfill sites in the Khon Kaen Province (Figure 4.13). Therefore, the results showed that there were forty potential locations suitable for hazardous waste landfill sites (Table 4.1).

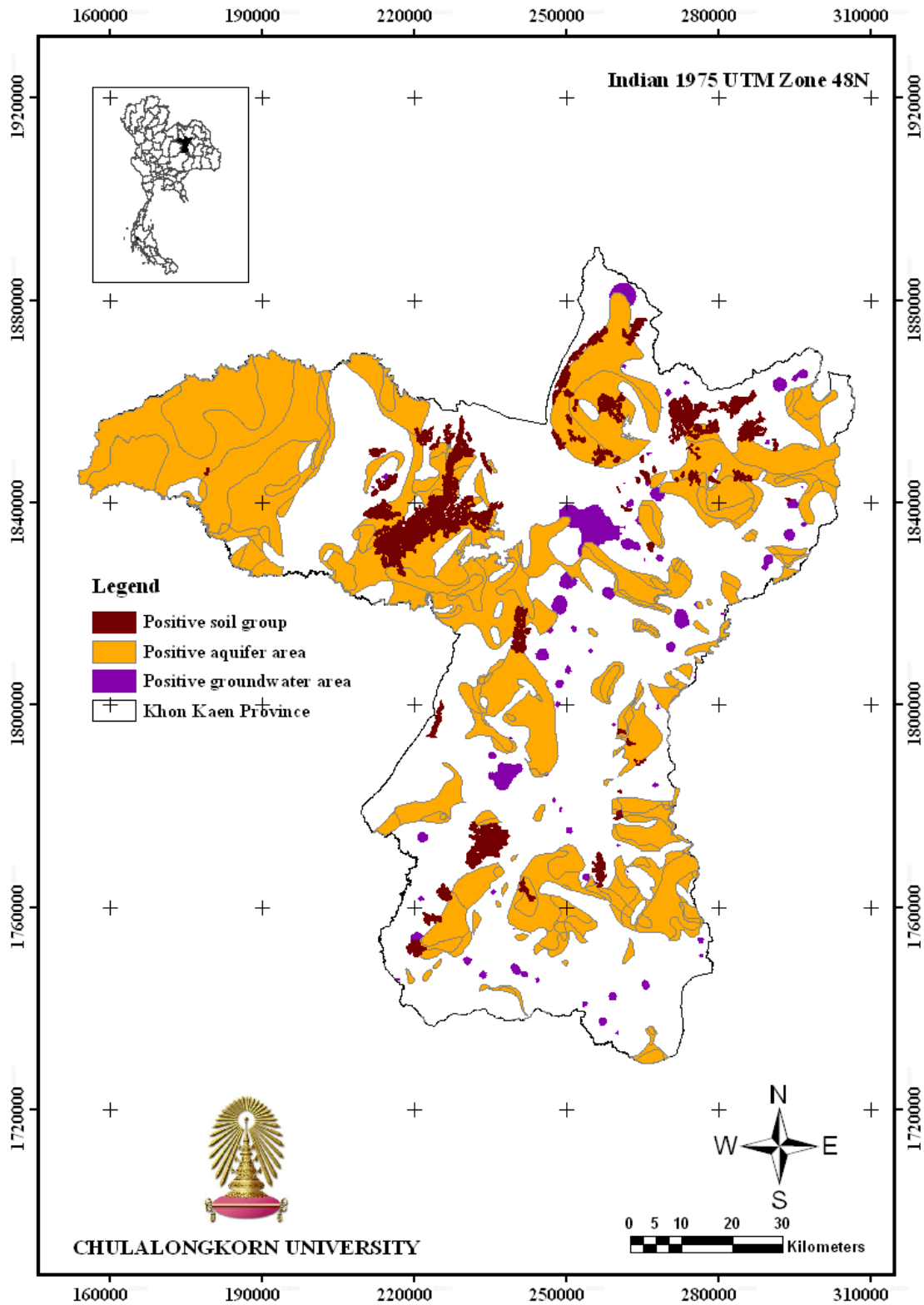


Figure 4.1 Map of positive soil group, aquifer, and groundwater table

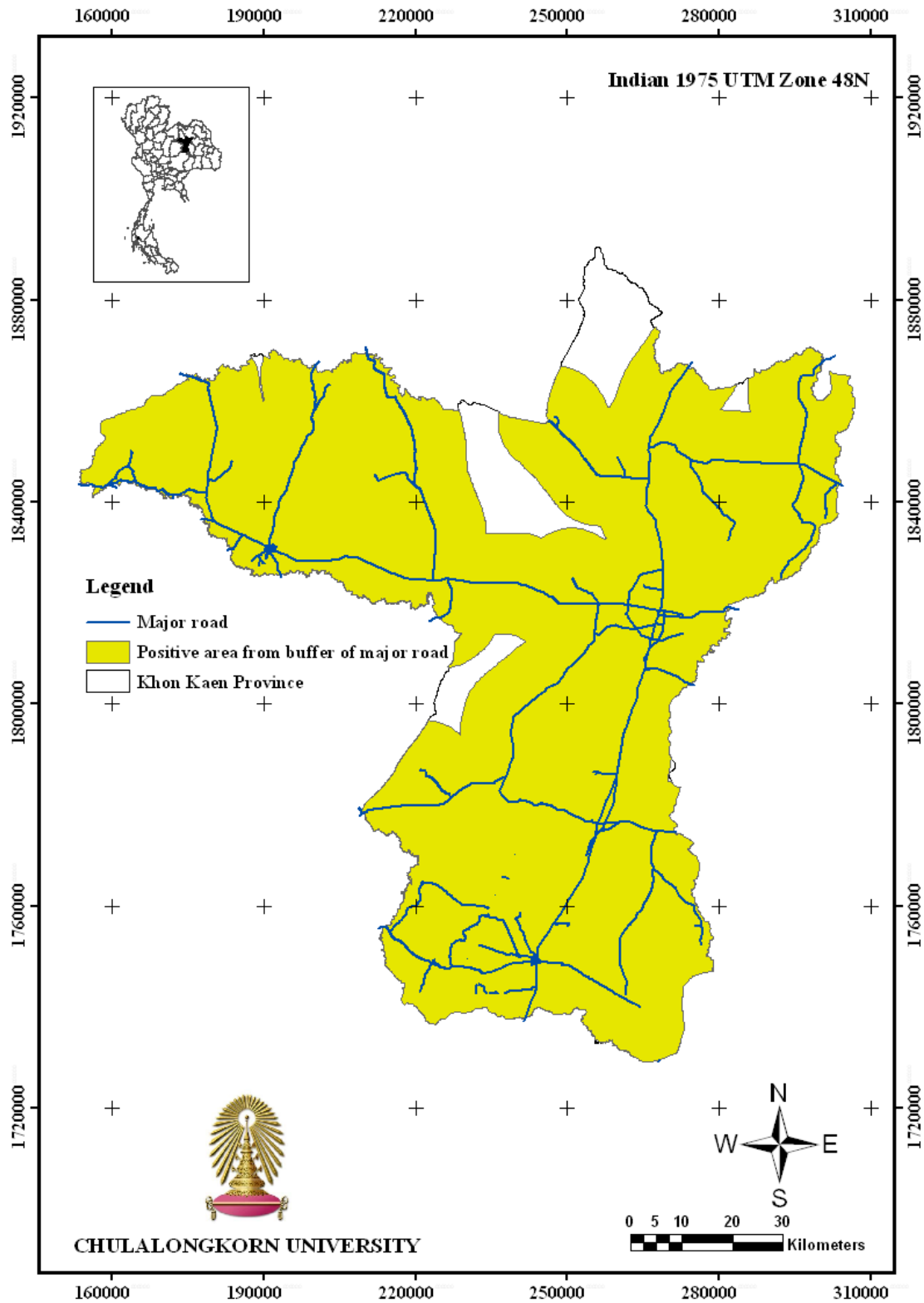


Figure 4.2 Map of positive major road buffer areas

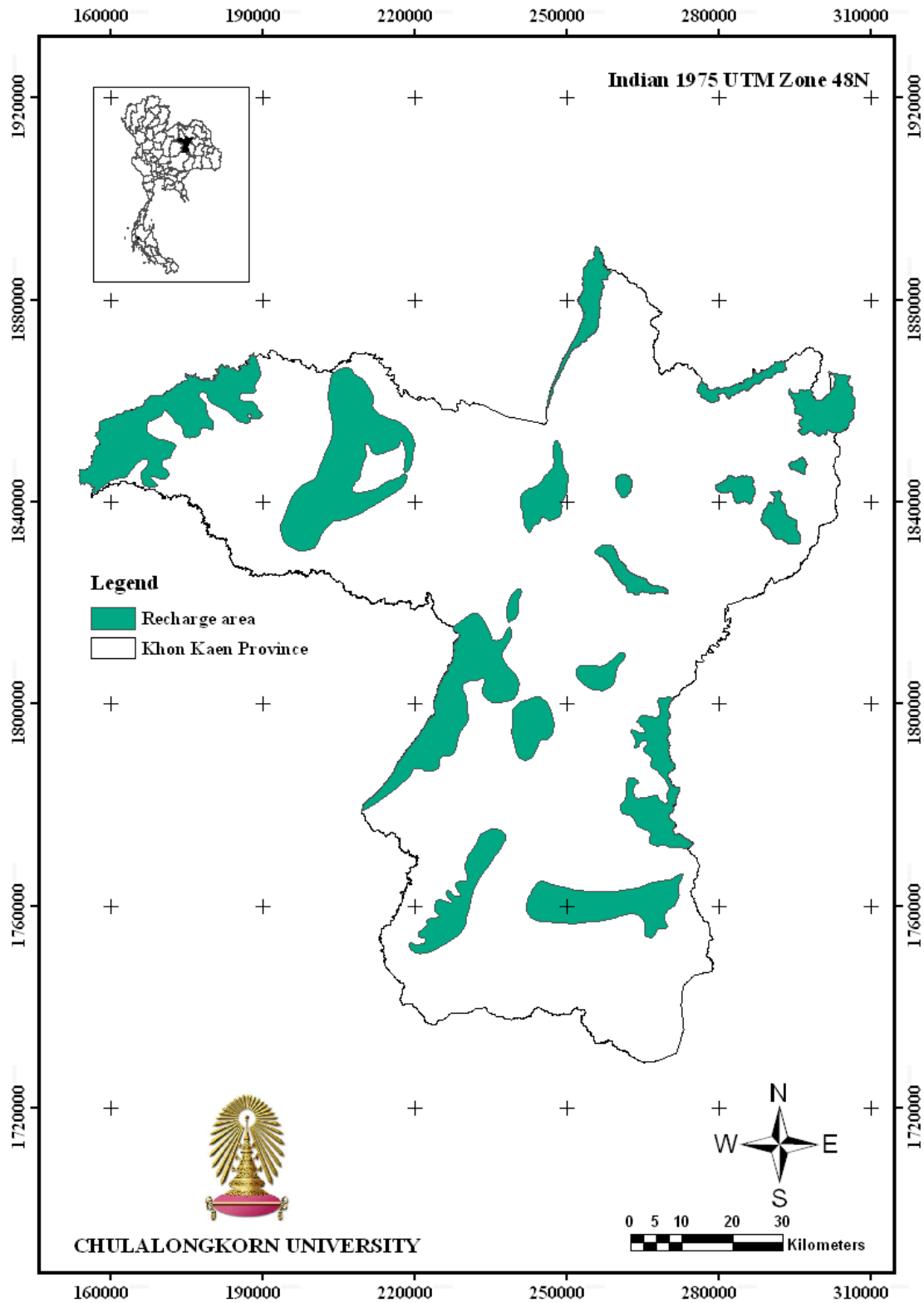


Figure 4.3 Map of positive recharge areas

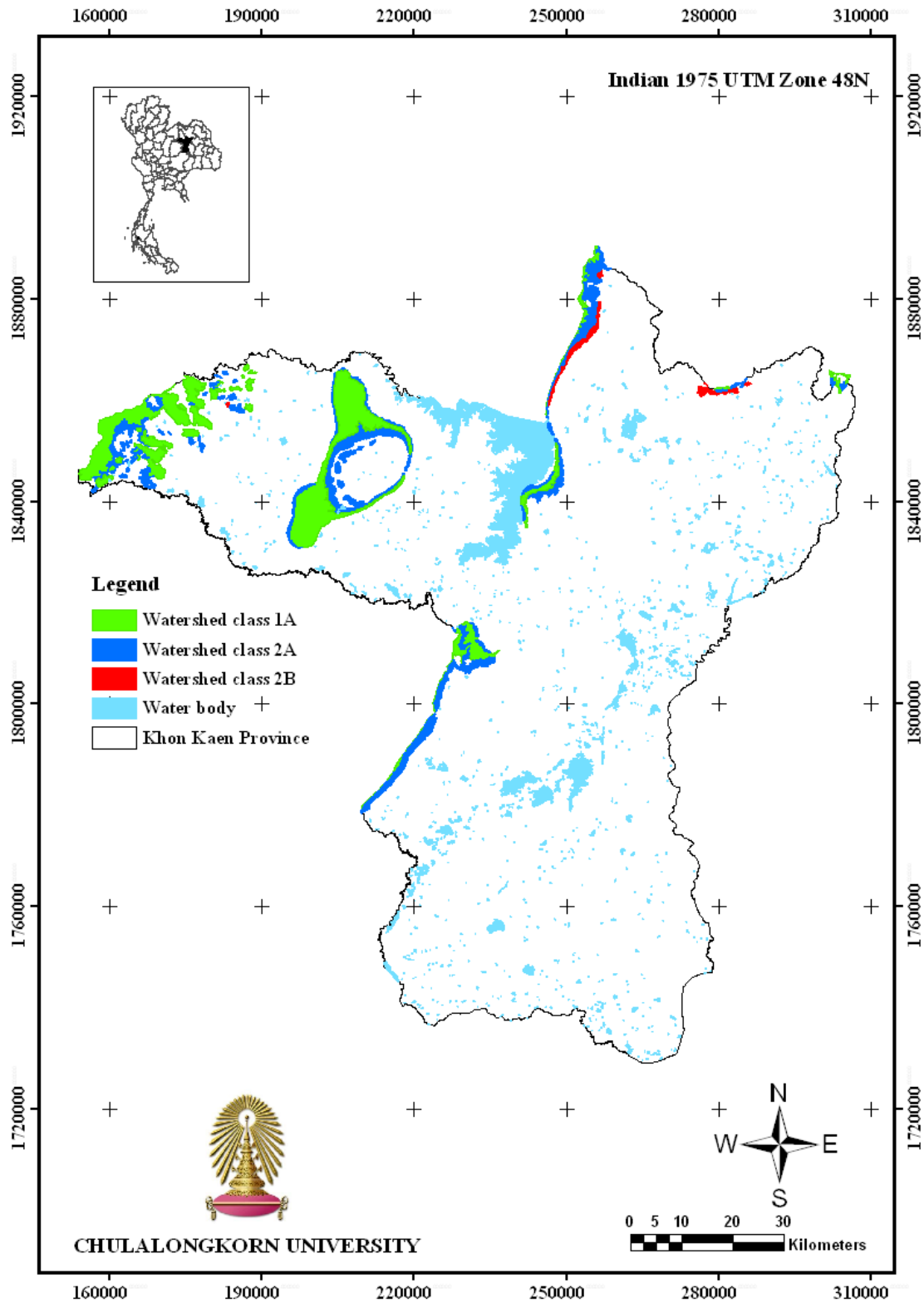


Figure 4.4 Map of negative watershed areas

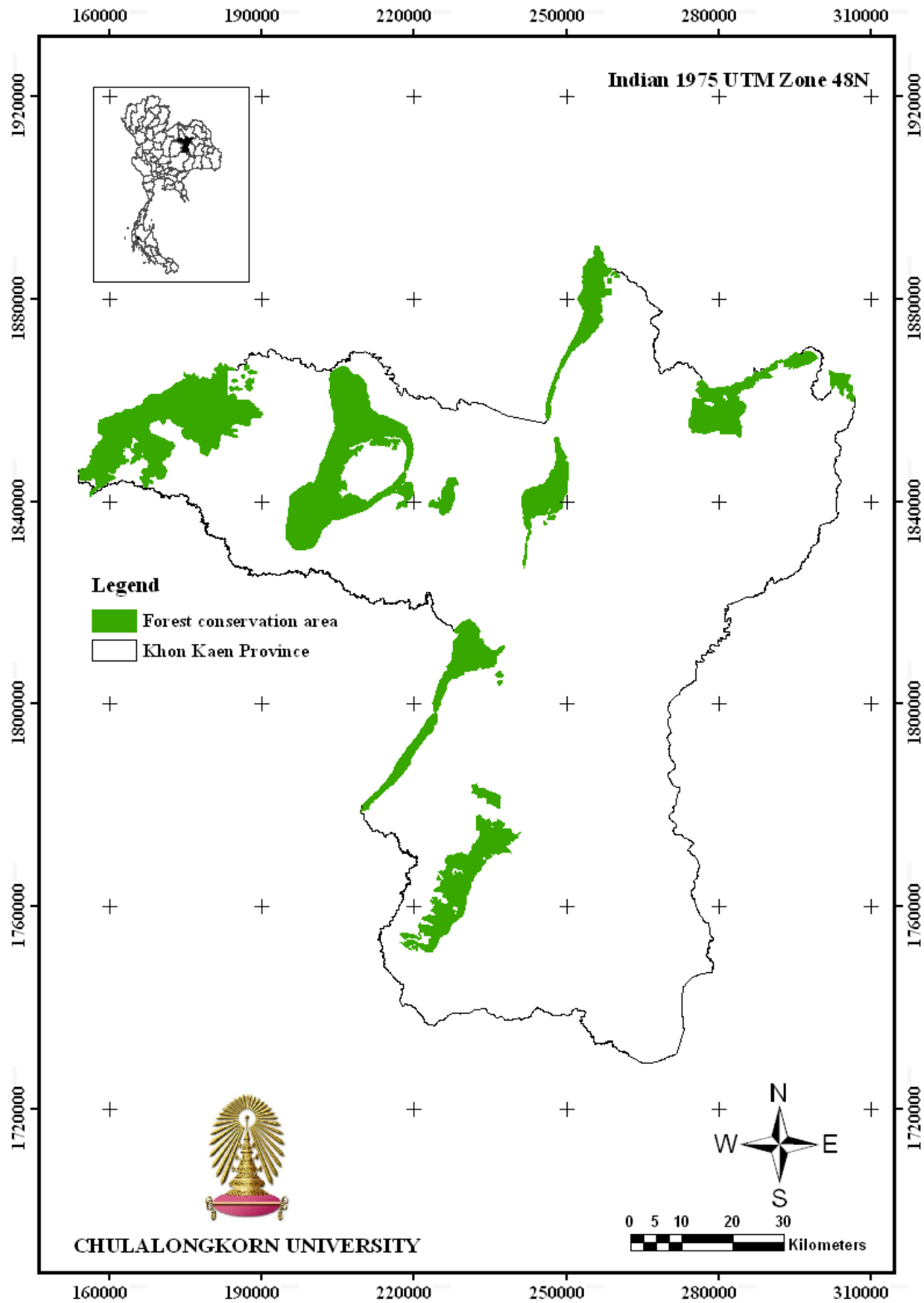


Figure 4.5 Map of forest conservation areas

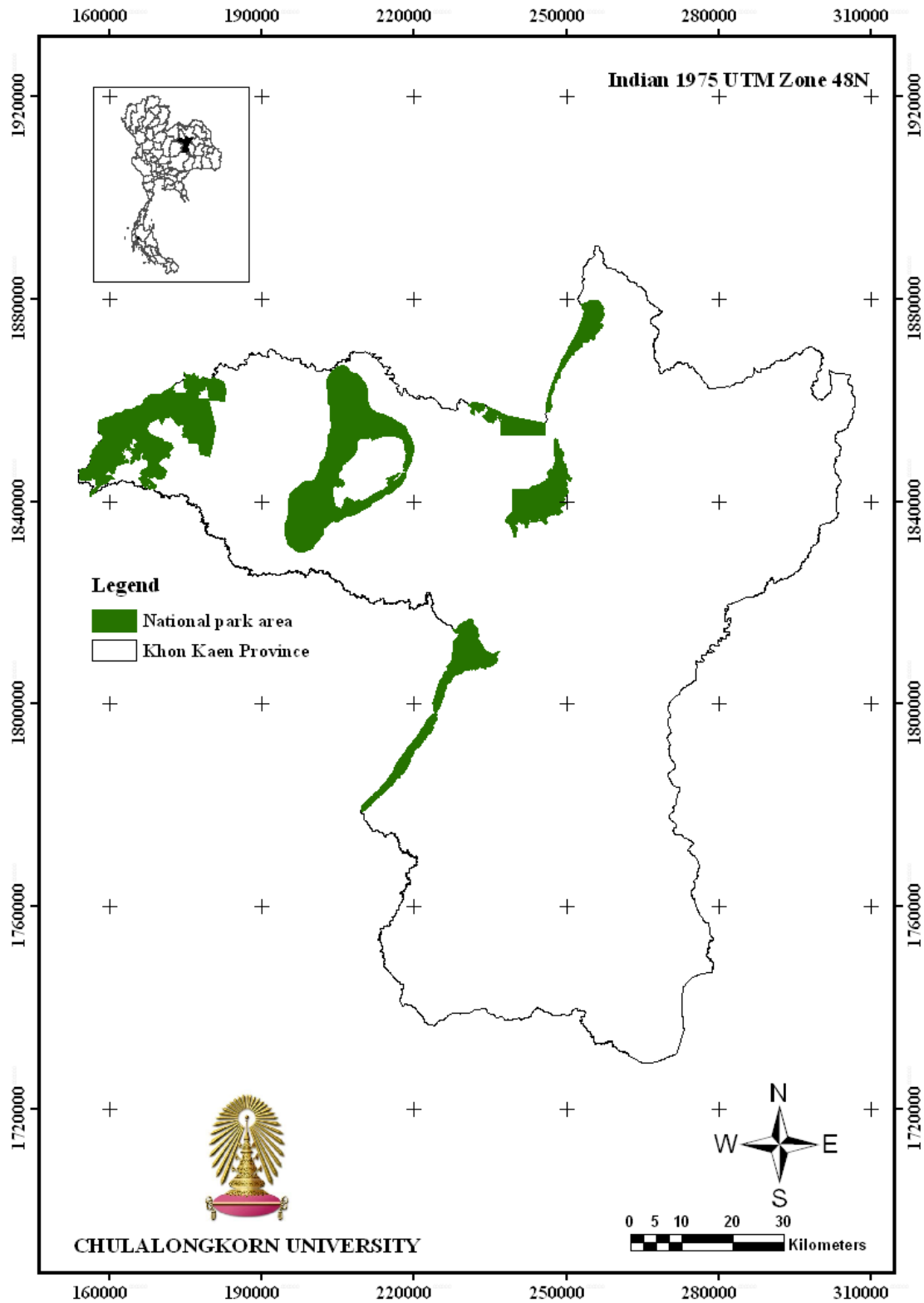


Figure 4.6 Map of national park areas

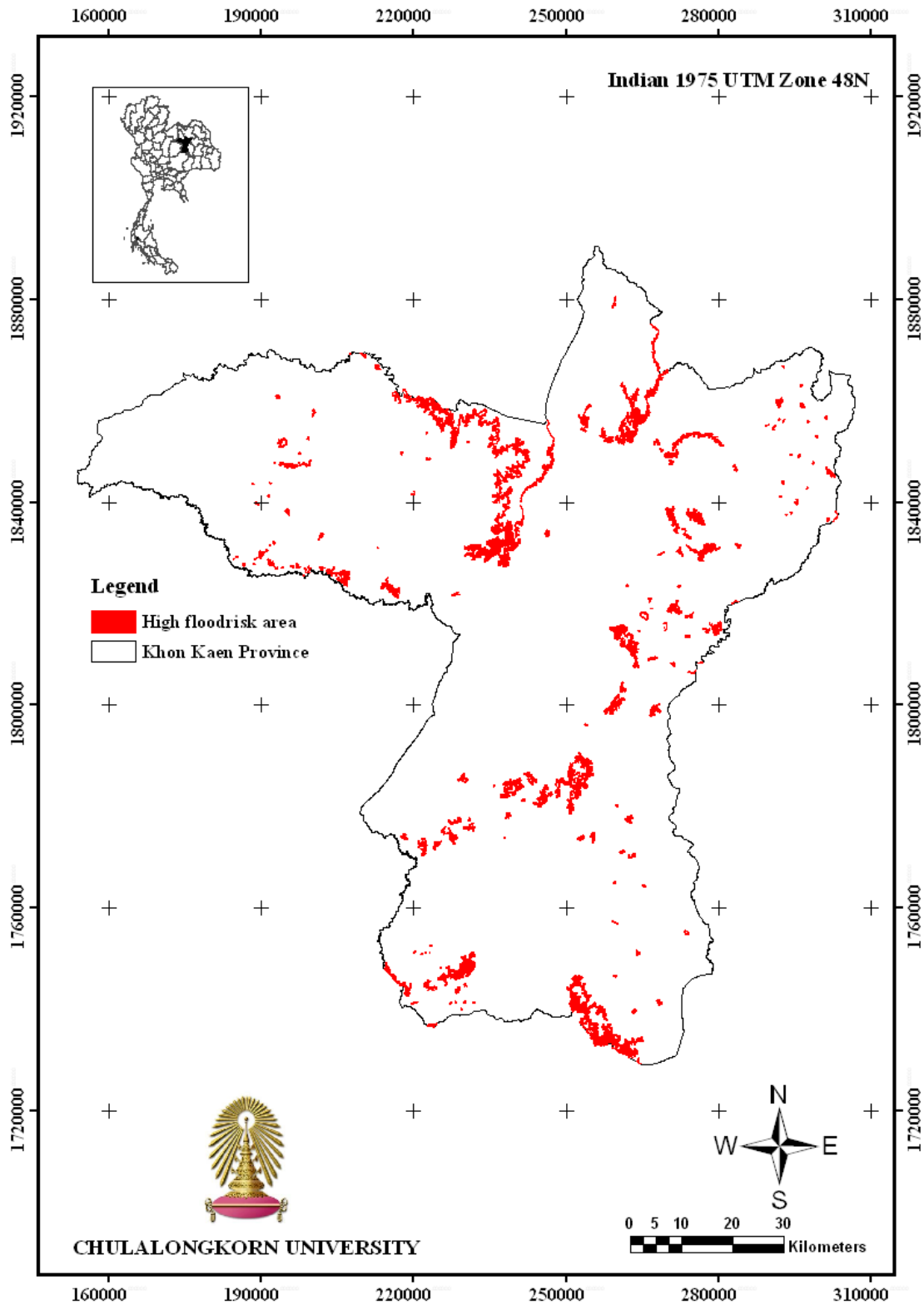


Figure 4.7 Map of high flood risk areas

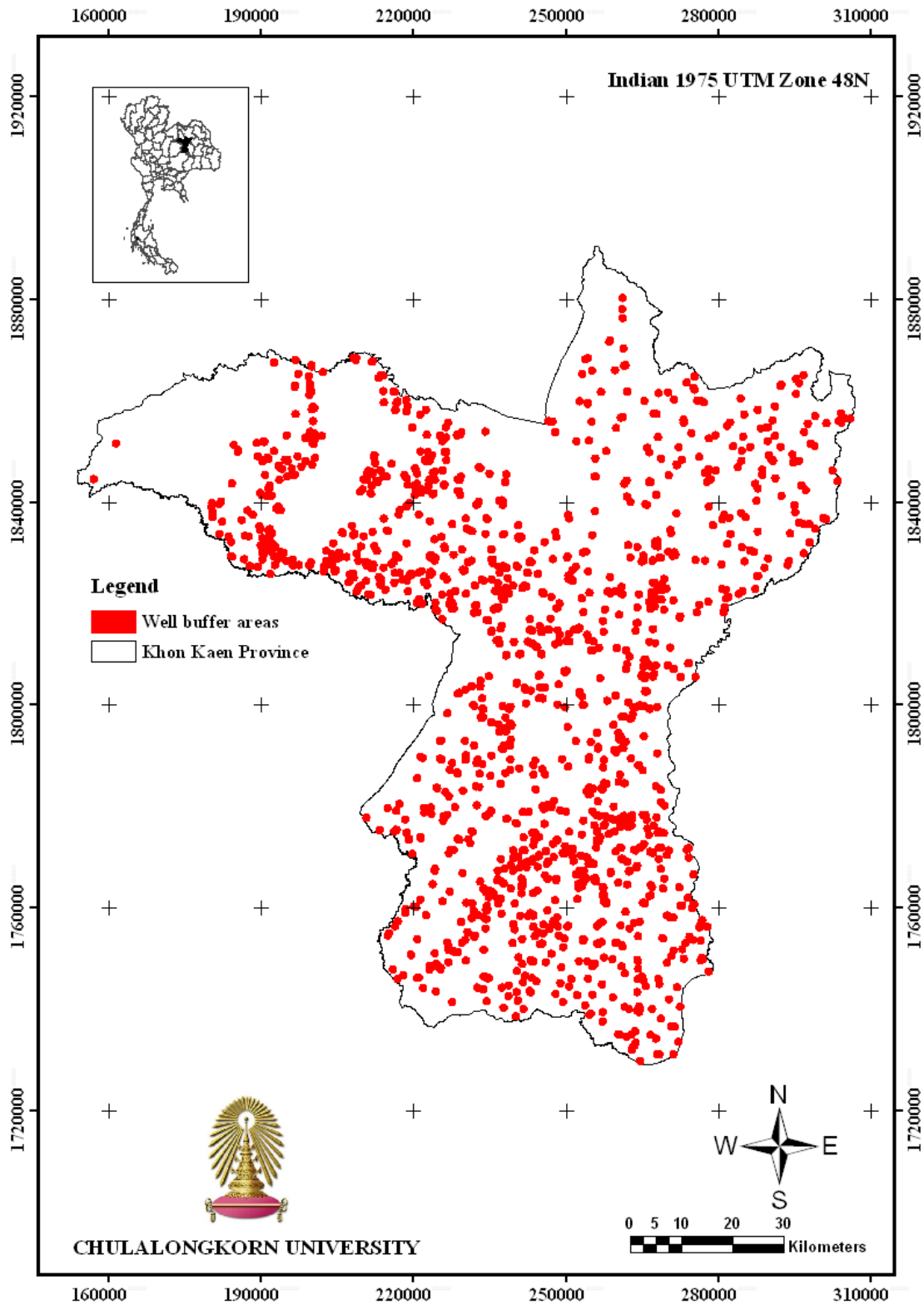


Figure 4.8 Map of well buffer areas

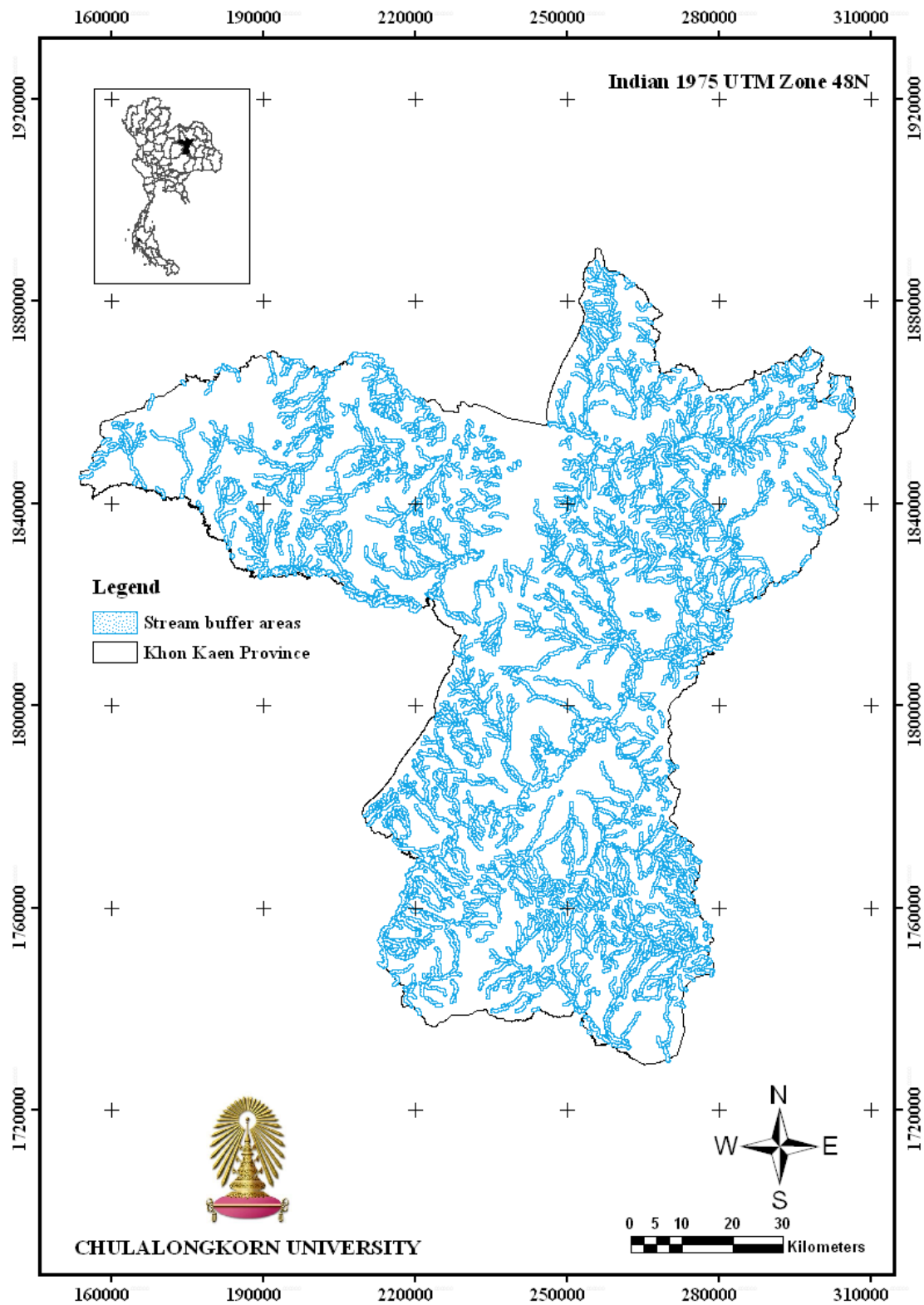


Figure 4.9 Map of stream buffer areas

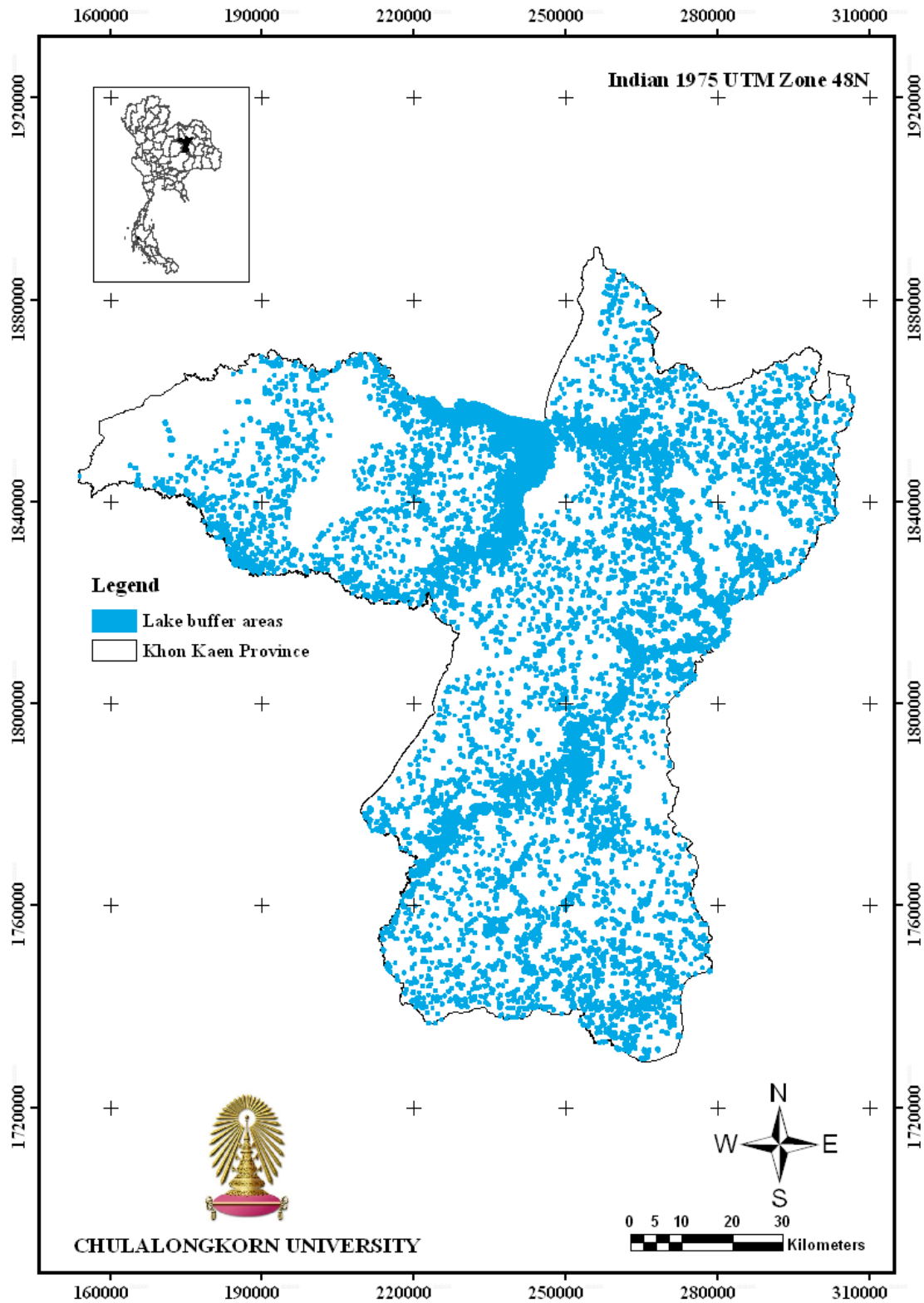


Figure 4.10 Map of lake buffer areas

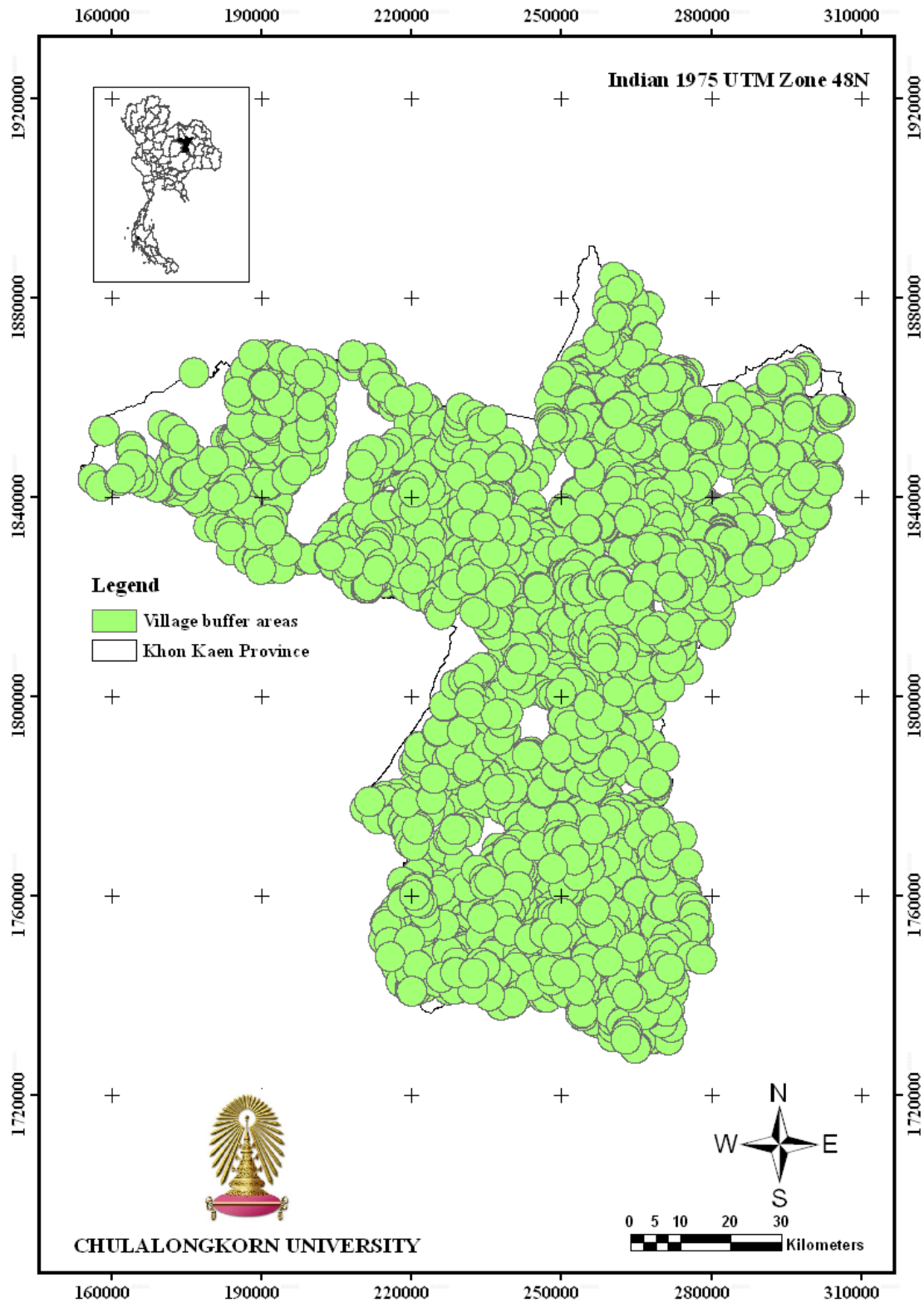


Figure 4.11 Map of village buffer areas

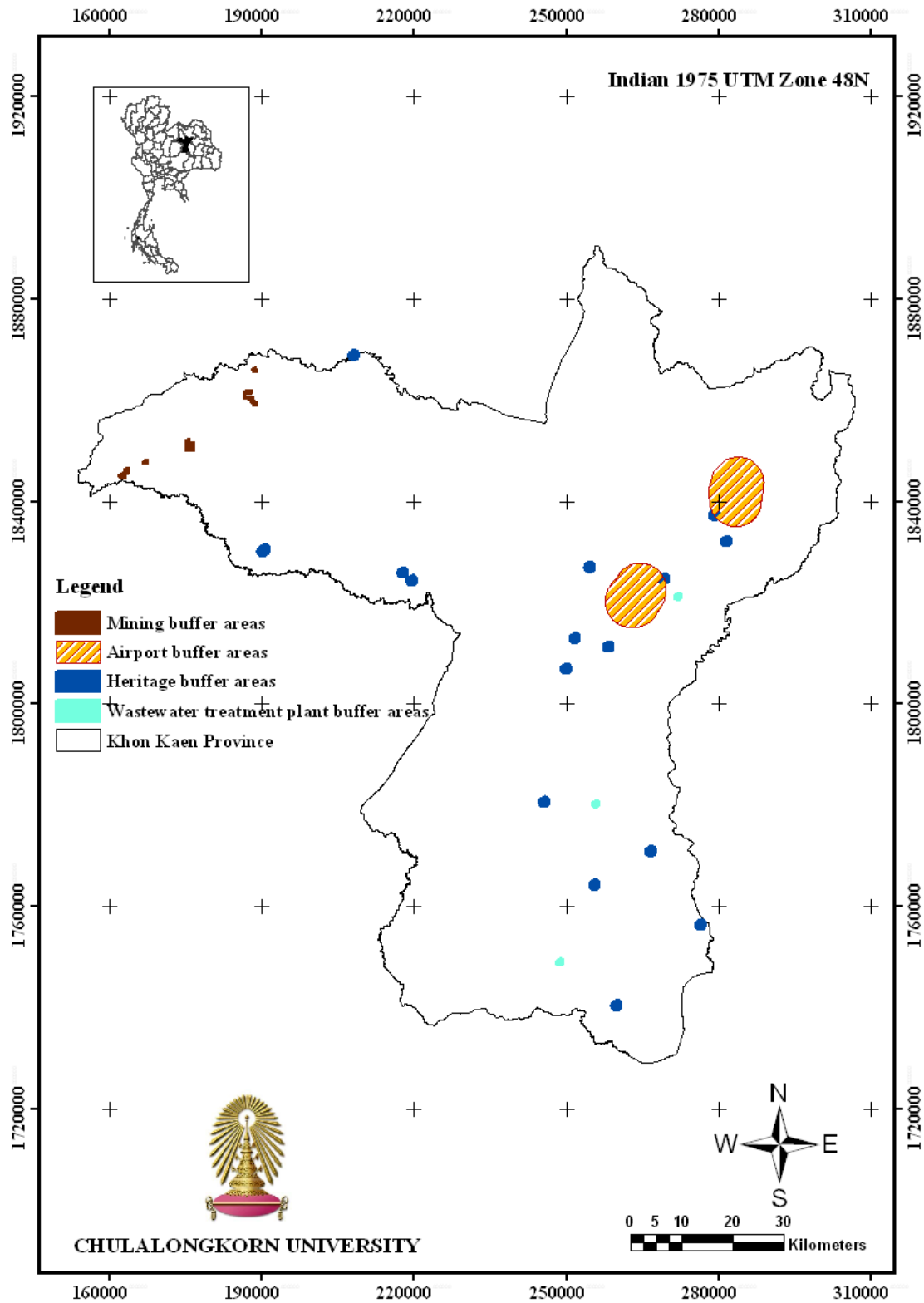


Figure 4.12 Map of mining, airport, heritage, and wastewater treatment plant buffer areas

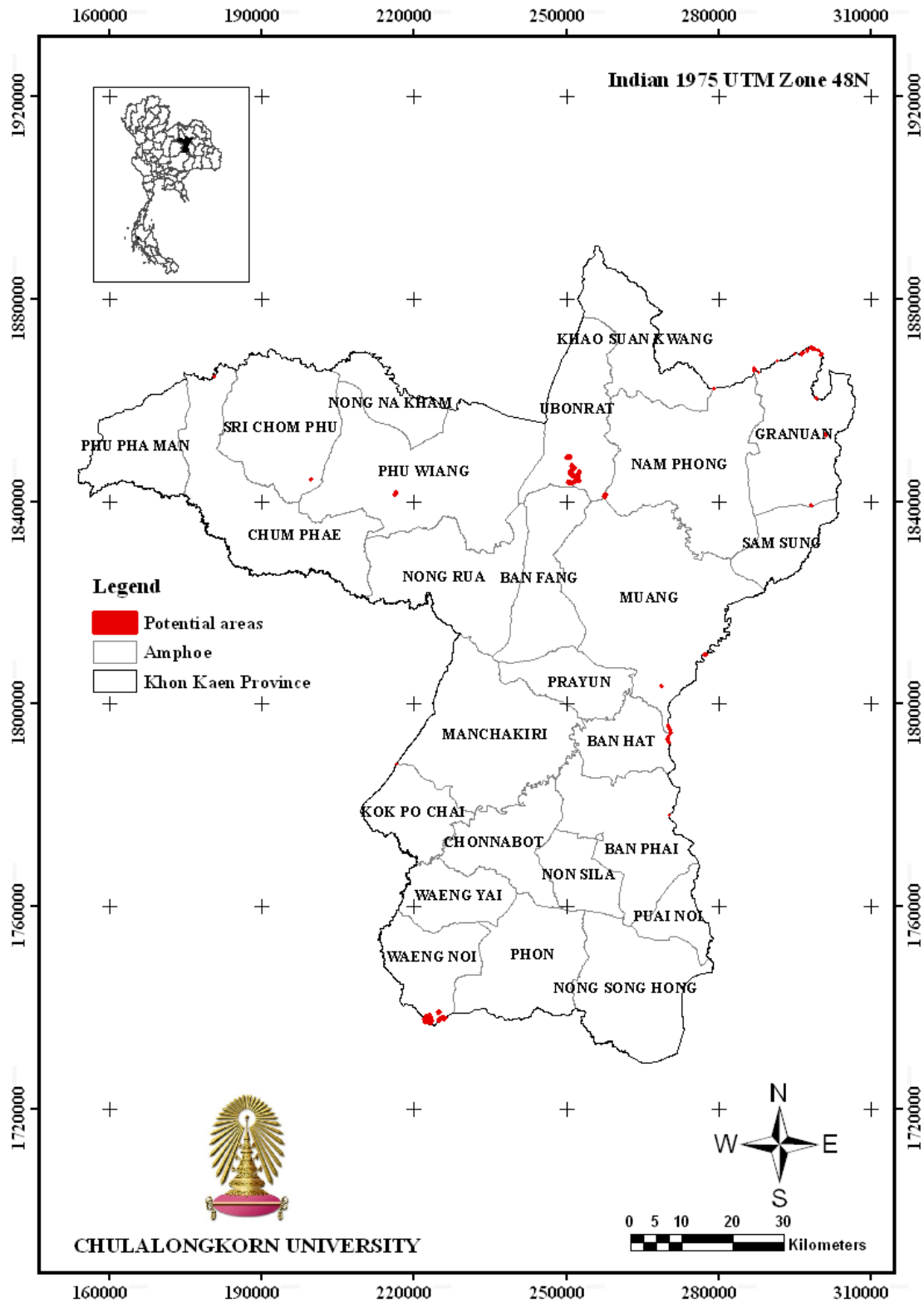


Figure 4.13 Map of potential areas

Table 4.1 Summary of the potential areas

| Site number | Area(m²) | Tombon | Amphoe |
|--------------------|----------------------------|---------------|-----------------|
| 1 | 727827.32 | Thawad | Waeng Noi |
| 2 | 1994889.44 | Thawad | Waeng Noi |
| 3 | 131197.14 | Thawad | Waeng Noi |
| 4 | 0.37 | Ban Khok | Kok Po Chai |
| 5 | 0.83 | Na Ngam | Manchakiri |
| 6 | 72069.86 | Tha Pra | Muang |
| 7 | 502.14 | Tha Pra | Muang |
| 8 | 0.02 | Phulek | Ban Phai |
| 9 | 0.06 | Hin Thang | Ban Phai |
| 10 | 39523.19 | Nongsang | Ban Hat |
| 11 | 837.16 | Nongsang | Ban Hat |
| 12 | 143.36 | Nongsang | Ban Hat |
| 13 | 764.47 | Non somboon | Ban Hat |
| 14 | 23513.93 | Na Chan | Sri Chom Phu |
| 15 | 1.09 | Na Nong Thum | Chum Phae |
| 16 | 164404.26 | Song Pluai | Phu Wiang |
| 17 | 44059.88 | Don Hun | Muang |
| 18 | 209988.71 | Muang Wan | Nam Phong |
| 19 | 12294.59 | Khok Song | Ubonrat |
| 20 | 175992.51 | Khok Song | Ubonrat |
| 21 | 1296321.82 | Khok Song | Ubonrat |
| 22 | 560064.43 | Khok Song | Ubonrat |
| 23 | 257022.54 | Thung Pong | Ubonrat |
| 24 | 16357.38 | Nong Kung Yai | Granuan |
| 25 | 2.37 | Huai Yang | Granuan |
| 26 | 0.07 | Huai Yang | Granuan |
| 27 | 141159.11 | Huai Yang | Granuan |
| 28 | 28805.45 | Huai Yang | Granuan |
| 29 | 25113.83 | Huai Yang | Granuan |
| 30 | 243.25 | Huai Yang | Granuan |
| 31 | 6139.31 | Huai Yang | Granuan |
| 32 | 164117.88 | Huai Yang | Granuan |
| 33 | 98317.55 | Dun Sat | Granuan |
| 34 | 4693.65 | Dun Sat | Granuan |
| 35 | 5063.46 | Dun Sat | Granuan |
| 36 | 2217.07 | Hua Na Kham | Granuan |
| 37 | 63762.21 | Hua Na Kham | Granuan |
| 38 | 1.03 | Pangtui | Nam Phong |
| 39 | 1.04 | Kham Muang | Khao Suan Kwang |
| 40 | 10720.81 | Don Hun | Muang |

4.2 Selection of potential site

Based on the equation in the previous section, an appropriately size area for the hazardous waste landfill was calculated for at least 20 years as shown below. The results from the calculation showed that the appropriate area was about 10,103 meter² for which 18 potential sites were found within Khon Kaen Province (Figure 4.14). Table 4.2 shows the area sizes for the potential sites ranging from 10,702 to 1,994,889 meter².

To calculate the appropriate area, based on the information from the previous studies, the number of years of operation, amount of waste, density of waste compression, height of landfill, and buffer distance were 20 years, 682 ton/year, 0.45 ton/meter³, 4.5 meters, and 1.5, respectively, then the volume of the waste and minimum area required for the hazardous waste landfill can be computed as follows:

$$V = \frac{N \times W}{D} = \frac{20 \times 682}{0.45} = 30,311 \text{ m}^3$$

And

$$A = \frac{V \times k}{H} = \frac{30,311 \times 1.5}{4.5} = 10,103 \text{ m}^2$$

Remark:

1) Based on the recently report from PIC in 2007, 682 tons per year was used as the amount of waste in the study and does not change over time.

2) The operational period of 20 years is commonly used for designing a small landfill size that would receive less than 1,300 tons of waste per year (EPA, 2007). Moreover, an investment of landfill should be economically sound, since all types of landfill facilities require high operation cost.

3) The capacity of landfill for disposal waste is increased when the waste is high compaction. Typically range of waste compaction density is about 0.36 - 0.54 tons/m³ (Leonard and Floom, 2000). Therefore, study used 4.5 tons/m³ because of it is suitable for hazardous waste.

4) Area size can be calculated from volume of waste, buffer distance, and height of landfill's classes. Typically, height for each class is 1.5 meters. Therefore, for three classes, the total height would be 4.5 meters.

5) Buffer distance provides separation between the landfill and sensitive land uses in order to act as a primary control of potential adverse impacts and also provide for area of building facilities, liquid waste system and tree planting. The constant of buffer zone is depending on the size of landfill and landfill operation. Large landfill size may operate with treatment facilities which require larger area. For this study, constant of buffer zone was use 1.5 that suitable for a small landfill size (Chiangmai University, 2003).

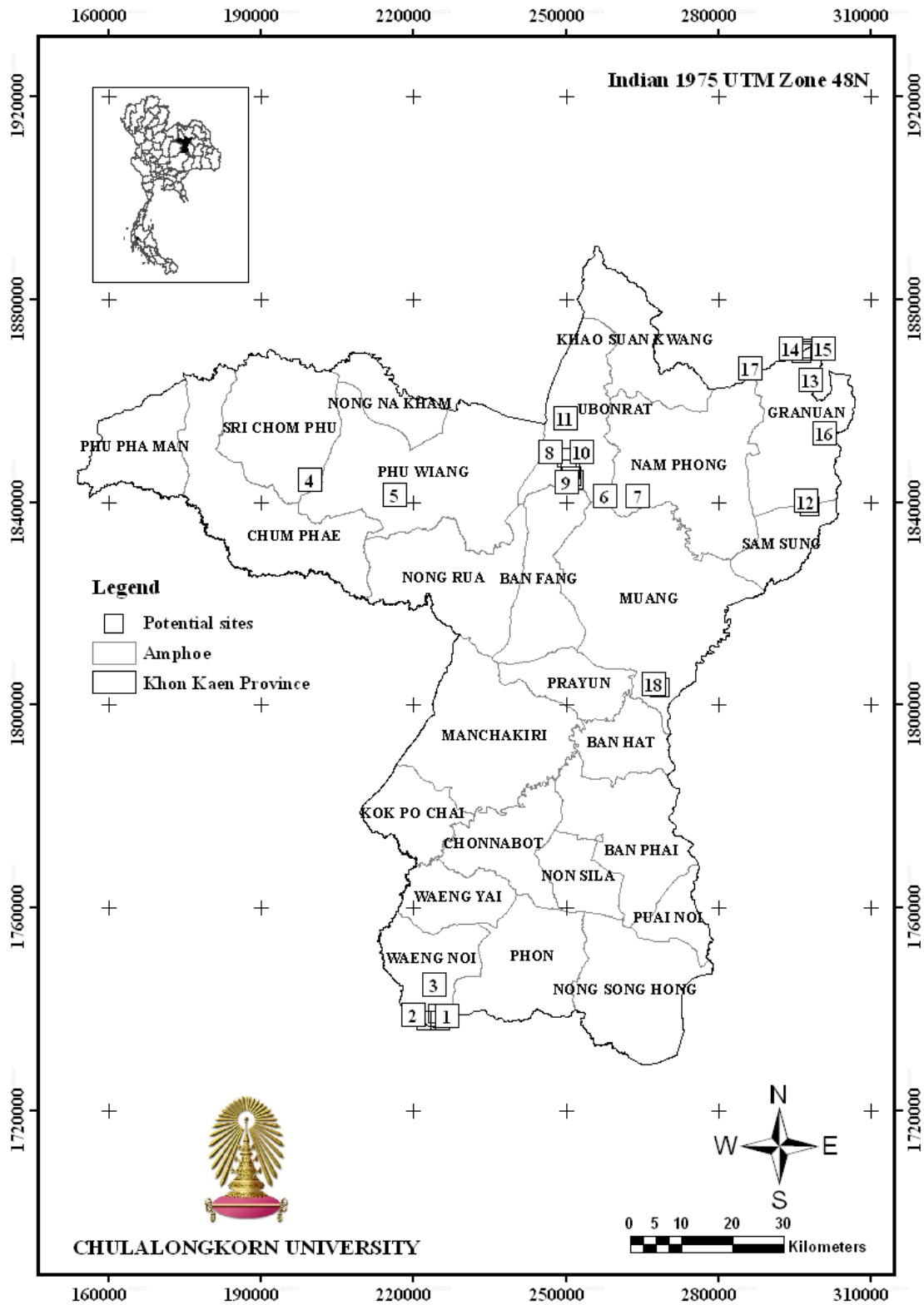


Figure 4.14 Potential sites

Table 4.2 Summary of the potential sites

| Site | Area (m ²) | Tombon | Amphoe |
|------|------------------------|---------------|--------------|
| 1 | 727827.32 | THAWAD | Waeng Noi |
| 2 | 1994889.44 | THAWAD | Waeng Noi |
| 3 | 131197.14 | THAWAD | Waeng Noi |
| 4 | 23513.93 | NA CHAN | Sri Chom Phu |
| 5 | 164404.26 | SONG PLUAI | Phu Wiang |
| 6 | 209988.71 | MUANG WAN | Nam Phong |
| 7 | 12294.59 | KHOK SONG | Ubonrat |
| 8 | 175992.51 | KHOK SONG | Ubonrat |
| 9 | 1296321.82 | KHOK SONG | Ubonrat |
| 10 | 560064.43 | KHOK SONG | Ubonrat |
| 11 | 257022.54 | THUNG PONG | Ubonrat |
| 12 | 16357.38 | NONG KUNG YAI | Granuan |
| 13 | 141159.11 | HUAI YANG | Granuan |
| 14 | 28805.45 | HUAI YANG | Granuan |
| 15 | 164117.88 | HUAI YANG | Granuan |
| 16 | 98317.55 | DUN SAT | Granuan |
| 17 | 63762.20 | HUA NA KHAM | Granuan |
| 18 | 10720.81 | DON HUN | Muang |

The method presented in the study is dissimilar to previous studies on hazardous waste landfill selection in terms of the factors and steps used. In this study, modified criteria from PCD are used in order to achieve suitable criteria for use in this study. Each area of Thailand has different environmental characteristics with respect to topography, hydrology, geology, and so on. Therefore siting criteria should be used flexibly to help make better decisions for siting analysis.

In the first step, potential areas were selected from the map by considering the following factors: watershed classes, flood risks, distance to water bodies, groundwater tables, recharge areas, wells, wastewater treatment plants, soil characteristics, national parks, forest zones, major roads, airports, community areas, heritage, and mining. The selection takes into account the environment of an area, for example the bodies of water, flood risk areas, sensitive areas, distance from historic sites, and residential areas, in order to protect noise, odor, and nuisance. After completion of this stage, potential areas for hazardous waste landfill were selected.

The second step was to select potential sites where the size of each potential area was large enough to be used for 20 years. Thus potential areas with

areas that were not sufficient for the disposal hazardous waste for at least 20 years were screened out.

4.3 Selection of the most suitable site

From the previous result, 18 sites in Granuan, Muang, Nam Phong, Phu Wiang, Sri Chom Phu, Ubonrat, and Waeng Noi amphoe are shown as potential sites for hazardous waste landfill. Transportation costs were then considered as the final selection procedure. The method for finding the best route of transport the hazardous waste has been mentioned in a previous chapter. The best route means the minimum transportation distance and lowest fuel cost to be used from the generator to the potential site. For the study, the best route can found using a GIS network analysis technique based on Dijkstra's algorithm. Since the study was only considering hazardous waste that could be disposed of in a landfill, there are thus 17 generators (Table 4.3) which have been added for route analysis to the 18 potential sites from the previous step. The analysis was divided into 3 methods with different situations in order to compare the best route of each method as follows.

Table 4.3 Generator data

| Generator | Tambon | Amphoe | Latitude | Longitude | Waste (ton/years) |
|------------------|----------------|----------------|-----------------|------------------|--------------------------|
| 1 | Nong rua | Nong rua | 16.48 | 102.42 | 13.00 |
| 2 | Tha pra | Muang | 16.34 | 102.80 | 1.39 |
| 3 | Kut nam sai | Nam phong | 16.67 | 102.73 | 176.50 |
| 4 | Ban phai | Ban phai | 16.07 | 102.72 | 10.30 |
| 5 | Muang wan | Nam phong | 16.67 | 102.75 | 22.00 |
| 6 | Nai muang | Muang | 16.48 | 102.83 | 41.50 |
| 7 | Nam phong | Nam phong | 16.72 | 102.84 | 22.50 |
| 8 | Ban hat | Ban hat | 16.17 | 102.75 | 3.00 |
| 9 | Kut nam sai | Nam phong | 16.70 | 102.75 | 52.60 |
| 10 | Ban hat | Ban hat | 16.23 | 102.76 | 0.57 |
| 11 | Sam ran | Muang | 16.55 | 102.82 | 5.00 |
| 12 | Nam phong | Nam phong | 16.73 | 102.84 | 0.50 |
| 13 | Khao suan kwan | Khao suan kwan | 16.84 | 102.85 | 3.80 |
| 14 | Ban wa | Muang | 16.42 | 102.70 | 50.00 |
| 15 | Kut nam sai | Nam phong | 16.70 | 102.74 | 6.60 |
| 16 | Muang phon | Phon | 15.78 | 102.60 | 0.70 |
| 17 | Ban hat | Ban hat | 16.12 | 102.74 | 5.00 |

4.3.1 Finding shortest distance by straight line method

The simple approach for determining the distance by using the point distance technique indicated that the first five lowest transport distances between generators and potential sites were site 6, site 7, site 9, site 8, and site 18 with distances of 522.52, 523.06, 576.91, 585.40, and 590.49 kilometers, respectively (Table 4.4). Site 6 is located in Tambon Muang Wan, Amphoe Nam Phong, sites 7, 8, and 9 are located in Tambon Khok Song, Amphoe Ubonrat, and site 18 is located in Tambon Don Hun, Amphoe Muang.

Table 4.4 Finding shortest distance by straight line result

| Potential site | Total distance from each generator to potential site (kilometer) | Fuel used (liter/years) |
|----------------|--|-------------------------|
| 1 | 1541.82 | 385.45 |
| 2 | 1563.01 | 390.75 |
| 3 | 1526.86 | 381.71 |
| 4 | 1206.57 | 301.64 |
| 5 | 953.96 | 238.49 |
| 6 | 522.52 | 130.63 |
| 7 | 523.06 | 130.76 |
| 8 | 585.40 | 146.35 |
| 9 | 576.91 | 144.23 |
| 10 | 596.73 | 149.18 |
| 11 | 621.83 | 155.46 |
| 12 | 853.94 | 213.48 |
| 13 | 1077.70 | 269.42 |
| 14 | 1094.62 | 273.65 |
| 15 | 1111.25 | 277.81 |
| 16 | 976.82 | 244.20 |
| 17 | 937.33 | 234.33 |
| 18 | 590.49 | 147.62 |

Remark: Fuel used = 0.25 * total distance from each generator to potential site.

4.3.2 Finding the shortest route based on road network method

The study was based on the assumptions as mentioned previously, where the distance affected the cost of transportation. Therefore, the only influencing factor was the distance from the generators to each potential site. Total transportation distance from all generators to potential sites can be simply computed by summation between the distances of each generator to the potential site. GIS network analysis

generated the best route from all generators to the potential sites, and the total distances for each potential site are shown in the Table 4.5. The results demonstrated that the first five lowest transport distances between generators and potential sites were site 7, site 6, site 9, site 18, and site 8, with distances of 640.52, 640.66, 661.54, 685.94, and 691.94 kilometers, respectively. Site 6 is located in Tambon Muang Wan, Amphoe Nam Phong, sites 7, 8, and 9 are located in Tambon Khok Song, Amphoe Ubonrat, and site 18 is located in Tambon Don Hun, Amphoe Muang.

Table 4.5 Finding the shortest route based on road network result

| Potential site | Total distance from each generator to potential site (kilometer) | Fuel used (liter/years) |
|----------------|--|-------------------------|
| 1 | 1,790.45 | 447.61 |
| 2 | 1,783.55 | 445.89 |
| 3 | 1,781.21 | 445.30 |
| 4 | 1,928.06 | 482.01 |
| 5 | 1,388.86 | 347.21 |
| 6 | 640.66 | 160.17 |
| 7 | 640.52 | 160.13 |
| 8 | 691.94 | 172.98 |
| 9 | 661.54 | 165.38 |
| 10 | 712.31 | 178.08 |
| 11 | 748.93 | 187.23 |
| 12 | 1,109.15 | 277.29 |
| 13 | 1,385.09 | 346.27 |
| 14 | 1,417.05 | 354.26 |
| 15 | 1,417.03 | 354.26 |
| 16 | 1,259.48 | 314.87 |
| 17 | 1,254.41 | 313.60 |
| 18 | 685.94 | 171.48 |

Remark: Fuel used = 0.25 * total distance from each generator to potential site.

4.3.3 Finding the shortest route based on road type method

The study was based on the assumptions previous mentioned. The influencing factors were the distance from the generators to each potential site, fuel used for each road type (types 1, 2, and 3), amount of hazardous waste produced, and truck capacity. Total fuel costs for transportation from all generators to potential sites can be simply computed by summation between the distances to potential site and unit

fuel cost of each road type (fuel used for road type 1 is defined as 0.25 liter per kilometer, while road type 2 and type 3 are defined as 0.33 liter per kilometer). GIS network analysis generated the best route from all the generators to potential sites, and the total distance of each potential site are shown in Table 4.6. The results demonstrated that the first five lowest transport distances between generator and potential site were site 6, site 7, site 9, site 8, and site 10, with distances of 1223.52, 1225.99, 1245.12, 1288.35, and 1350.90 kilometers, respectively. Site 6 is located in Tambon Muang Wan, Amphoe Nam Phong, and sites 7, 8, 9 and 10 are located in Tambon Khok Song, Amphoe Ubonrat.

Table 4.6 Finding the shortest route based on road type result

| Potential site | Total distance from each generator to potential site(kilometer) | Fuel used (liter/years) |
|-----------------------|--|--------------------------------|
| 1 | 6226.98 | 1773.30 |
| 2 | 6190.03 | 1761.11 |
| 3 | 6226.98 | 1773.30 |
| 4 | 5627.16 | 1542.36 |
| 5 | 3945.04 | 1100.77 |
| 6 | 1223.52 | 361.79 |
| 7 | 1225.99 | 362.61 |
| 8 | 1288.35 | 371.31 |
| 9 | 1245.12 | 368.33 |
| 10 | 1350.90 | 386.95 |
| 11 | 1445.56 | 412.21 |
| 12 | 3173.21 | 888.71 |
| 13 | 3950.21 | 1146.74 |
| 14 | 3950.21 | 1146.74 |
| 15 | 3950.21 | 1146.74 |
| 16 | 3522.20 | 985.00 |
| 17 | 3418.91 | 994.07 |
| 18 | 2338.46 | 659.21 |

The final step was to consider the total fuel cost and minimum transport distance from each generator to the potential sites. The study used GIS network analysis which various methods in order to compare the results of each method. The results of all methods showed that the first five lowest transport distances between generators and potential sites were quite similar. However, the ranking of the five potential sites changed for each method used. This depended on method and the specific hypothesis of the method such as road type and the amount of

hazardous waste produced by each generator, which influenced the finding the shortest route based on road type method, but did not influence finding shortest distance by straight line method and finding the shortest route based on the real road network method. The study has defined the fuel cost for each road type (fuel used for road type 1 is defined as 0.25 liters per kilometer, while road type 2 and type 3 are defined as 0.33 liters per kilometer). As a result, the fuel cost increases when more trucks transport hazardous waste via road type 2 and type 3. Moreover, the different amount of hazardous waste produced by the generators has an affect on the length and the fuel cost required for transportation. In addition, the truck has a capacity of 10 tons, thus the generator that produces more hazardous waste increases the distance and the fuel cost for transportation. Figures 4.15 - 4.20 show suitable routes for transporting the hazardous waste of the generators to the first five potential sites.

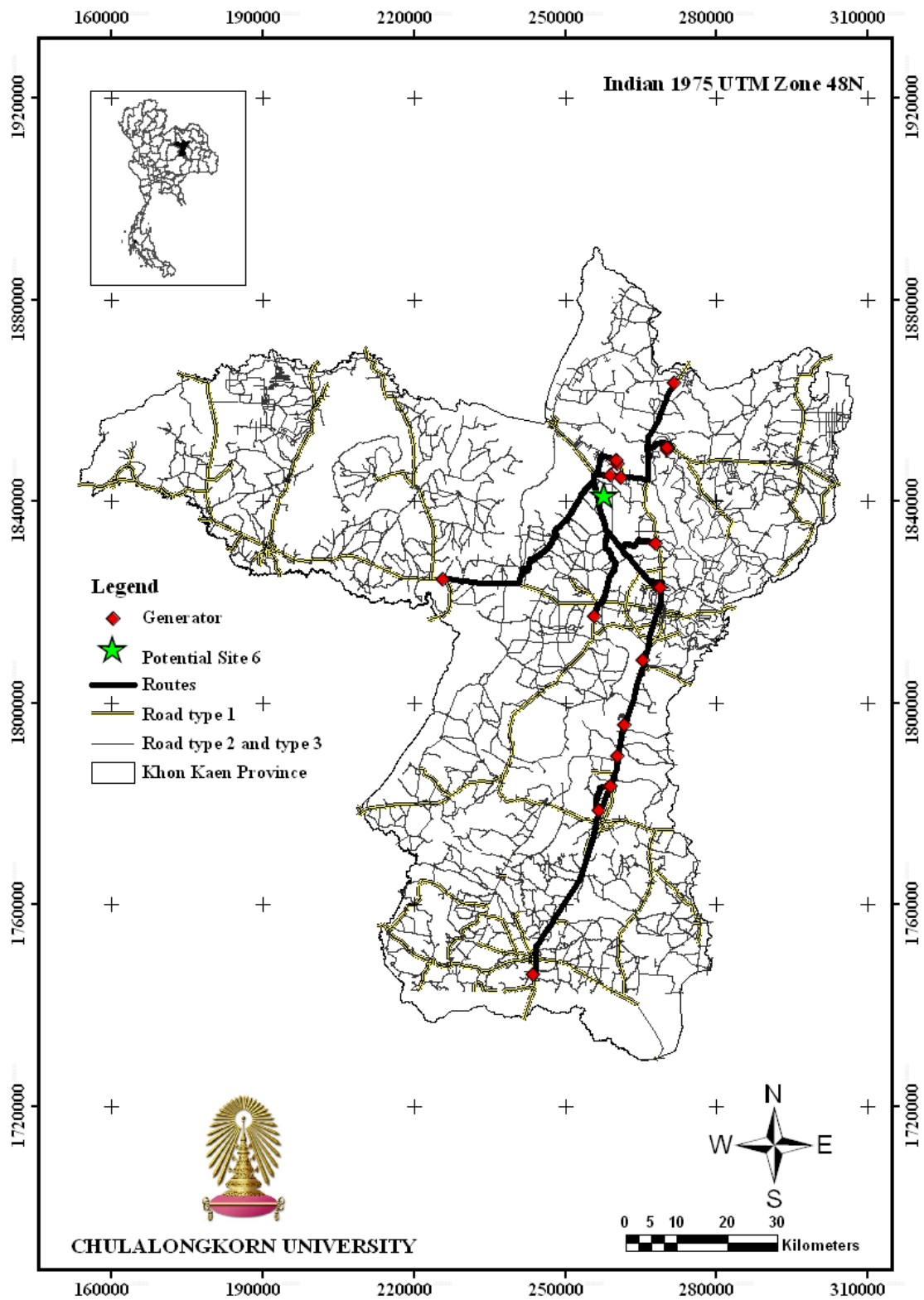


Figure 4.15 The suitable route for transport hazardous waste of generators to potential site 6

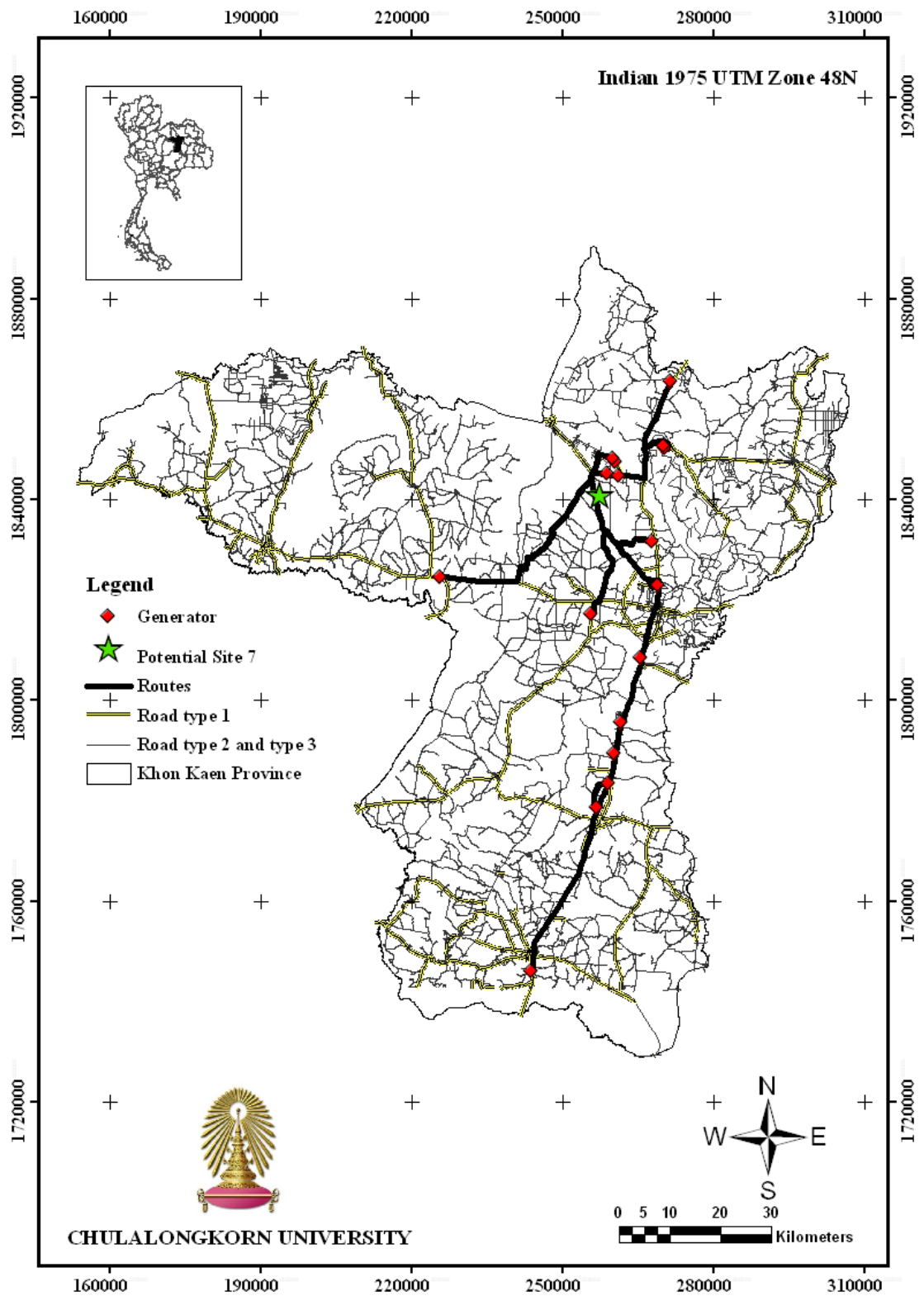


Figure 4.16 The suitable route for transport hazardous waste of generators to potential site 7

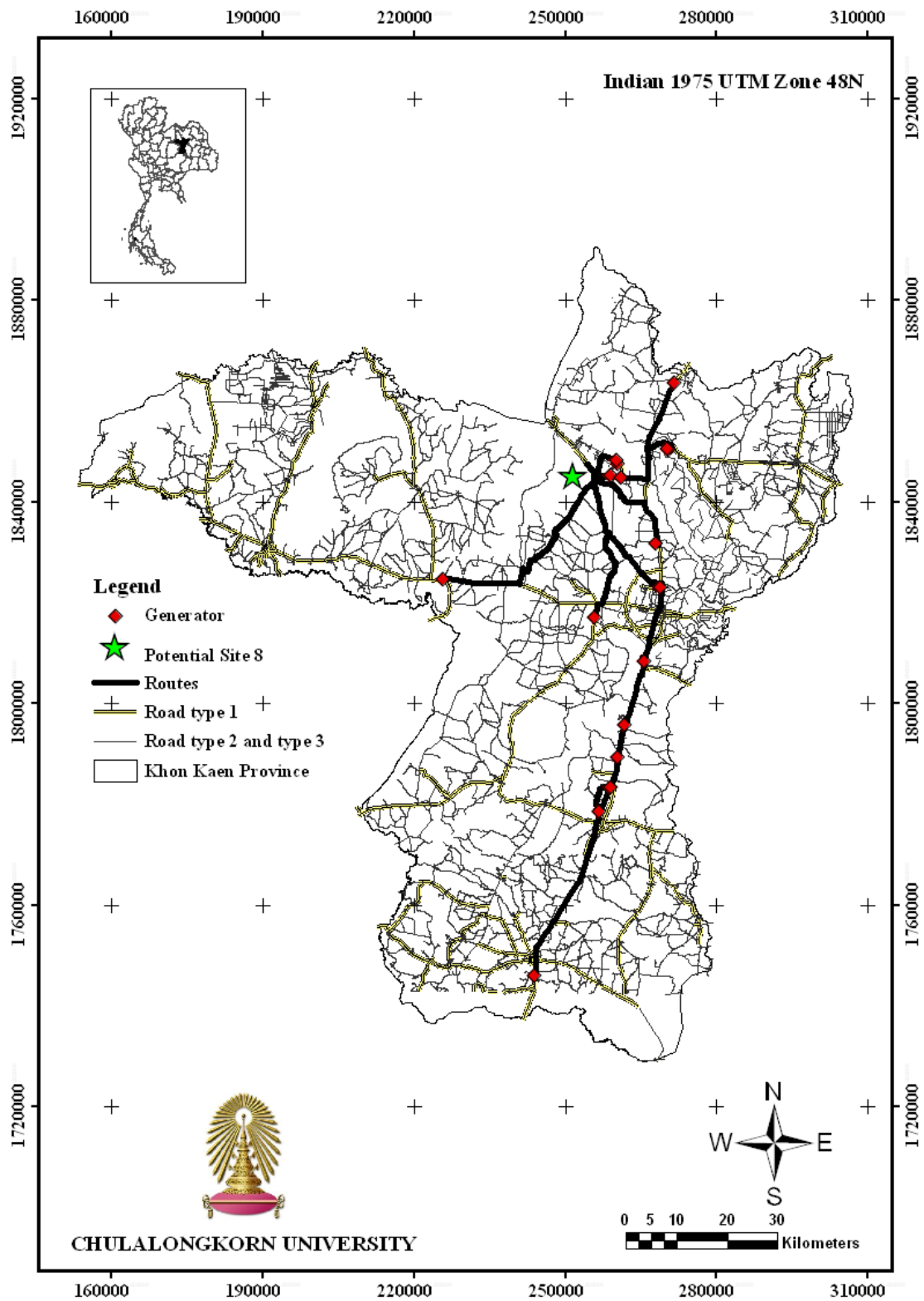


Figure 4.17 The suitable route for transport hazardous waste of generators to potential site 8

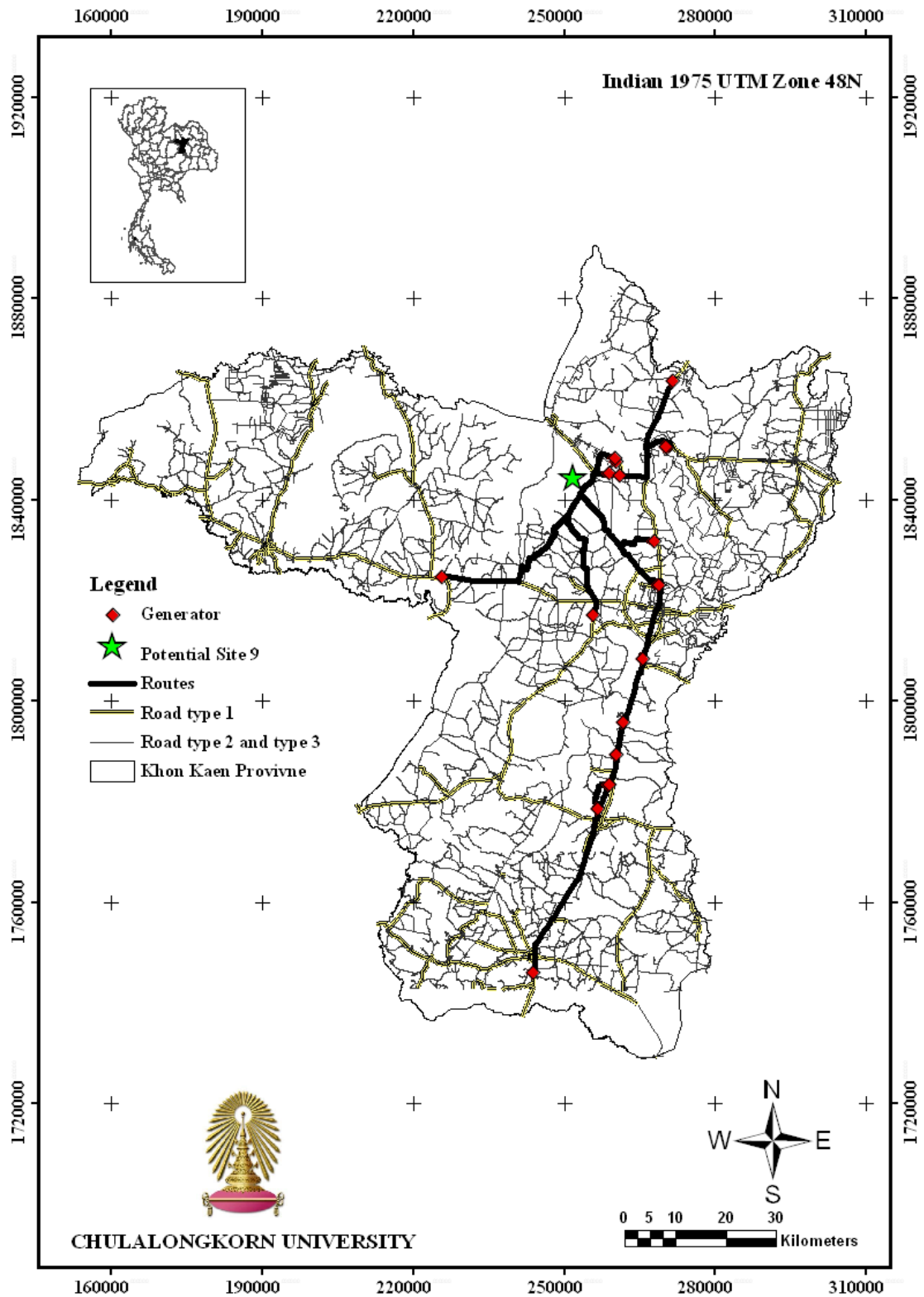


Figure 4.18 The suitable route for transport hazardous waste of generators to potential site 9

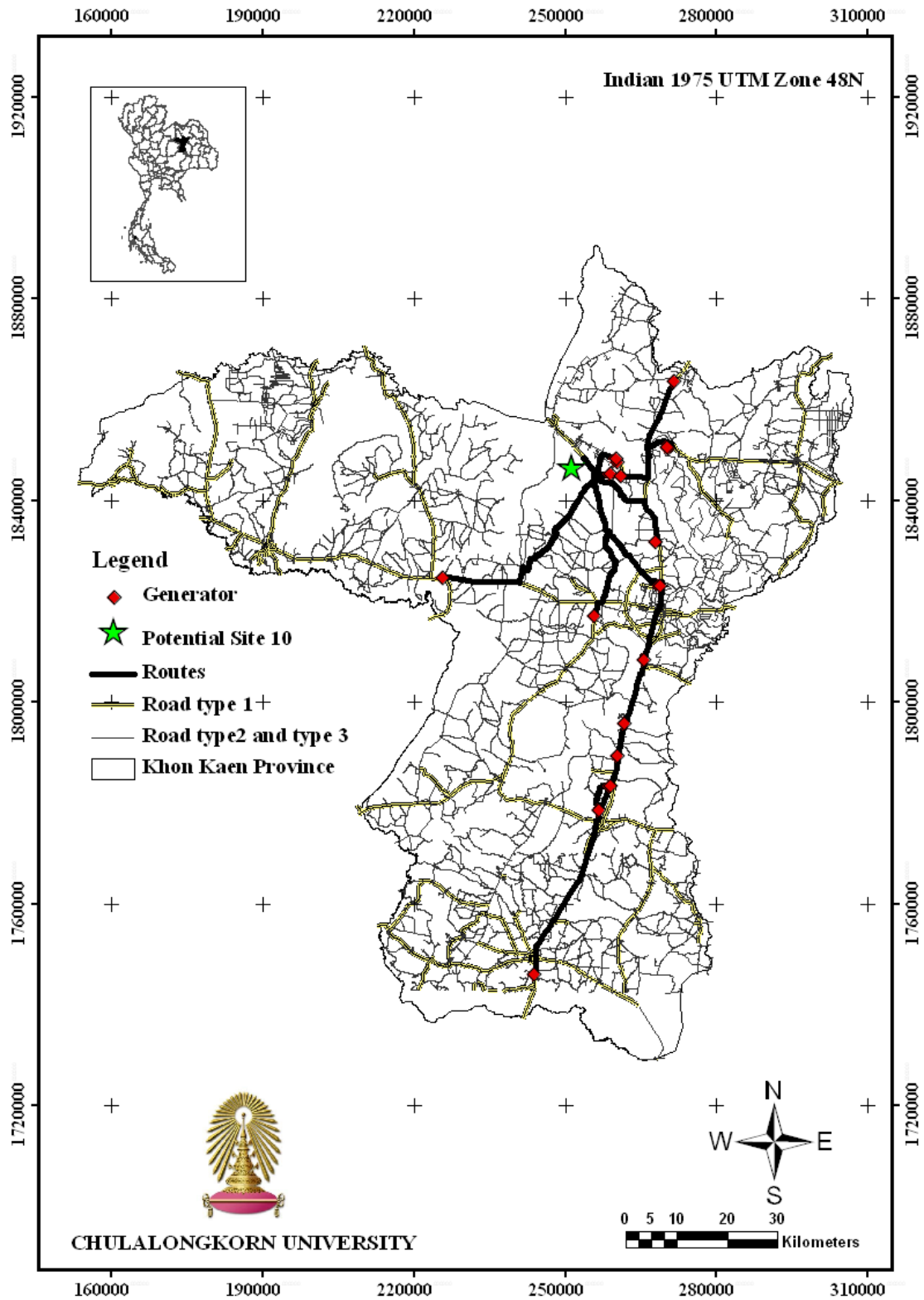


Figure 4.19 The suitable route for transport hazardous waste of generators to potential site 10

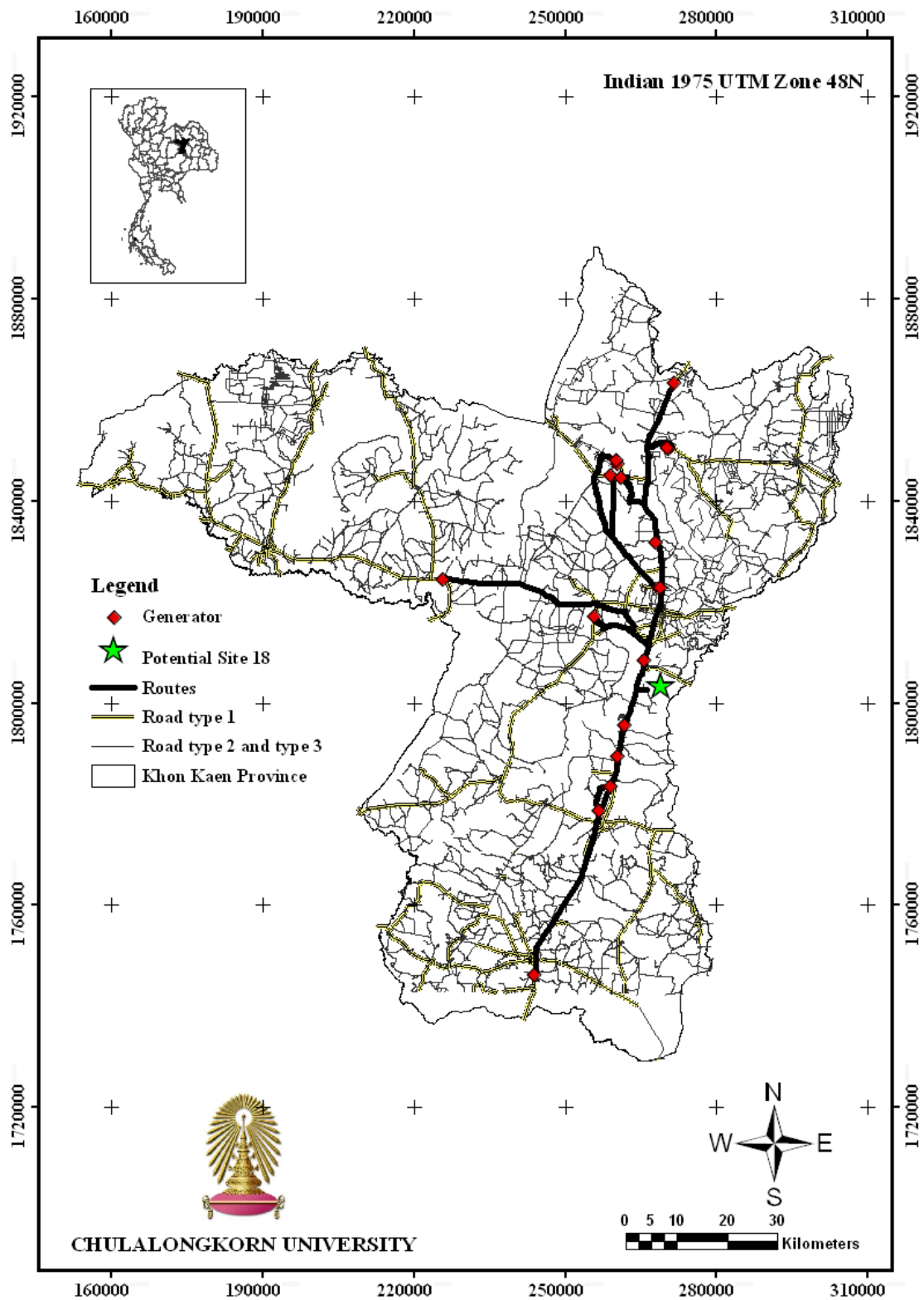


Figure 4.20 The suitable route for transport hazardous waste of generators to potential site 18

CHAPTER V

CONCLUSION

5.1 Conclusion

The improper management of hazardous waste, such as co-disposal with solid waste at municipality disposal sites and illegal dumping, can be potentially hazardous to the environment, human health, and living organisms, and also can cause contamination to the surface soil and groundwater. Landfill is a common method for final waste disposal which is used in many countries, since it can decrease the harmful effects on humans and the environment around from the improper management. However, developing landfill sites is an extremely difficult task to accomplish, especially with regards to hazardous waste landfill, because it involves diverse environmental, economic, social and political factors. Siting hazardous waste landfill is the one of the most difficult tasks in hazardous waste management, since communities usually respond to plans to build a landfill with the stance of 'Not in My Back Yard'. Furthermore, siting hazardous waste landfill requires the evaluation of many factors in order to determine the most suitable site. The evaluation factors include water resources, land use, geology, sensitive areas, community areas, and other related matters. Therefore, site selection plays an important role in the hazardous waste management processes. The goals of site selection should be to minimize health risk, environment impact and cost, while maximizing public acceptability (Batstone, Smith, and Wilson, 1989). Therefore the objective of this study is to identify the most suitable site for the construction of a hazardous waste landfill within the Khon Kaen Province by using GIS.

In this study, the criteria for hazardous waste landfill were modified from the PCD of Thailand in order to achieve suitable criteria for the Khon Kaen Province. Using the GIS technique, the results showed that 40 potential sites were found within the Khon Kaen Province. Due to the fact that the disposal area should be large enough to be used for 20 years, from the calculation step the appropriate area size was calculated as 10,103 m². The results indicated that only 18 potential sites

were found within the Khon Kaen Province, with areas ranging from 10,702 to 1,994,889 m².

Although site selection is an important part of landfill construction, for the transportation of hazardous waste it is necessary to consider the safety and cost of transportation. The proper planning and management of hazardous waste transportation helps a generator obtain a benefit with respect to cost reduction and minimizing the threat to human health and the environment resulting from an accident or improper practice. Therefore, another objective of the study is to select a suitable transportation route for the hazardous waste from the generator to the disposal facilities using GIS based on Dijkstra's algorithm. Using various methods of GIS network analysis the results obtained are quite similar (Table 5.1). The study provides various results depending on the method modeled, such how by defining the various the amount of hazardous waste produced by each generator and the truck capacity can affect the distance and fuel cost of transportation.

Table 5.1 The first five least fuel cost and transport distance of generator to potential site

| Potential site rank | Finding shortest distance by straight line | Finding the shortest route based on road network | Finding the shortest route based on road type |
|----------------------------|---|---|--|
| 1 | Potential site 6 | Potential site 7 | Potential site 6 |
| 2 | Potential site 7 | Potential site 6 | Potential site 7 |
| 3 | Potential site 9 | Potential site 9 | Potential site 9 |
| 4 | Potential site 8 | Potential site 18 | Potential site 8 |
| 5 | Potential site 18 | Potential site 8 | Potential site 10 |

5.2 Recommendations

1. Site selection must not only consider the environmental and economic factors as described in the study, but also political and social factors must be incorporated with the other factors in order to determine the really suitable site.

2. Site surveys play an important part of the site selection process which should be completed before selecting the most suitable site.

3. The integrity of the data affects the accuracy level of the GIS network analysis, with respect to results such as traffic density, population density, and the environment in the vicinity of the road.

4. Hazardous waste competition should be considered when transporting it to a management facility. Since some hazardous waste cannot be transported in the same vehicle with other hazardous waste.

5. Typical, treatment process should be done before disposal hazardous waste, in order to convert the waste into harmless forms, or immobilize toxic components, or reduce the quantity of the waste. In some case, the proper treatment helps generator to get benefit from cost reduction. However, pollution prevention is the best practice in hazardous waste management which is eliminate the generation of hazardous waste at it source. Moreover, this practice can help the generator to achieve a benefit such as reduce cost of their production and transportation of the waste to disposal facilities.

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APPENDICES

Appendix A

Performing GIS network analysis

A.1 Network Dataset

Networks used by ArcGIS Network Analyst are stored as network datasets. Network datasets are made of network elements. Network elements are generated from the sources used to create the network dataset. The geometry of the source features is used to establish connectivity. In addition, network elements have attributes that control navigation over the network.

There are three kinds of network elements: edges, junctions, and turns. Edges are elements that connect to other elements (junctions) and are the links over which resources flow. Junctions connect edges and facilitate navigation from one edge to another. Turn elements record information about movement between two or more edges.

Edges and junctions form the basic structure of any network. Connectivity in a network deals with connecting edges and junctions to each other. Turns are optional elements that store information about a particular turning movement; for instance, a left turn is restricted from one particular edge to another.

There are three types of network sources that participate in the creation of a network dataset: edge feature sources, junction feature sources, and turn feature sources. Line feature classes participate as edge feature sources. Point feature classes participate as junction feature sources. Turn feature classes participate as turn feature sources in a network.

1. Preparation for creating a network dataset

Once users have developed network dataset design, users are ready to create a network dataset. There are four main steps preparation for creating a network dataset:

1.1 Prepare the feature dataset and sources

- If users are creating a geodatabase-based network dataset, all feature classes participating as sources in a network should be present in one feature dataset.

- If users are creating a network from shapefiles, users need to organize all the feature classes that will participate as sources into the same folder.

- Users may need to create new feature datasets or new feature classes, and users may need to edit features.

1.2 Prepare the sources for appropriate roles inside the network dataset

- Be sure all sources have fields that represent all network impedance values (distance, travel time, and so on).

- If users are modeling one-way streets, be sure that edge sources have a field specifying one-way street information.

- If users' data uses Z-elevation or Z-level values to model overpasses and underpasses, be sure this information is stored in a pair of integer.

- If users plan to generate driving directions text of your network analyses, be sure that edge sources have fields containing the information need to generate driving directions such as road class, street names, highway shields, and boundary information.

1.3 Prepare turn feature classes

- Be sure turn feature class contains fields containing information that will be used in the network attributes, such as turn impedances (for example, this turn takes two minutes to make), or conditional turning restrictions (for example, only trucks cannot make this turn).

1.4 Create the network dataset using the New Network Dataset wizard

- The New Network Dataset wizard will walk users through naming the network dataset, identifying the network sources, setting up the connectivity, identifying elevation data (if necessary), specifying turn sources (if necessary), defining attributes (such as costs, descriptors, restrictions, and hierarchy), and setting up the directions reporting specifications.

2. Create network dataset

Steps to create network dataset can be performing in ArcCatalog as follow.

1. Start ArcCatalog.

2. Click Tools and click Extensions.
3. Check Network Analyst.
4. Click Close.
5. If users are creating a geodatabase-based network dataset, navigate to the feature dataset location in the Catalog tree.
6. If users are creating a shapefile-based network dataset, navigate to the shapefile location in the Catalog tree.
7. Right-click the feature dataset, point to New, then click Network Dataset.
8. If users are creating a shapefile-based network, right-click the shapefile and click New Network Dataset.
9. Type a name for the network dataset. Click Next.
10. Check all the feature classes that will be used as network sources in the network. Click Next.
11. Accept the default connectivity settings or click Connectivity and make changes to the connectivity settings. Click Next.
12. Click Next if don't need to modify the connectivity with elevation field data or elevation field settings.
13. Click No if users are not using turns.
14. Optionally, check the Turn Sources check box. Click Next.
15. Accept the settings for the Attributes, or make the required changes to the settings. Click Next.
16. Click No if don't want to establish driving directions.
17. Optionally, click Directions and adjust the settings on the Network Dataset Properties dialog box. Click Next.
18. Review the network dataset summary. Click Finish.
19. Click Yes to build the network dataset.
20. Optionally, click No if users want to build the network dataset at another time.

A.2 Performing Network Analysis

All network analyses in ArcGIS Network Analyst follow a similar work flow. The basic steps to perform any type of network analysis in ArcGIS are:

1. Creating the analysis layer
2. Adding network locations
3. Setting analysis properties
4. Performing the analysis and displaying the results

1. Finding the best route

ArcGIS Network Analyst can find the best way to get from one location to another or the best way to visit several locations. The locations can be specified interactively by placing points on the screen, by entering an address, or by using points in an existing feature class or feature layer. The best route can be determined for the order of locations as specified by the user. Alternatively, ArcGIS Network Analyst can determine the best sequence to visit the locations.

Creating a route can mean finding the quickest, shortest, or most scenic route, depending on the impedance chosen. If the impedance is time, then the best route is the quickest route. Hence, the best route can be defined as the route that has the lowest impedance, or least cost, where the impedance is chosen by the user. Any cost attribute can be used as the impedance when determining the best route. Steps to finding the best route in ArcMap can be performing as follow.

1. Start ArcMap.
2. Click Tools and click Extensions.
3. Check Network Analyst.
4. Click Close.
5. Click the Add Data button.
6. Navigate to the network dataset location.
7. Click the network dataset and click Add.
8. Click No to add only the network dataset to the map, or click Yes to add all the feature classes that participate in the network to the map.

9. If the Network Analyst toolbar is not present, click the View menu, point to Toolbars, and click Network Analyst.
10. If the Network Analyst Window is not already open, on the Network Analyst toolbar, click the Network Analyst Window button.
11. On the Network Analyst toolbar, click the Network Analyst drop-down 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.
12. There are two ways to add stops: from a point feature class or by adding points to the display.
 - a. In the Network Analyst Window, right-click Stops and click Load Locations.
 - b. Click the browse button and choose a point feature class.
 - c. Click Add.
 - d. Click OK.Or
 - a. In the Network Analyst Window, click Stops.
 - b. On the Network Analyst toolbar, click the Create Network Location tool.
 - c. Click the locations on the display where users want to add stop locations.
13. If users need to adjust a stop location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
14. There are two ways to add barriers: from a point feature class or by adding points to the display.
 - i. In the Network Analyst Window, right-click Barriers and click Load Locations.
 - ii. Click the Browse button and choose a point feature class.
 - iii. Click Add.
 - iv. Click OK.

Or

- i. On the Network Analyst Window, click Barriers.
 - ii. On the Network Analyst toolbar, click the Create Network Location tool.
 - iii. Click the locations on the display where users want to add barriers.
15. If users need to adjust a barrier location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
 16. In the table of contents, right-click the Route layer and click Properties.
 17. Click the Analysis Settings tab.
 18. Set the route properties to be used in the analysis.
 19. If users want to set properties for the directions, click the Directions tab. Click OK.
 20. If users have multiple analysis layers in document, ensure users have the current route analysis layer visible on the Network Analyst Window.
 21. Click the Solve button on the Network Analyst toolbar.

2. Finding the closest facility

When finding closest facilities, user can specify how many to find and whether the direction of travel is toward or away from them. Once user have found the closest facilities, user can display the best route to or from them, return the travel cost for each route, and display directions to each facility. Additionally, user can specify an impedance cutoff beyond which ArcGIS Network Analyst should not search for a facility. For instance, user can set up a closest facility problem to search for hospitals within 15 minutes' drive time of the site of an accident. Any hospitals that take longer than 15 minutes to reach will not be included in the results. The hospitals are referred to as facilities, and the accident is referred to as an incident. ArcGIS Network Analyst allows user to perform multiple closest facility analyses simultaneously. This means user can have multiple incidents and find the closest

facility (or facilities) to each incident. Steps to finding the closest facility in ArcMap can be performing as follow.

1. Start ArcMap.
 2. Click the Tools menu and click Extensions.
 3. Check Network Analyst.
 4. Click Close.
 5. Click the Add Data button.
 6. Navigate to the network dataset location.
 7. Click the network dataset and click Add.
 8. Click No to add only the network dataset to the map, or click Yes to add all the feature classes that participate in the network to the map.
 9. If the Network Analyst toolbar is not present, click the View menu, point to Toolbars, and click Network Analyst.
 10. If the Network Analyst Window is not already open, on the Network Analyst toolbar, click the Network Analyst Window button.
 11. On the Network Analyst toolbar, click the Network Analyst drop-down menu and click New Closest Facility. The Network Analyst Window now contains empty lists of Facilities, Incidents, Routes, and Barriers information. Additionally, the table of contents contains a new Closest Facility analysis layer.
 12. There are two ways to add facilities: from a point feature class or by adding points to the display.
 - i. On the Network Analyst Window, right-click Facilities and click Load Locations.
 - ii. Click the Browse button and choose a point feature class.
 - iii. Click Add.
 - iv. Click OK.
- Or
- i. On the Network Analyst Window, click Facilities.

- ii. On the Network Analyst toolbar, click the Create Network Location tool.
 - iii. On the display, click the locations where users want to add facility locations.
13. If users need to adjust a facility location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
14. There are two ways to add incidents: from a point feature class or by adding points to the display.
 - i. On the Network Analyst Window, right-click Incidents and click Load Locations.
 - ii. Click the Browse button and choose a point feature class.
 - iii. Click Add.
 - iv. Click OK.

Or

 - i. On the Network Analyst Window, click Incidents.
 - ii. On the Network Analyst toolbar, click the Create Network Location tool.
 - iii. On the display, click the locations where users want to add incident locations.
15. If users need to adjust an incident location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
16. There are two ways to add barriers: from a point feature class or by adding points to the display.
 - i. On the Network Analyst Window, right-click Barriers and click Load Locations.
 - ii. Click the Browse button and choose a point feature class.
 - iii. Click Add.
 - iv. Click OK.

Or

 - i. On the Network Analyst Window, click Barriers.
 - ii. On the Network Analyst toolbar, click the Create Network Location tool.

- iii. Click the locations on the display where users want to add barriers.
17. If users need to adjust a barrier location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
18. In the table of contents, right-click the Closest Facility layer and click Properties.
19. Click the Analysis Settings tab.
20. Set the properties to be used in the analysis.
21. If users want to set properties for the directions, click the Directions tab. Click OK.
22. On the Network Analyst toolbar, click the Solve button.

3. Solving a vehicle routing problem

The objectives in solving such vehicle routing problems (VRP) are to provide a high level of customer service by honoring any time windows while keeping the overall operating and investment costs for each route as low as possible. The constraints are to complete the routes with available resources and within the time limits imposed by driver work shifts, driving speeds, and customer commitments.

Various organizations use a fleet of vehicles to service a set of orders. For example, a large furniture store might use several trucks to deliver furniture to their customers' homes. A specialized company might route trucks from a facility to pick up used grease from restaurants. A health department might schedule daily inspection visits for each of its health inspectors.

The problem that is common to the examples listed above is the VRP. Each organization needs to determine which orders (homes, restaurants, or inspection sites) should be serviced by each route (truck or inspector) and in what sequence the orders should be visited. The primary goal is to service the orders and minimize the overall operating cost for the fleet of vehicles. Thus, while the Network Analyst Route solver finds the best route for a single vehicle, the VRP solver finds the best routes for a fleet of vehicles servicing many orders. In addition, the VRP solver can answer more specific problems because numerous options are available, such as

matching vehicle capacities with order quantities, giving breaks to drivers, and pairing orders into the same route. Steps to Solving a vehicle routing problem in ArcMap can be performing as follow.

1. Start ArcMap.
2. Click Tools and click Extensions.
3. Click Network Analyst.
4. Click Close.
5. Click the Add Data button.
6. Navigate to the network dataset location.
7. Click the network dataset and click Add.
8. Click No to add only the network dataset to the map, or click Yes to add all the feature classes that participate in the network to the map.
9. If the Network Analyst toolbar is not present, click the View menu, point to Toolbars, then click Network Analyst.
10. If the Network Analyst Window is not already open, on the Network Analyst toolbar, click the Network Analyst Window button.
11. On the Network Analyst toolbar, click the Network Analyst drop-down menu and click New Vehicle Routing Problem. The Network Analyst Window now contains empty lists of Orders, Depots, Routes, Depot Visits, Breaks, Route Zones, Route Seed Points, Route Renewals, Specialties, Order Pairs, and Barriers classes. Additionally, the table of contents contains a new vehicle routing problem analysis layer.
12. There are two ways to add orders: from a point feature class or by adding points to the display.
 - a. In the Network Analyst Window, right-click Orders and click Load Locations.
 - b. Click the browse button and choose a point feature class.
 - c. Click Add.
 - d. Click OK.

Or

- a. In the Network Analyst Window, click Orders.
 - b. On the Network Analyst toolbar, click the Create Network Location tool.
 - c. Click the locations on the display where users want to add order locations.
13. If users need to adjust an order location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
14. There are two ways to add depots: from a point feature class or by adding points to the display.
- a. In the Network Analyst Window, right-click Depots and click Load Locations.
 - b. Click the browse button and choose a point feature class.
 - c. Click Add.
 - d. Click OK.

Or

- a. In the Network Analyst Window, click Depots.
 - b. In the Network Analyst toolbar, click the Create Network Location tool.
 - c. Click the locations on the display where users want to add depots.
15. If users need to adjust a depot location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
16. There are two ways to add routes: from a line feature class or by creating new routes from the Network Analyst Window. For each route, the StartDepotName and EndDepotName fields must be specified before the VRP solver will generate valid results.
- a. In the Network Analyst Window, right-click Routes and click Load Locations.
 - b. Click the browse button and choose a line feature class.
 - c. Click Add.
 - d. Click OK.

Or

- a. In the Network Analyst Window, click Routes.
- b. Right-click Routes and click Add Item.
- c. In the Properties window, specify properties for the new route and click OK.

17. There are two ways to add breaks: from a table or by creating new breaks from the Network Analyst Window. For each break, the RouteName field must be specified before the VRP solver will generate valid results.

- a. In the Network Analyst Window, right-click Breaks and click Load Locations.
- b. Click the browse button and choose a table.
- c. Click Add.
- d. Click OK.

Or

- a. In the Network Analyst Window, click Breaks.
- b. Right-click Breaks and click Add Item.
- c. In the Properties window, specify the properties for the new break and click OK.

18. There are two ways to add route zones: from a polygon feature class or by adding polygons to the display. For each route zone, the RouteName field must be specified before the VRP solver will generate valid results.

- a. In the Network Analyst Window, right-click Route Zones and click Load Locations.
- b. Click the browse button and choose a polygon feature class.
- c. Click Add.
- d. Click OK.

Or

- a. In the Network Analyst Window, click Route Zones.
- b. On the Network Analyst toolbar, click the Create Network Location tool.

- c. Click the locations on the display to digitize the route zone.
 - d. Double-click the new route zone in the Network Analyst Window to open the Properties window.
 - e. In the Properties window, specify the properties for the route zone and click OK.
19. There are two ways to add route seed points: from a point feature class or by adding points to the display. For each route seed point, the RouteName field must be specified before the VRP solver will generate valid results.
- a. In the Network Analyst Window, right-click Route Seed Points and click Load Locations.
 - b. Click the browse button and choose a point feature class.
 - c. Click Add.
 - d. Click OK.
- Or
- a. In the Network Analyst Window, click Route Seed Points.
 - b. On the Network Analyst toolbar, click the Create Network Location tool.
 - c. Click the locations on the display where you want to add route seed points.
 - d. Double-click the new route seed point in the Network Analyst Window to open the Properties window.
 - e. In the Properties window, specify the properties for the route seed point and click OK.
20. If users need to adjust a route seed point location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
21. There are two ways to add route renewals: from a table or by creating new route renewals from the Network Analyst Window. For each route renewal, the RouteName and DepotName fields must be specified before the VRP solver will generate valid results.

- a. In the Network Analyst Window, right-click Route Renewals and click Load Locations.
- b. Click the browse button and choose a table.
- c. Click Add.
- d. Click OK.

Or

- a. In the Network Analyst Window, click Route Renewals.
- b. Right-click Route Renewals and click Add Item.
- c. In the Properties window, specify the properties for the new route renewal and click OK.

22. There are two ways to add specialties: from a table or by creating new specialties from the Network Analyst Window.

- a. In the Network Analyst Window, right-click Specialties and click Load Locations.
- b. Click the browse button and choose a table.
- c. Click Add.
- d. Click OK.

Or

- a. In the Network Analyst Window, click Specialties.
- b. Right-click Specialties and click Add Item.
- c. In the Properties window specify the properties for the new specialty and click OK.

23. There are two ways to add order pairs: from a table or by creating new order pairs from the Network Analyst Window. For each order pair, the FirstOrderName and SecondOrderName fields must be specified before the VRP solver will generate valid results.

- a. In the Network Analyst Window, right-click Order Pairs and click Load Locations.
- b. Click the browse button and choose a table.
- c. Click Add.
- d. Click OK.

Or

- a. In the Network Analyst Window, click Order Pairs.
 - b. Right-click Order Pairs and click Add Item.
 - c. In the Properties window specify the properties for the new order pair and click OK.
24. There are two ways to add barriers: from a point feature class or by adding points to the display.
- a. In the Network Analyst Window, right-click Barriers and click Load Locations.
 - b. Click the browse button and choose a point feature class.
 - c. Click Add.
 - d. Click OK.
- Or
- a. In the Network Analyst Window, click Barriers.
 - b. On the Network Analyst toolbar, click the Create Network Location tool.
 - c. Click the locations on the display where you want to add barriers.
25. If users need to adjust a barrier location, on the Network Analyst toolbar, click the Select/Move Network Location tool.
26. In the table of contents, right-click the Vehicle Routing Problem layer and click Properties.
27. Click the Analysis Settings tab.
28. Set the vehicle routing problem properties to be used in the analysis. Click OK.
29. If users have multiple analysis layers in your document, ensure users have the current vehicle routing problem analysis layer visible in the Network Analyst Window.
30. Click the Solve button on the Network Analyst toolbar.

Appendix B
Layout of the suitable route for transport hazardous waste of
generators to potential

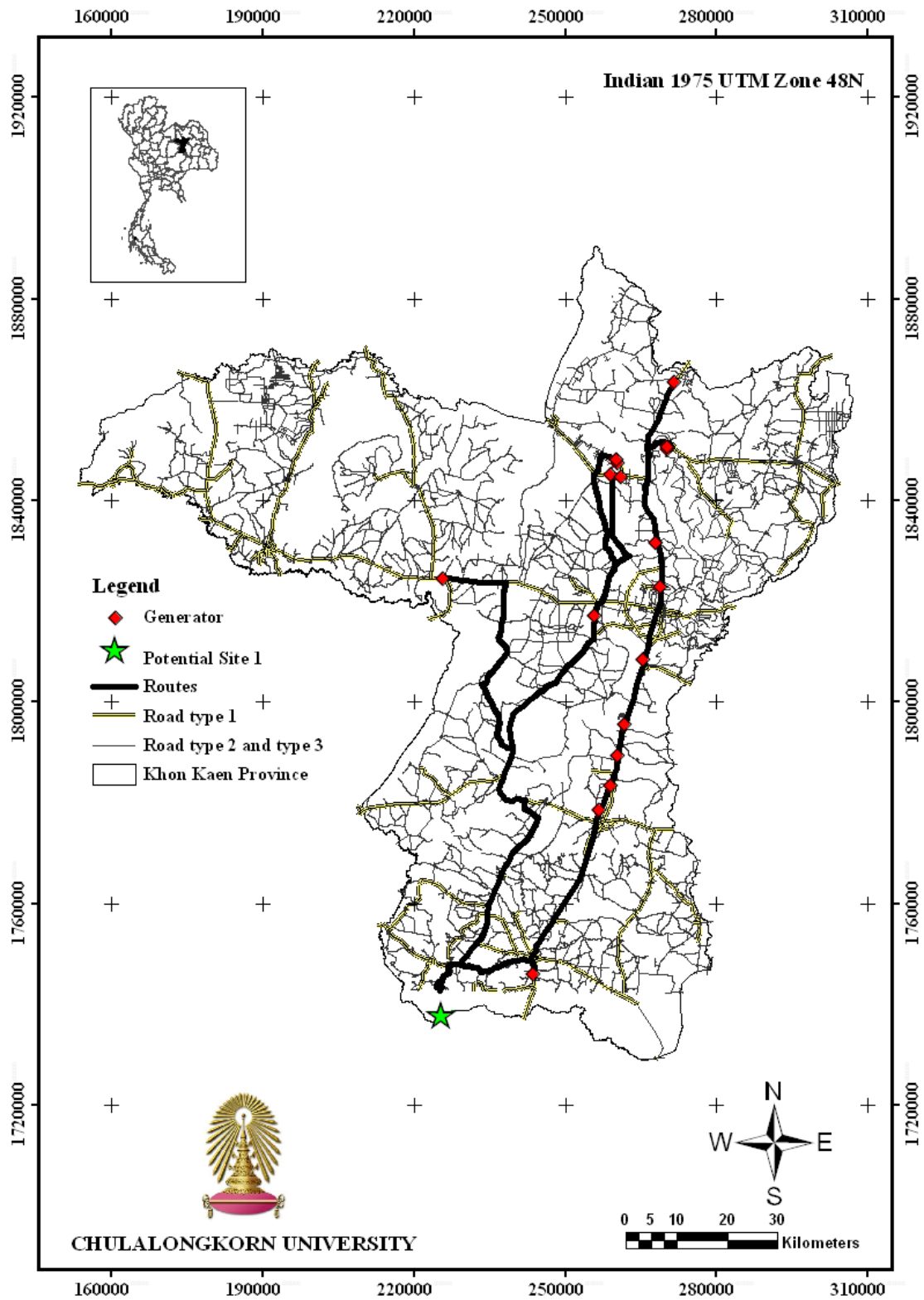


Figure B-1 The suitable route for transport hazardous waste of generators to potential site 1

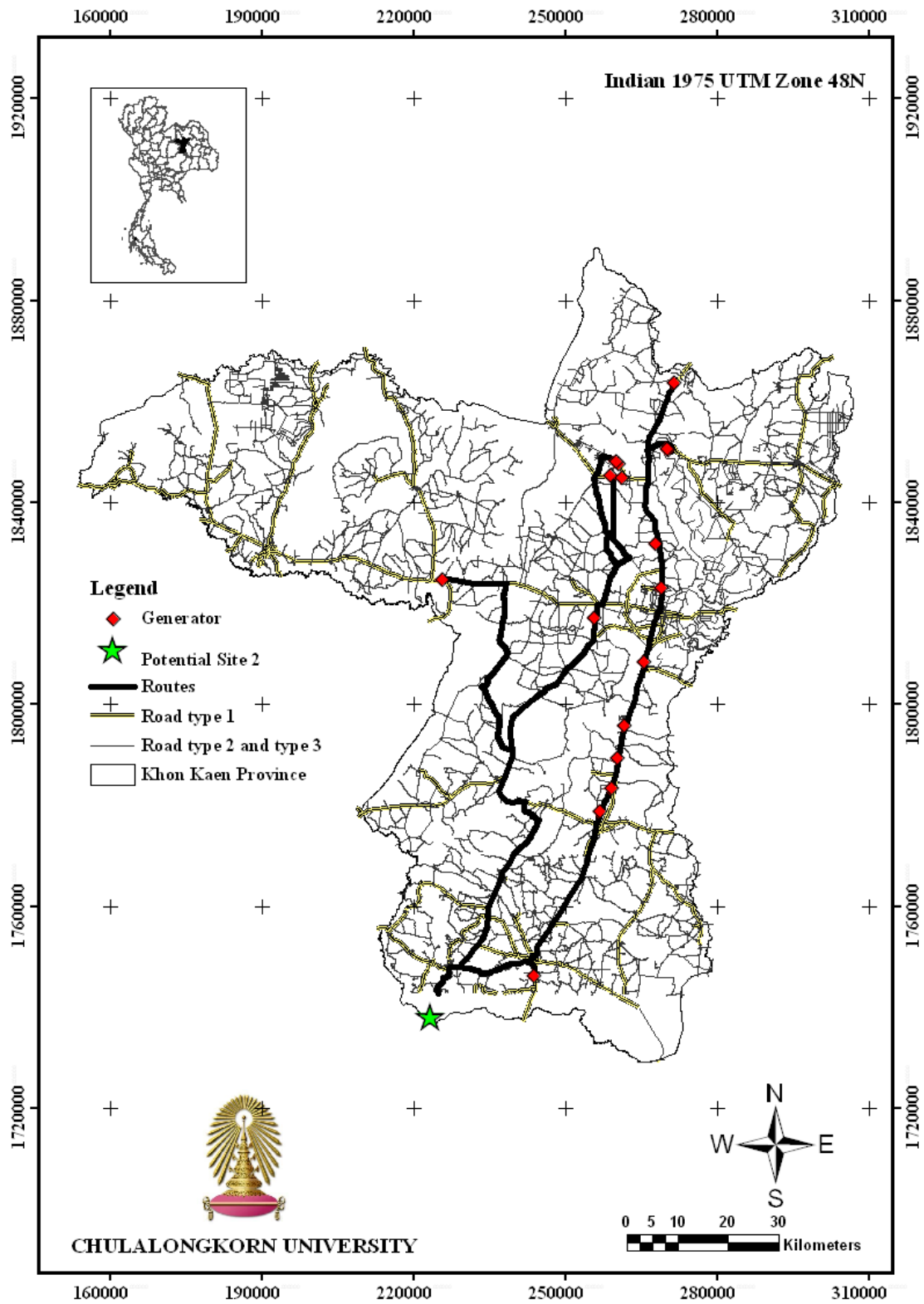


Figure B-2 The suitable route for transport hazardous waste of generators to potential site 2

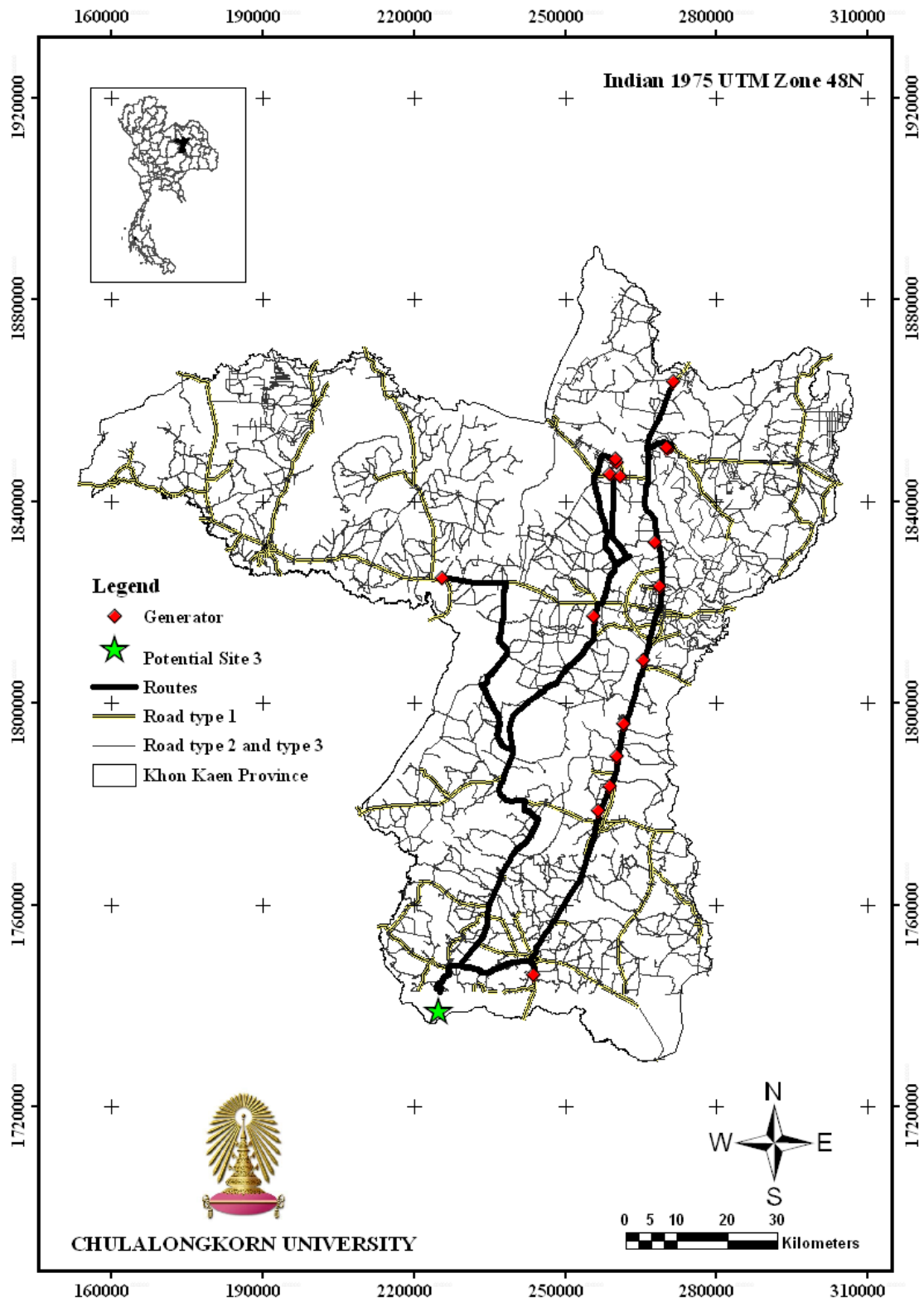


Figure B-3 The suitable route for transport hazardous waste of generators to potential site 3

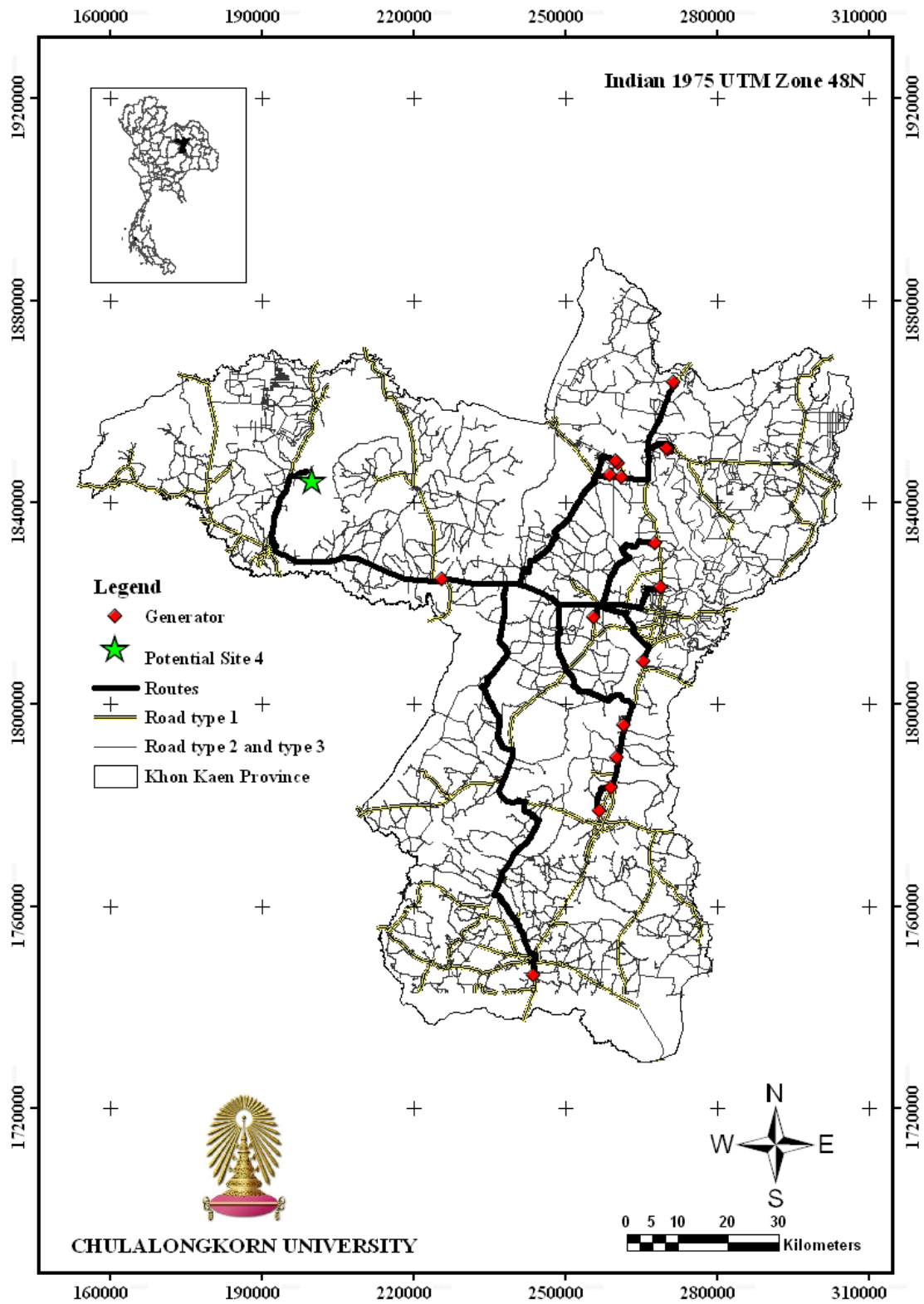


Figure B-4 The suitable route for transport hazardous waste of generators to potential site 4

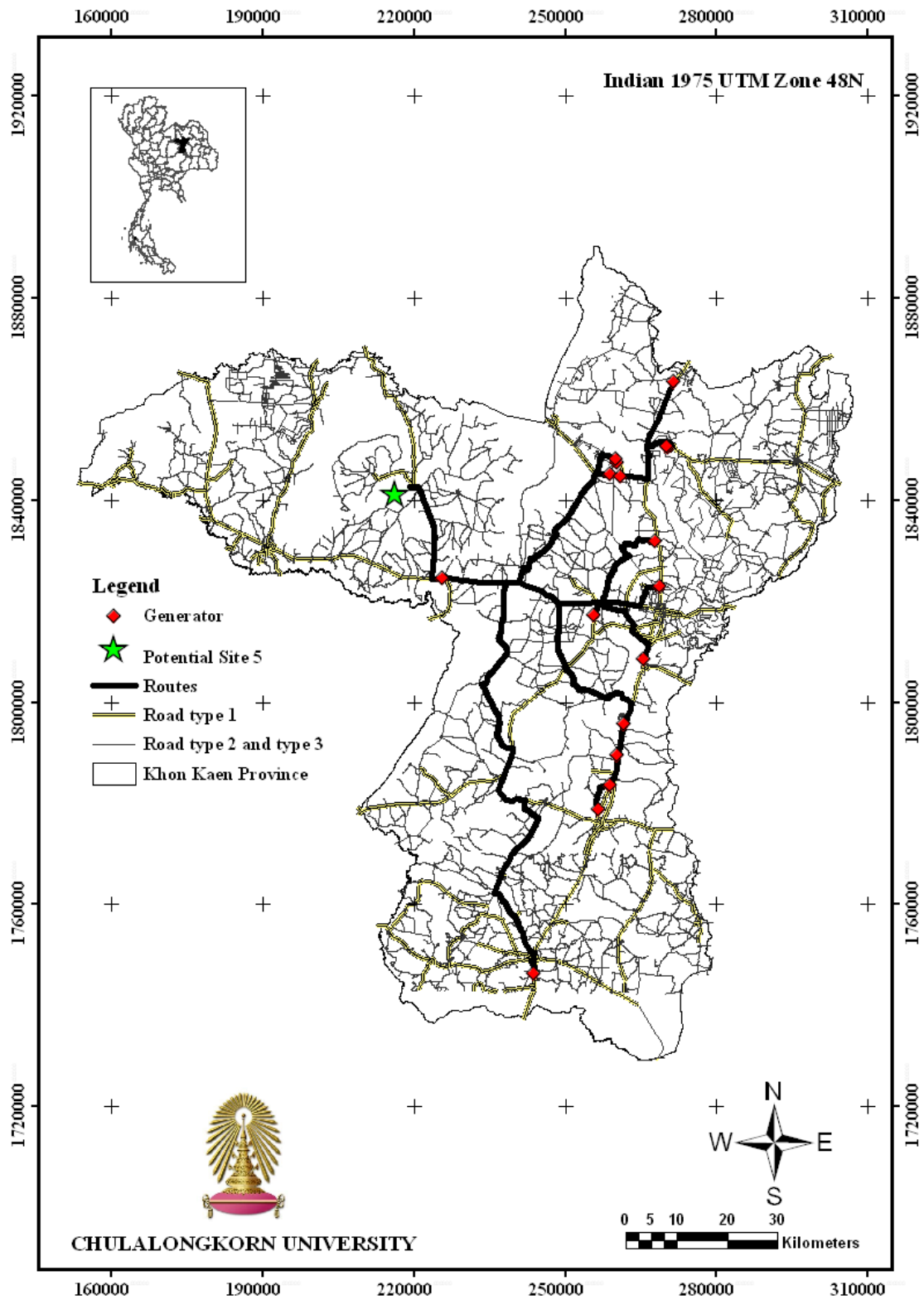


Figure B-5 The suitable route for transport hazardous waste of generators to potential site 5

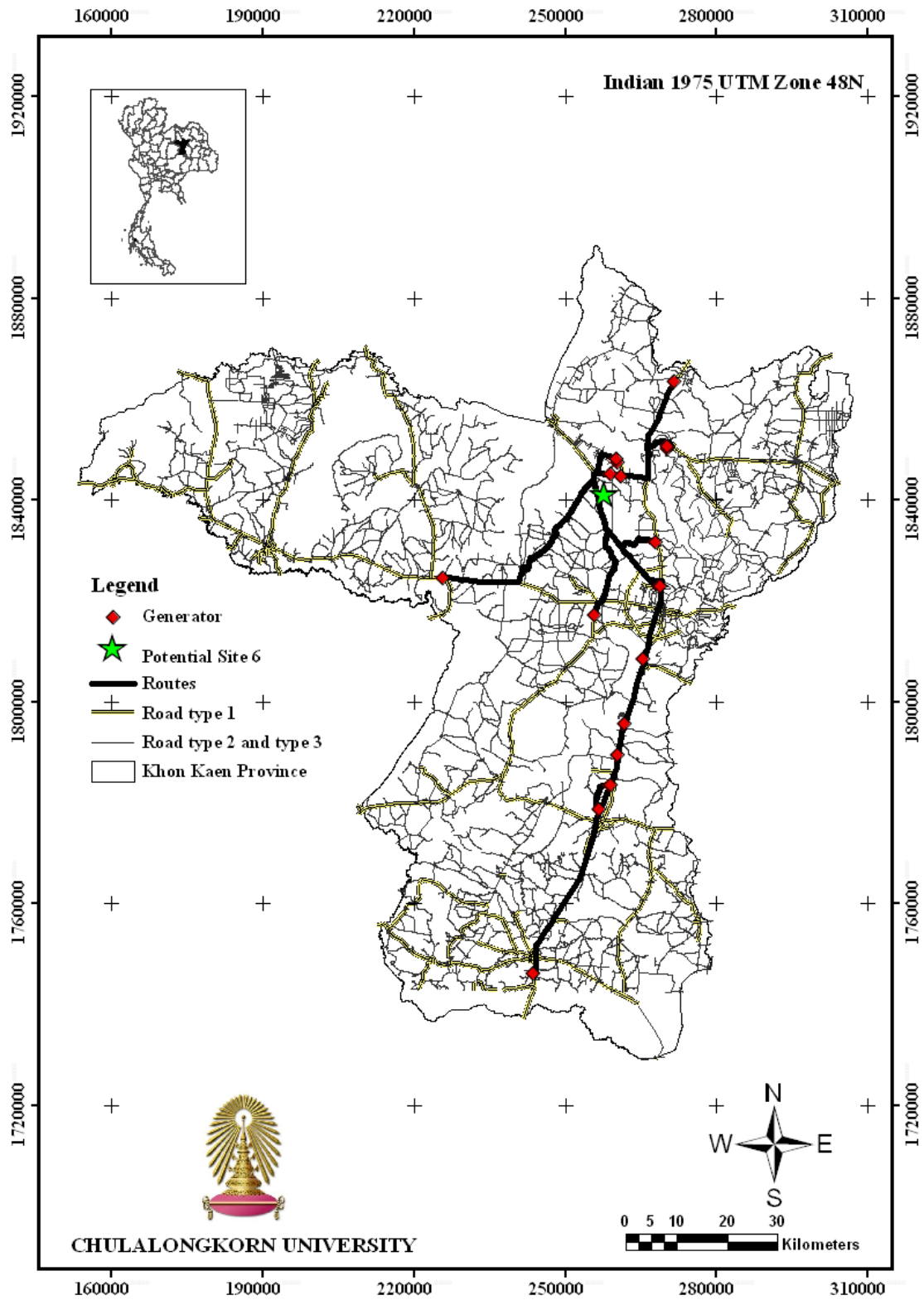


Figure B-6 The suitable route for transport hazardous waste of generators to potential site 6

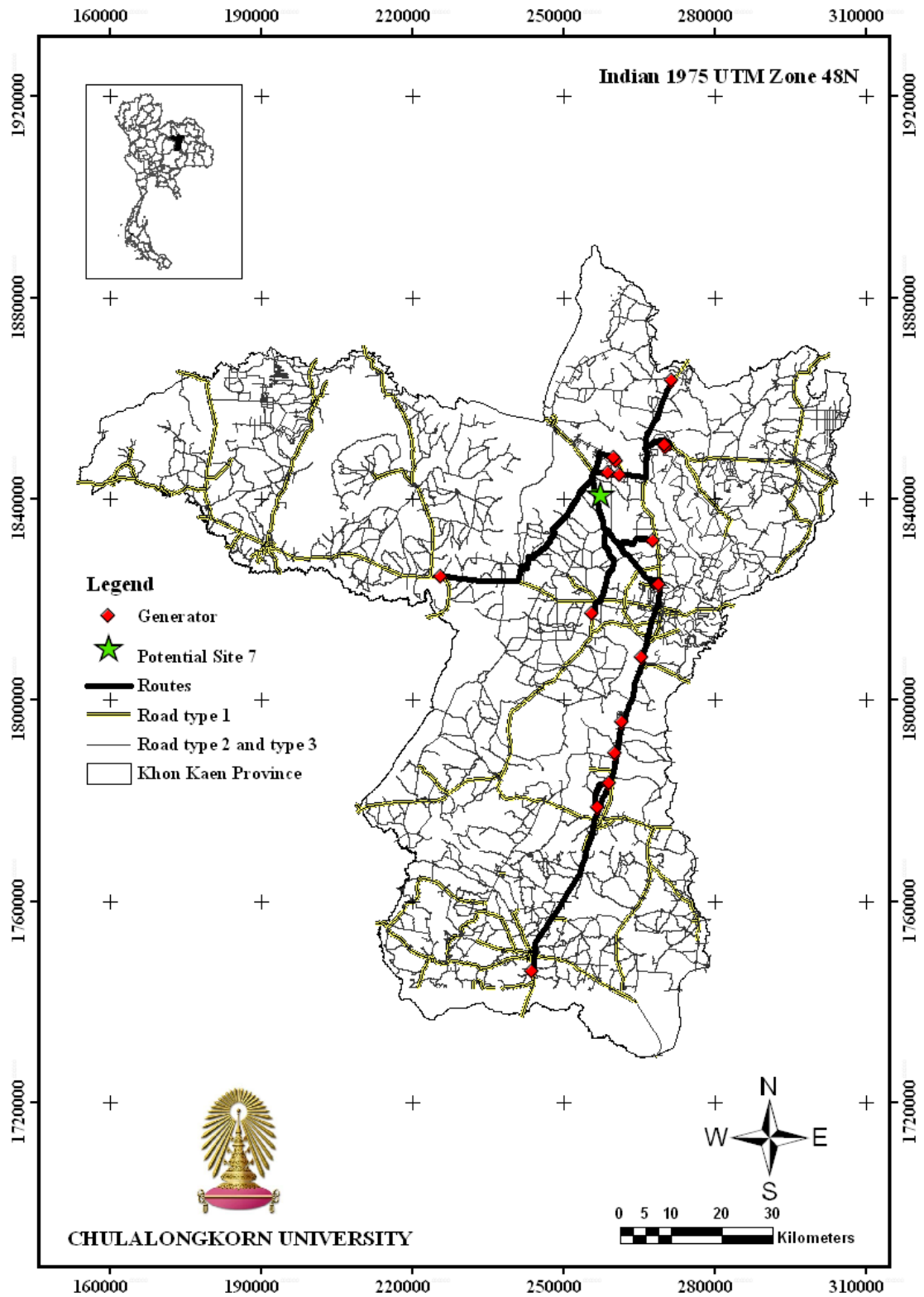


Figure B-7 The suitable route for transport hazardous waste of generators to potential site 7

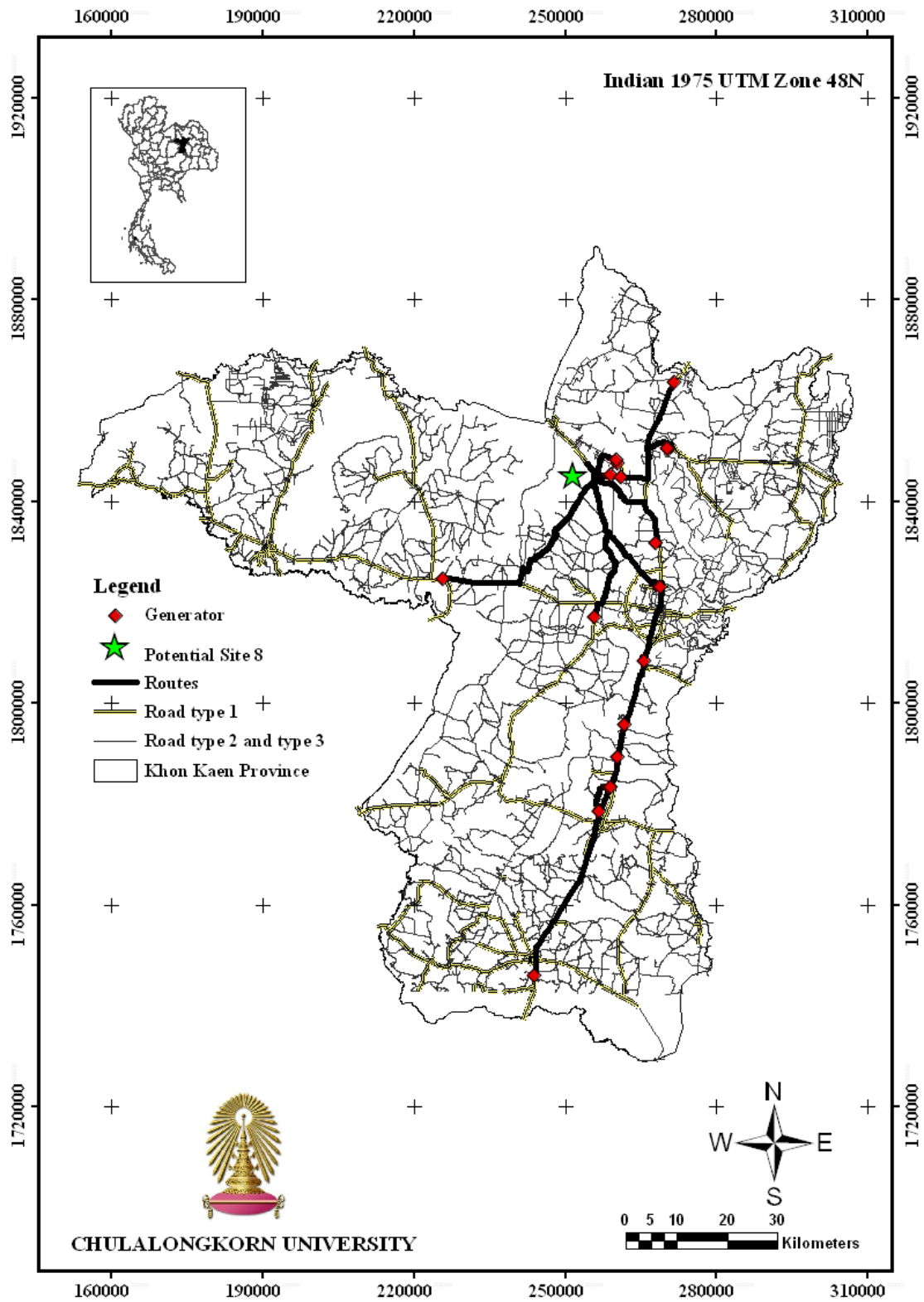


Figure B-8 The suitable route for transport hazardous waste of generators to potential site 8

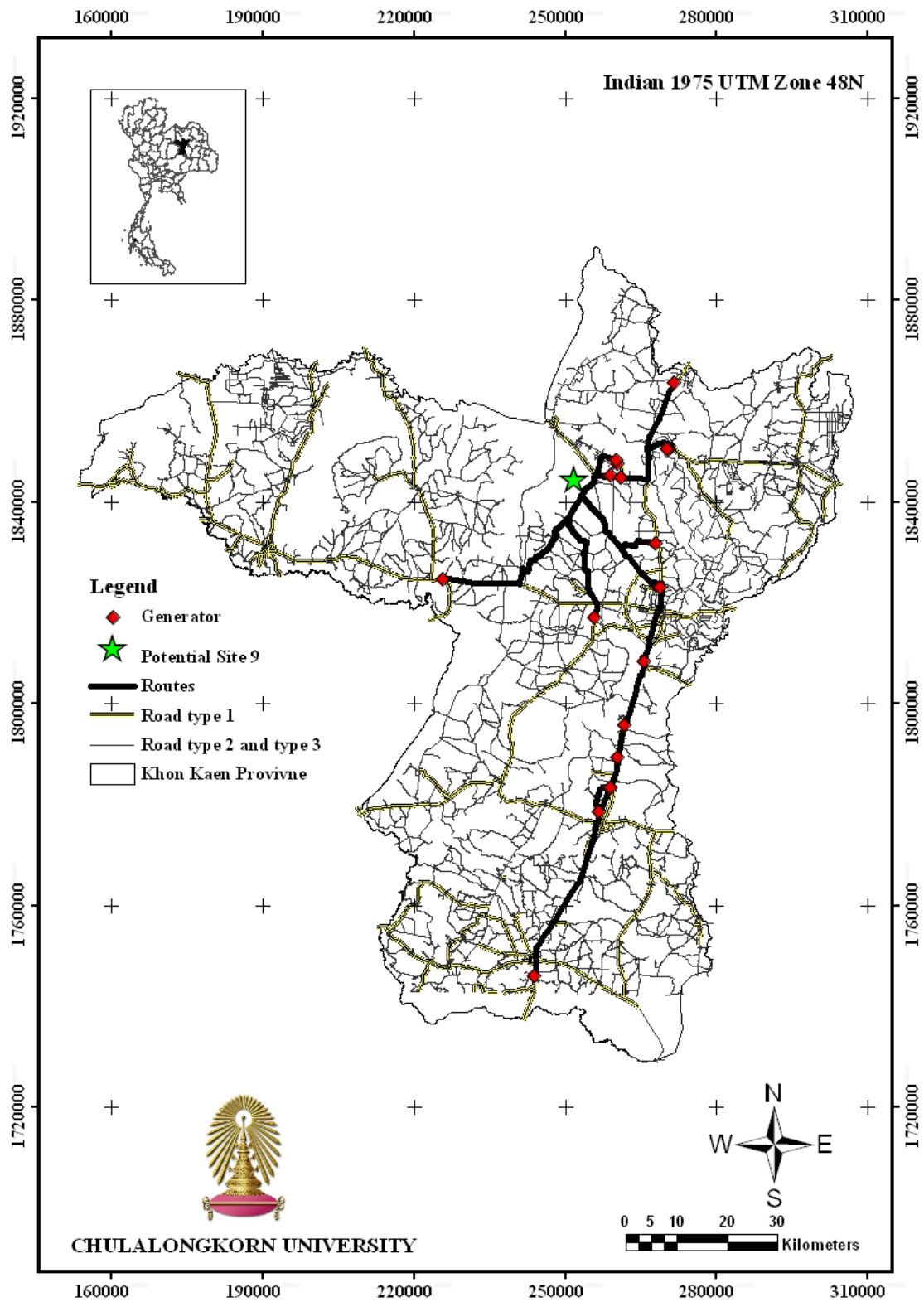


Figure B-9 The suitable route for transport hazardous waste of generators to potential site 9

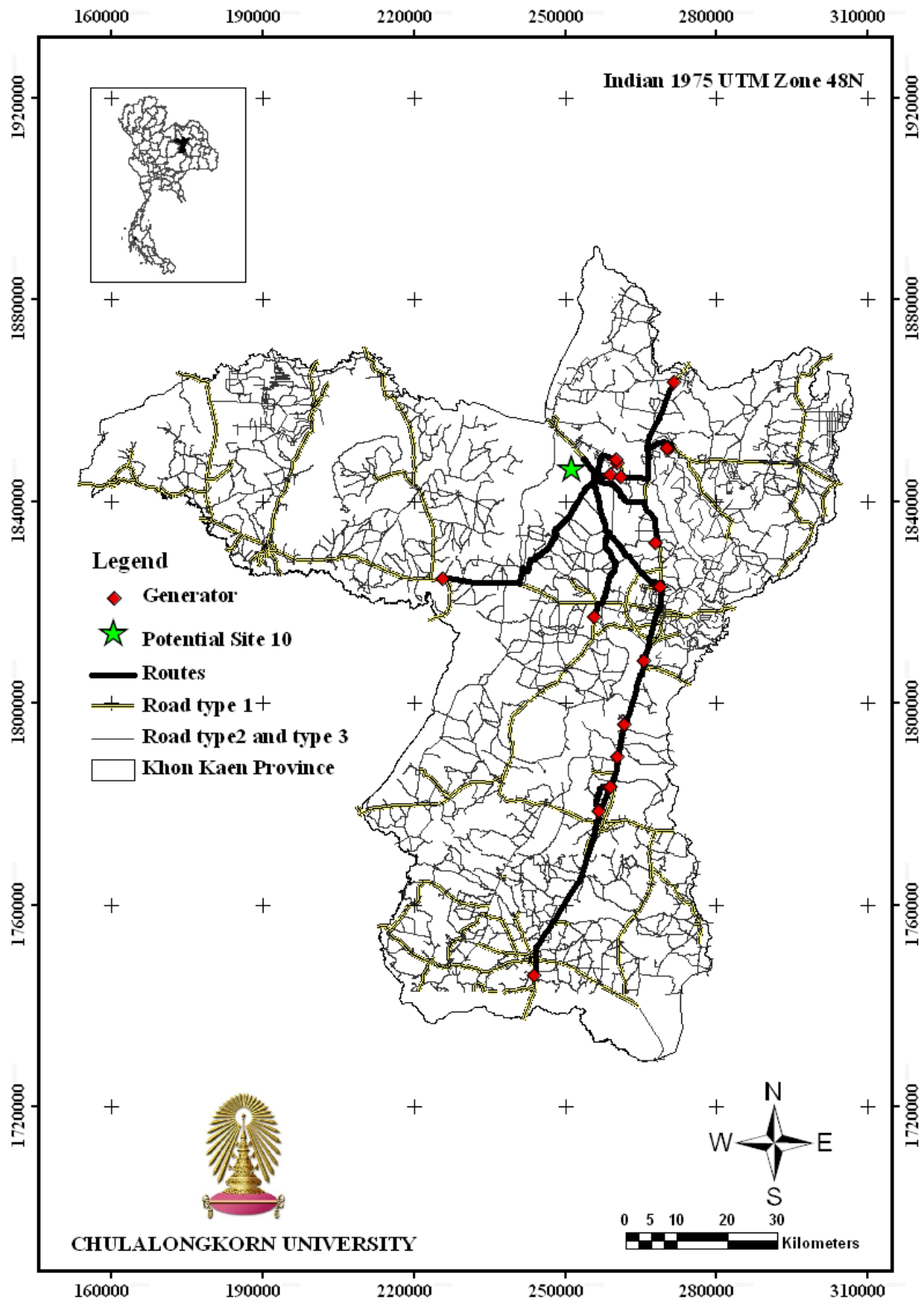


Figure B-10 The suitable route for transport hazardous waste of generators to potential site 10

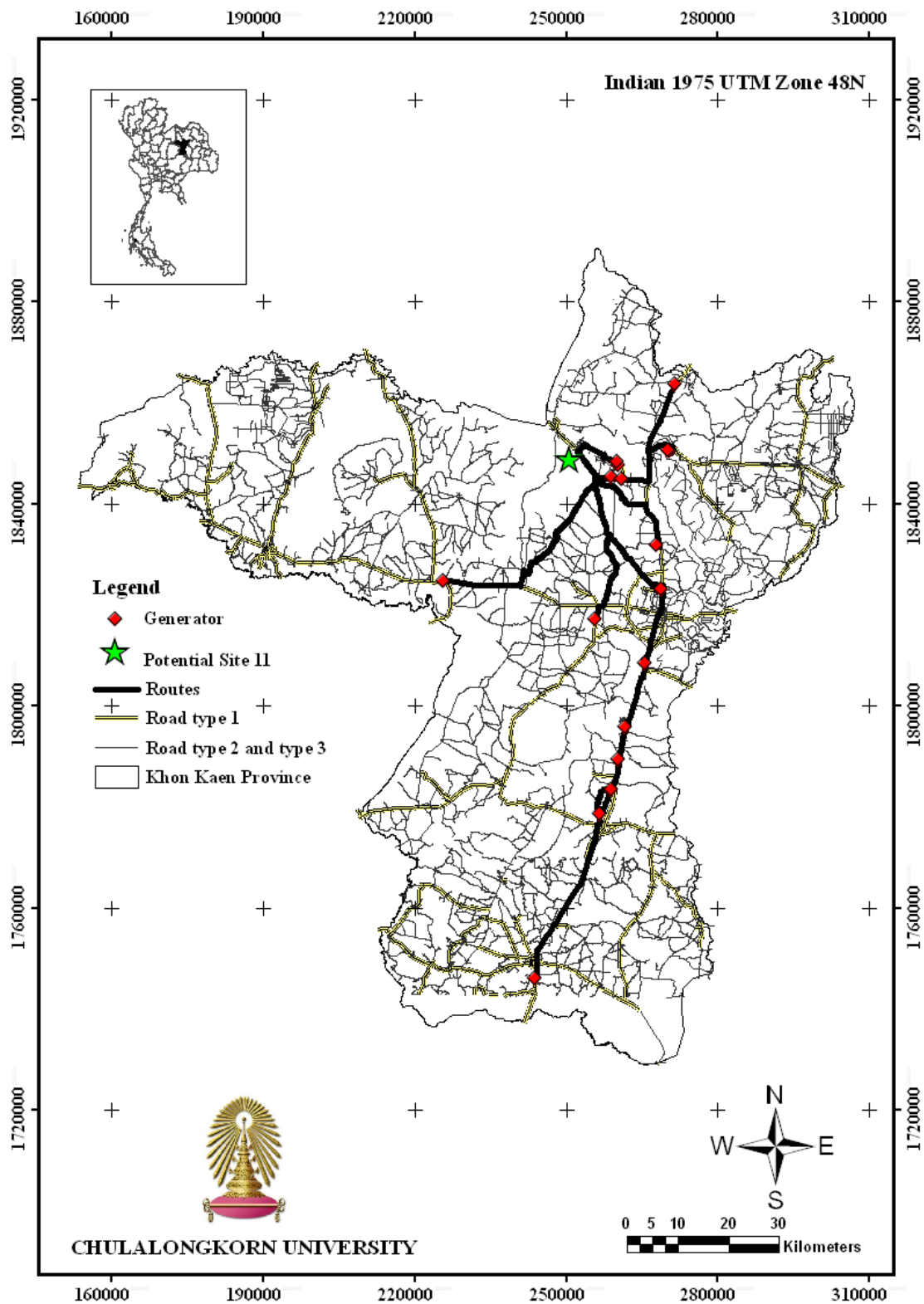


Figure B-11 The suitable route for transport hazardous waste of generators to potential site 11

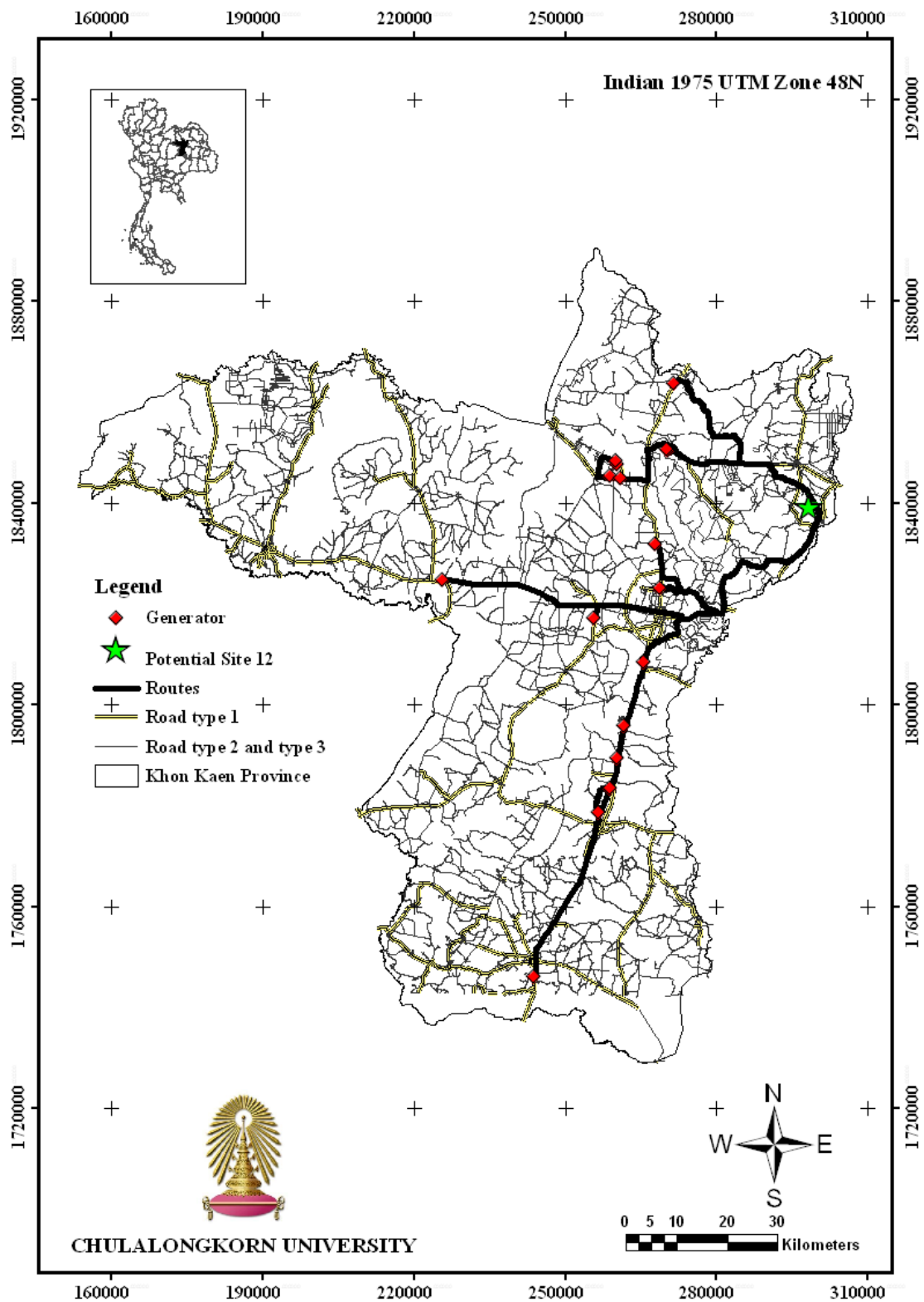


Figure B-12 The suitable route for transport hazardous waste of generators to potential site 12

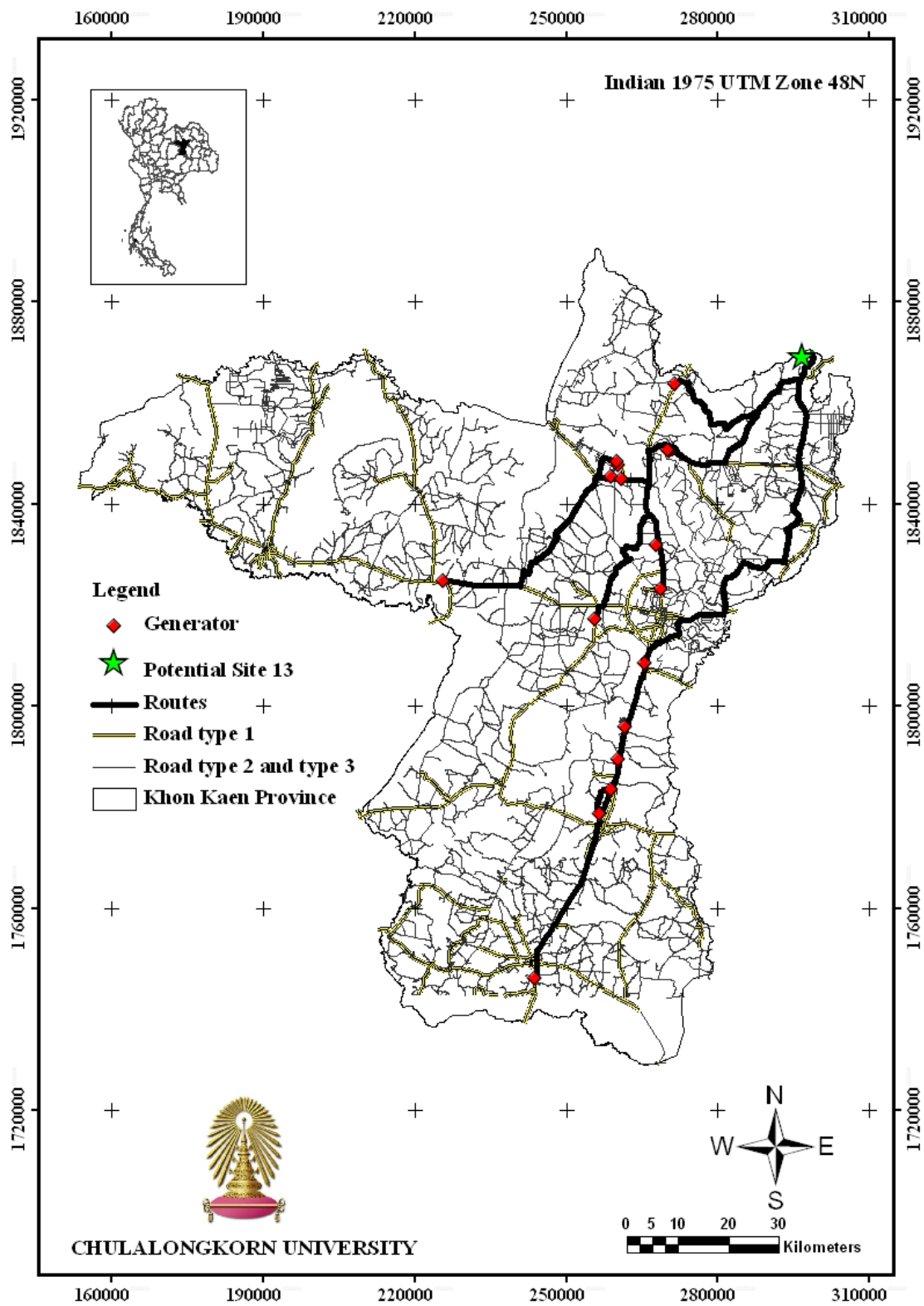


Figure B-13 The suitable route for transport hazardous waste of generators to potential site 13

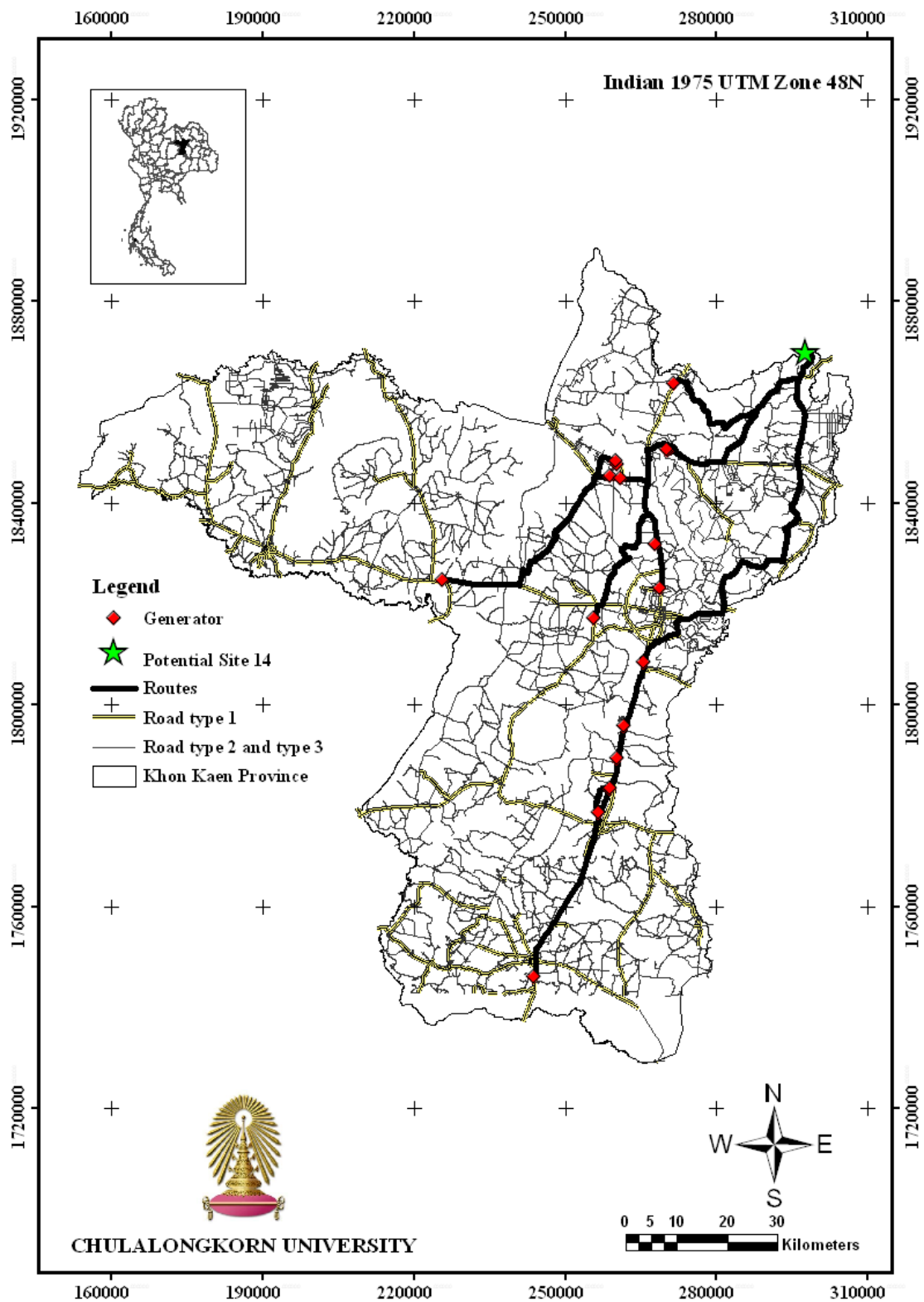


Figure B-14 The suitable route for transport hazardous waste of generators to potential site 14

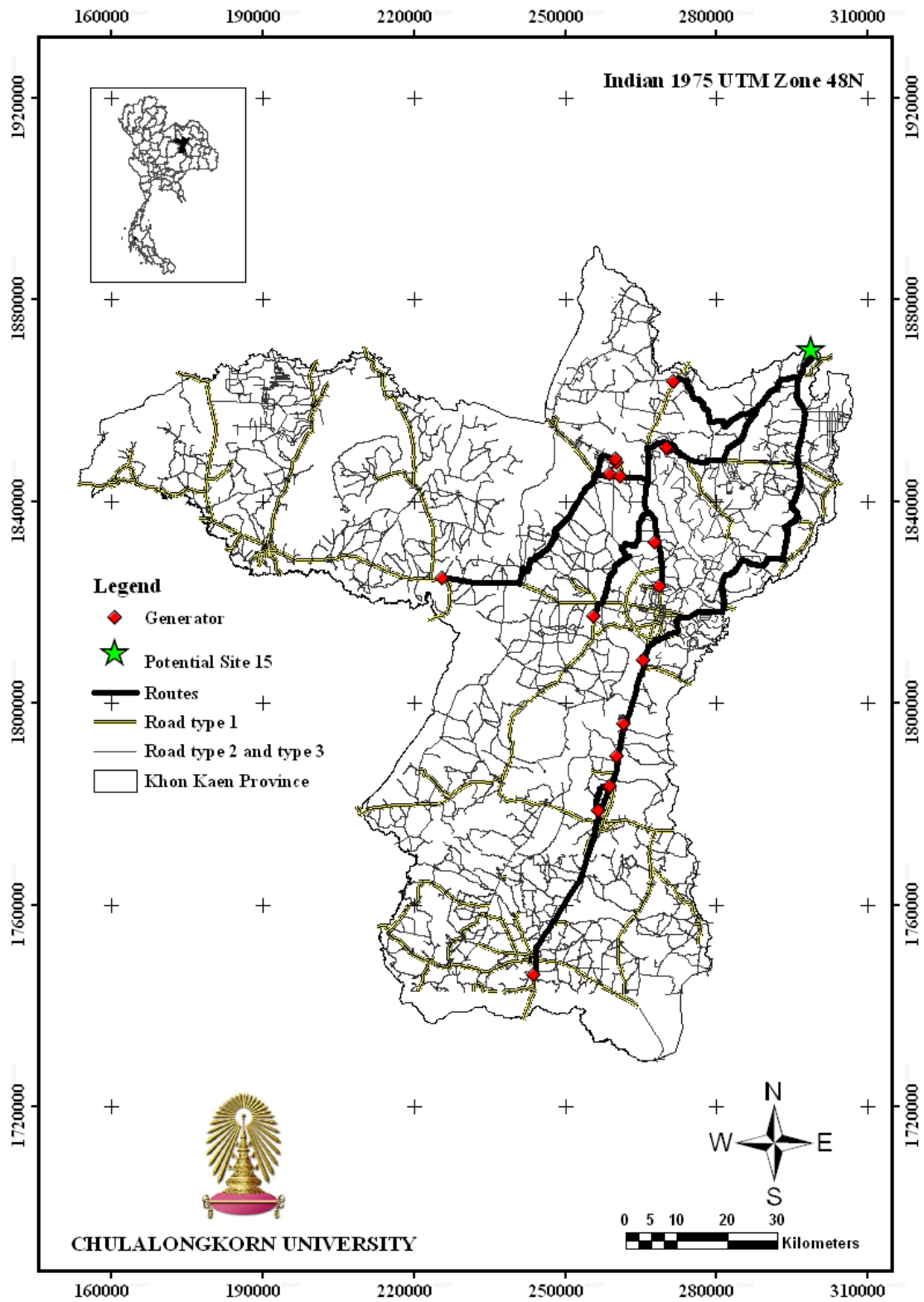


Figure B-15 The suitable route for transport hazardous waste of generators to potential site 15

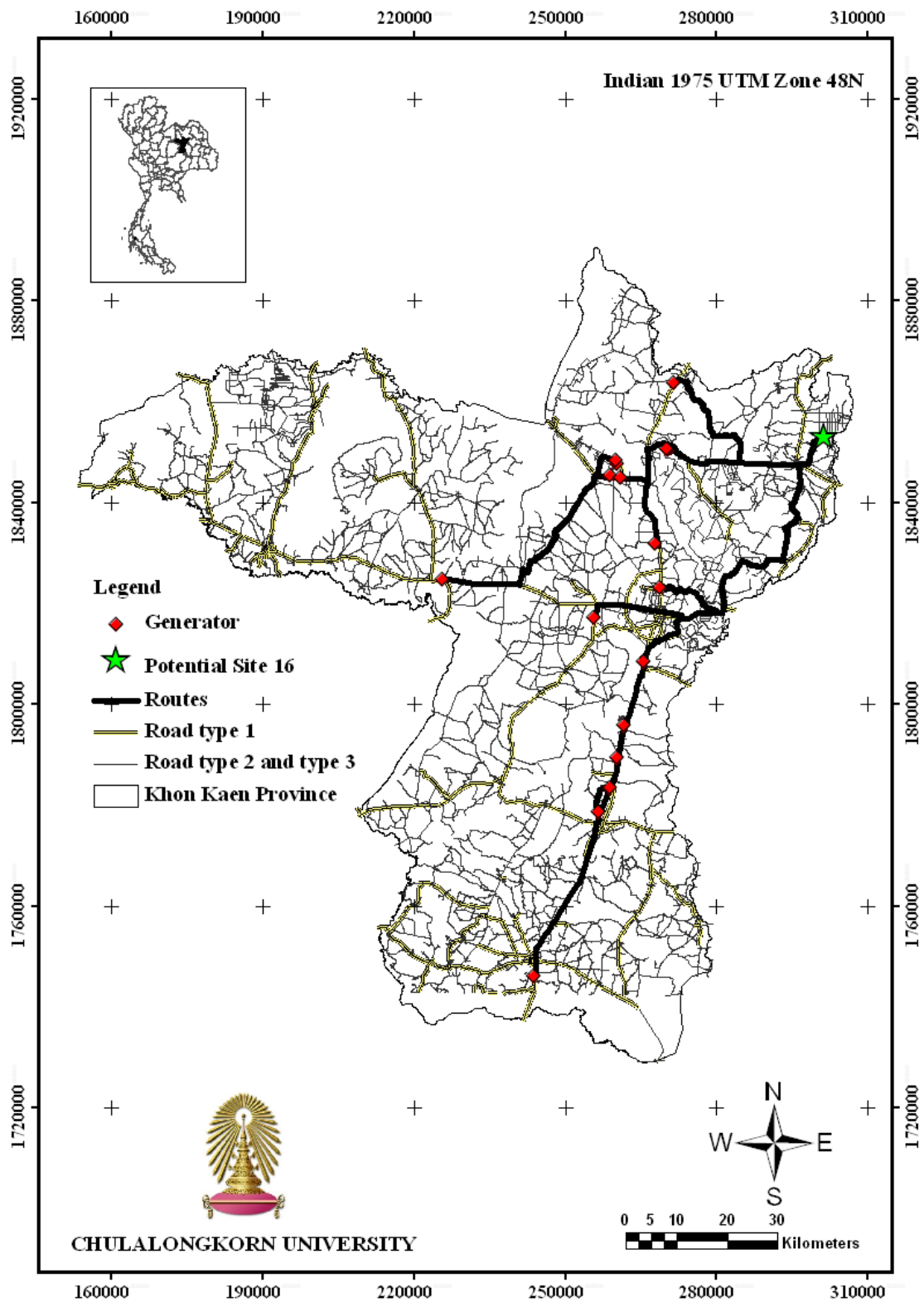


Figure B-16 The suitable route for transport hazardous waste of generators to potential site 16

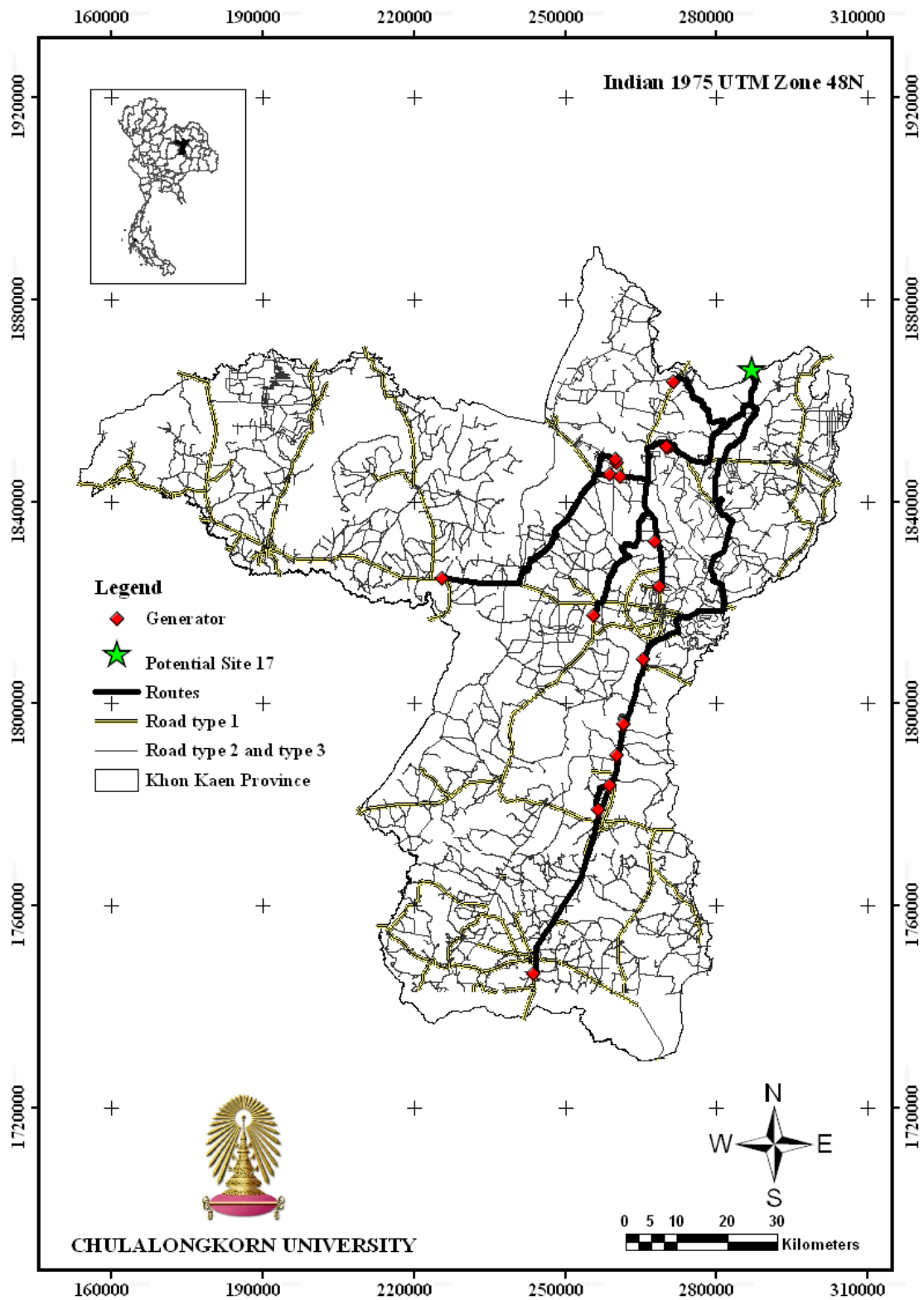


Figure B-17 The suitable route for transport hazardous waste of generators to potential site 17

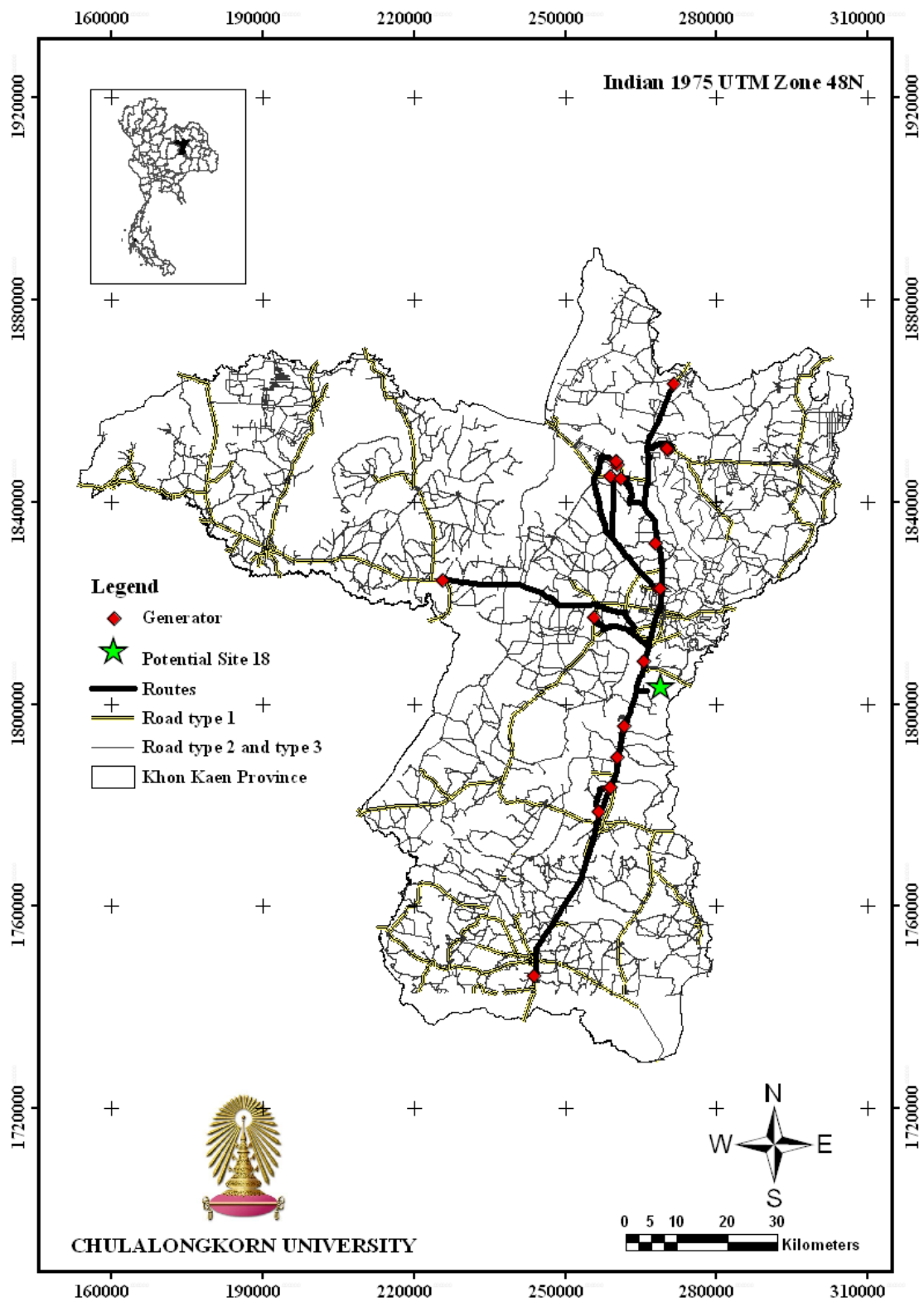


Figure B-18 The suitable route for transport hazardous waste of generators to potential site 18

Appendix C

GIS network analysis results

C.1 Finding shortest distance by straight line result

Table C-1 Potential site 1 to 6

| Generator | Distance from generator to potential site (kilometer) | | | | | |
|-----------------------|---|---------|---------|---------|--------|--------|
| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 |
| 1 | 86.75 | 86.92 | 85.49 | 32.46 | 19.15 | 36.10 |
| 2 | 81.14 | 82.57 | 80.31 | 74.72 | 59.02 | 33.42 |
| 3 | 112.46 | 113.38 | 111.41 | 59.10 | 42.66 | 4.34 |
| 4 | 51.41 | 53.13 | 50.73 | 86.76 | 74.47 | 62.31 |
| 5 | 112.67 | 113.64 | 111.64 | 61.24 | 44.76 | 4.96 |
| 6 | 95.52 | 96.84 | 94.63 | 72.21 | 55.53 | 21.15 |
| 7 | 121.08 | 122.19 | 120.10 | 70.70 | 54.57 | 15.56 |
| 8 | 62.20 | 63.80 | 61.45 | 81.65 | 68.02 | 51.69 |
| 9 | 115.10 | 116.04 | 114.06 | 60.66 | 44.40 | 7.00 |
| 10 | 68.25 | 69.77 | 67.46 | 78.53 | 64.19 | 45.42 |
| 11 | 103.02 | 104.24 | 102.09 | 69.12 | 52.27 | 13.63 |
| 12 | 121.32 | 122.42 | 120.34 | 70.63 | 54.53 | 15.66 |
| 13 | 133.86 | 134.90 | 132.85 | 74.18 | 59.33 | 26.36 |
| 14 | 84.84 | 85.92 | 83.85 | 62.02 | 46.07 | 23.96 |
| 15 | 115.62 | 116.55 | 114.57 | 60.35 | 44.14 | 7.50 |
| 16 | 19.99 | 22.44 | 19.99 | 107.40 | 98.98 | 95.86 |
| 17 | 56.58 | 58.26 | 55.88 | 84.83 | 71.87 | 57.58 |
| Total distance | 1541.82 | 1563.01 | 1526.86 | 1206.57 | 953.96 | 522.52 |

Table C-2 Potential site 7 to 12

| Generator | Distance from generator to potential site (kilometer) | | | | | |
|-----------------------|---|--------|--------|---------|---------|---------|
| | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 | Site 12 |
| 1 | 35.83 | 32.94 | 32.85 | 33.60 | 34.62 | 74.13 |
| 2 | 33.34 | 39.13 | 38.30 | 40.41 | 42.78 | 44.97 |
| 3 | 4.54 | 7.44 | 7.06 | 7.73 | 9.00 | 39.90 |
| 4 | 62.17 | 66.53 | 65.77 | 67.83 | 70.15 | 73.38 |
| 5 | 5.21 | 9.59 | 9.16 | 9.92 | 11.16 | 37.71 |
| 6 | 21.16 | 28.07 | 27.23 | 29.22 | 31.46 | 33.66 |
| 7 | 15.83 | 19.51 | 19.31 | 19.41 | 19.75 | 30.25 |
| 8 | 51.56 | 56.34 | 55.56 | 57.65 | 60.00 | 62.61 |
| 9 | 7.22 | 9.26 | 9.07 | 9.21 | 9.87 | 38.87 |
| 10 | 45.30 | 50.30 | 49.51 | 51.61 | 53.97 | 56.84 |
| 11 | 13.71 | 21.04 | 20.25 | 22.03 | 24.08 | 31.41 |
| 12 | 15.93 | 19.50 | 19.31 | 19.38 | 19.68 | 30.45 |
| 13 | 26.59 | 27.24 | 27.43 | 26.54 | 25.67 | 36.35 |
| 14 | 23.81 | 28.19 | 27.41 | 29.49 | 31.85 | 48.05 |
| 15 | 7.70 | 9.12 | 9.00 | 8.97 | 9.47 | 39.36 |
| 16 | 95.69 | 99.14 | 98.45 | 100.41 | 102.63 | 107.81 |
| 17 | 57.45 | 62.04 | 61.27 | 63.35 | 65.69 | 68.19 |
| Total distance | 523.06 | 585.40 | 576.91 | 596.73 | 621.83 | 853.94 |

Table C-3 Potential site 13 to 18

| Generator | Distance from generator to potential site (kilometer) | | | | | |
|-----------------------|---|---------|---------|---------|---------|---------|
| | Site 13 | Site 14 | Site 15 | Site 16 | Site 17 | Site 18 |
| 1 | 83.85 | 84.92 | 86.04 | 80.87 | 74.07 | 48.12 |
| 2 | 68.22 | 69.16 | 70.00 | 57.26 | 61.43 | 6.12 |
| 3 | 44.71 | 45.77 | 46.90 | 43.14 | 34.99 | 42.96 |
| 4 | 98.86 | 99.77 | 100.55 | 86.75 | 92.40 | 27.55 |
| 5 | 43.17 | 44.24 | 45.35 | 41.13 | 33.58 | 42.06 |
| 6 | 53.91 | 54.88 | 55.77 | 44.32 | 46.71 | 19.54 |
| 7 | 32.43 | 33.50 | 34.61 | 31.20 | 22.97 | 46.94 |
| 8 | 87.64 | 88.55 | 89.34 | 75.76 | 81.12 | 16.44 |
| 9 | 42.24 | 43.31 | 44.44 | 41.31 | 32.45 | 44.90 |
| 10 | 81.32 | 82.24 | 83.05 | 69.75 | 74.68 | 10.56 |
| 11 | 47.21 | 48.23 | 49.20 | 39.72 | 39.25 | 28.37 |
| 12 | 32.34 | 33.41 | 34.52 | 31.27 | 22.84 | 47.23 |
| 13 | 25.86 | 26.85 | 28.01 | 31.67 | 15.83 | 60.20 |
| 14 | 66.24 | 67.26 | 68.23 | 58.15 | 58.08 | 19.08 |
| 15 | 42.22 | 43.28 | 44.42 | 41.59 | 32.37 | 45.62 |
| 16 | 133.86 | 134.76 | 135.53 | 121.44 | 127.38 | 62.52 |
| 17 | 93.60 | 94.51 | 95.29 | 81.50 | 87.17 | 22.29 |
| Total distance | 1077.70 | 1094.62 | 1111.25 | 976.82 | 937.33 | 590.49 |

C.2 Finding the shortest route based on the real road network result

Table C-4 Potential site 1 to 6

| Generator | Distance from generator to potential site (kilometer) | | | | | |
|-----------------------|---|---------|---------|---------|---------|--------|
| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 |
| 1 | 116.11 | 114.64 | 115.35 | 55.18 | 23.46 | 46.30 |
| 2 | 90.68 | 89.21 | 89.92 | 105.03 | 73.31 | 38.27 |
| 3 | 131.37 | 129.91 | 130.61 | 103.29 | 71.57 | 8.08 |
| 4 | 58.80 | 60.96 | 58.80 | 134.36 | 102.64 | 70.70 |
| 5 | 131.68 | 133.83 | 131.68 | 104.96 | 73.24 | 9.75 |
| 6 | 105.15 | 107.30 | 105.15 | 103.20 | 71.48 | 23.67 |
| 7 | 141.00 | 139.51 | 140.20 | 123.11 | 91.39 | 27.90 |
| 8 | 70.81 | 69.34 | 70.05 | 121.78 | 90.07 | 58.13 |
| 9 | 135.64 | 134.16 | 134.89 | 108.16 | 76.44 | 12.93 |
| 10 | 77.35 | 75.89 | 76.58 | 115.26 | 83.52 | 51.59 |
| 11 | 115.78 | 114.31 | 115.00 | 109.98 | 78.27 | 20.16 |
| 12 | 140.17 | 138.71 | 139.39 | 122.29 | 90.58 | 27.09 |
| 13 | 148.62 | 147.16 | 147.84 | 130.74 | 99.03 | 35.52 |
| 14 | 98.50 | 97.03 | 97.74 | 89.43 | 57.71 | 27.12 |
| 15 | 136.41 | 134.92 | 135.63 | 108.90 | 77.18 | 13.68 |
| 16 | 28.38 | 30.53 | 28.38 | 164.56 | 132.84 | 105.59 |
| 17 | 63.99 | 66.14 | 63.99 | 127.84 | 96.12 | 64.17 |
| Total distance | 1790.45 | 1783.55 | 1781.21 | 1928.06 | 1388.86 | 640.66 |

Table C-5 Potential site 7 to 12

| Generator | Distance from generator to potential site (kilometer) | | | | | |
|-----------------------|---|--------|--------|---------|---------|---------|
| | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 | Site 12 |
| 1 | 46.44 | 47.32 | 40.97 | 48.53 | 50.69 | 93.73 |
| 2 | 38.12 | 45.56 | 41.99 | 46.75 | 48.91 | 58.42 |
| 3 | 8.22 | 6.02 | 7.16 | 7.22 | 9.38 | 52.97 |
| 4 | 70.55 | 78.00 | 74.42 | 79.19 | 81.36 | 90.87 |
| 5 | 9.89 | 7.69 | 8.82 | 8.89 | 11.04 | 50.94 |
| 6 | 23.54 | 30.98 | 27.40 | 32.18 | 34.33 | 52.24 |
| 7 | 28.04 | 25.83 | 26.97 | 27.03 | 29.18 | 35.72 |
| 8 | 57.99 | 65.42 | 61.85 | 66.61 | 68.78 | 78.28 |
| 9 | 13.08 | 10.88 | 12.02 | 12.08 | 14.24 | 53.33 |
| 10 | 51.44 | 58.88 | 55.32 | 60.09 | 62.23 | 71.75 |
| 11 | 20.02 | 26.43 | 23.88 | 27.63 | 29.78 | 60.54 |
| 12 | 27.22 | 25.03 | 26.16 | 26.22 | 28.36 | 34.91 |
| 13 | 35.68 | 33.48 | 34.61 | 34.67 | 36.83 | 46.46 |
| 14 | 26.97 | 34.41 | 29.98 | 35.61 | 37.77 | 64.81 |
| 15 | 13.83 | 11.64 | 12.76 | 12.83 | 14.98 | 54.09 |
| 16 | 105.46 | 112.90 | 109.32 | 114.10 | 116.25 | 125.76 |
| 17 | 64.04 | 71.48 | 67.90 | 72.68 | 74.83 | 84.34 |
| Total distance | 640.52 | 691.94 | 661.54 | 712.31 | 748.93 | 1109.15 |

Table C-6 Potential site 13 to 18

| Generator | Distance from generator to potential site (kilometer) | | | | | |
|-----------------------|---|---------|---------|---------|---------|---------|
| | Site 13 | Site 14 | Site 15 | Site 16 | Site 17 | Site 18 |
| 1 | 106.66 | 109.33 | 109.33 | 102.57 | 99.39 | 58.04 |
| 2 | 86.50 | 89.17 | 89.16 | 74.20 | 80.40 | 8.19 |
| 3 | 58.91 | 61.57 | 61.57 | 54.81 | 51.62 | 50.05 |
| 4 | 121.88 | 121.88 | 121.88 | 106.63 | 113.09 | 35.67 |
| 5 | 59.58 | 59.58 | 59.58 | 52.79 | 49.37 | 50.97 |
| 6 | 76.48 | 76.48 | 76.48 | 68.01 | 66.27 | 23.43 |
| 7 | 41.67 | 44.32 | 44.33 | 37.57 | 34.38 | 58.48 |
| 8 | 106.36 | 109.03 | 109.03 | 94.05 | 100.27 | 16.08 |
| 9 | 59.27 | 61.94 | 61.94 | 55.18 | 52.00 | 53.36 |
| 10 | 99.82 | 102.50 | 102.50 | 87.52 | 93.73 | 9.54 |
| 11 | 67.06 | 69.71 | 69.71 | 62.95 | 59.77 | 33.29 |
| 12 | 40.85 | 43.51 | 43.51 | 36.76 | 33.57 | 57.69 |
| 13 | 40.89 | 43.55 | 43.54 | 48.30 | 33.52 | 66.12 |
| 14 | 86.98 | 89.65 | 89.65 | 80.58 | 79.70 | 25.26 |
| 15 | 60.03 | 62.70 | 62.68 | 55.92 | 52.74 | 54.12 |
| 16 | 156.78 | 156.78 | 156.78 | 141.53 | 148.00 | 63.54 |
| 17 | 115.36 | 115.36 | 115.36 | 100.11 | 106.58 | 22.12 |
| Total distance | 1385.09 | 1417.05 | 1417.03 | 1259.48 | 1254.41 | 685.94 |

C.3 Finding the shortest route based on road type

Table C-7 Potential site 1 to 6

| Generator | Distance from generator to potential site (kilometer) | | | | | |
|-----------------------|---|---------|---------|---------|---------|---------|
| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 |
| 1 | 231.69 | 230.29 | 231.69 | 109.53 | 46.05 | 93.53 |
| 2 | 90.23 | 89.53 | 90.23 | 105.10 | 73.36 | 38.28 |
| 3 | 2354.88 | 2342.34 | 2354.88 | 1850.95 | 1279.66 | 136.20 |
| 4 | 117.66 | 116.26 | 117.66 | 268.86 | 205.38 | 141.44 |
| 5 | 395.19 | 393.10 | 395.19 | 315.03 | 219.82 | 29.24 |
| 6 | 525.93 | 522.44 | 525.93 | 516.28 | 357.59 | 118.45 |
| 7 | 421.87 | 419.78 | 421.87 | 370.61 | 275.39 | 84.82 |
| 8 | 70.18 | 69.48 | 70.18 | 121.74 | 90.00 | 58.03 |
| 9 | 822.63 | 818.45 | 822.63 | 644.79 | 454.36 | 73.21 |
| 10 | 76.64 | 75.94 | 76.64 | 115.28 | 83.55 | 51.57 |
| 11 | 114.70 | 114.00 | 114.70 | 109.69 | 77.95 | 19.82 |
| 12 | 139.31 | 138.61 | 139.31 | 122.22 | 90.48 | 26.96 |
| 13 | 147.82 | 147.12 | 147.82 | 130.73 | 98.99 | 35.47 |
| 14 | 489.39 | 485.90 | 489.39 | 446.99 | 288.30 | 135.13 |
| 15 | 136.45 | 135.76 | 136.45 | 106.81 | 75.08 | 11.55 |
| 16 | 28.40 | 27.70 | 28.40 | 164.65 | 132.91 | 105.63 |
| 17 | 64.03 | 63.33 | 64.03 | 127.90 | 96.16 | 64.19 |
| Total distance | 6226.98 | 6190.03 | 6226.98 | 5627.16 | 3945.04 | 1223.52 |

Table C-8 Potential site 7 to 12

| Generator | Distance from generator to potential site (kilometer) |
|-----------|---|
|-----------|---|

| | Site 7 | Site 8 | Site 9 | Site 10 | Site 11 | Site 12 |
|-----------------------|---------------|---------------|---------------|----------------|----------------|----------------|
| 1 | 93.82 | 95.62 | 82.85 | 97.98 | 102.34 | 188.42 |
| 2 | 38.14 | 45.59 | 42.01 | 46.77 | 48.96 | 58.45 |
| 3 | 138.82 | 99.22 | 119.56 | 120.47 | 159.73 | 956.25 |
| 4 | 141.15 | 156.05 | 148.89 | 158.41 | 162.78 | 181.77 |
| 5 | 29.68 | 23.08 | 26.47 | 26.62 | 33.16 | 152.84 |
| 6 | 117.72 | 155.00 | 137.08 | 160.90 | 171.81 | 261.30 |
| 7 | 85.25 | 78.65 | 82.04 | 82.19 | 88.74 | 108.26 |
| 8 | 57.89 | 65.34 | 61.76 | 66.52 | 68.70 | 78.20 |
| 9 | 74.08 | 60.88 | 67.66 | 67.96 | 63.08 | 378.19 |
| 10 | 51.43 | 58.88 | 55.30 | 60.06 | 62.24 | 71.74 |
| 11 | 19.67 | 26.10 | 23.54 | 27.28 | 29.46 | 60.20 |
| 12 | 27.10 | 24.90 | 26.03 | 26.08 | 28.27 | 34.78 |
| 13 | 35.61 | 33.41 | 34.54 | 34.59 | 36.77 | 46.53 |
| 14 | 134.41 | 171.68 | 149.49 | 177.58 | 188.49 | 323.72 |
| 15 | 11.70 | 9.50 | 10.63 | 10.68 | 9.86 | 62.38 |
| 16 | 105.49 | 112.94 | 109.36 | 114.12 | 116.31 | 125.80 |
| 17 | 64.04 | 71.50 | 67.91 | 72.68 | 74.86 | 84.36 |
| Total distance | 1225.99 | 1288.35 | 1245.12 | 1350.90 | 1445.56 | 3173.22 |

Table C-9 Potential site 13 to 18

| Generator | Distance from generator to potential site (kilometer) | | | | | |
|-----------------------|--|----------------|----------------|----------------|----------------|----------------|
| | Site 13 | Site 14 | Site 15 | Site 16 | Site 17 | Site 18 |
| 1 | 219.68 | 219.68 | 219.68 | 206.08 | 199.26 | 117.02 |
| 2 | 89.47 | 89.47 | 89.47 | 74.21 | 80.69 | 8.48 |
| 3 | 1111.92 | 1111.92 | 1111.92 | 989.55 | 928.11 | 904.38 |
| 4 | 243.81 | 243.81 | 243.81 | 213.29 | 226.24 | 57.29 |
| 5 | 178.78 | 178.78 | 178.78 | 158.39 | 148.15 | 152.97 |
| 6 | 382.53 | 382.53 | 382.53 | 340.09 | 331.47 | 117.17 |
| 7 | 134.21 | 134.21 | 134.21 | 113.81 | 103.57 | 176.61 |
| 8 | 109.22 | 109.22 | 109.22 | 93.96 | 100.44 | 15.96 |
| 9 | 430.08 | 430.08 | 430.08 | 389.29 | 368.81 | 351.97 |
| 10 | 102.76 | 102.76 | 102.76 | 87.50 | 93.98 | 9.50 |
| 11 | 69.41 | 69.41 | 69.41 | 62.61 | 59.20 | 32.95 |
| 12 | 43.42 | 43.42 | 43.42 | 36.63 | 33.21 | 57.56 |
| 13 | 43.67 | 43.67 | 43.67 | 48.38 | 33.37 | 66.07 |
| 14 | 448.03 | 448.03 | 448.03 | 402.51 | 396.98 | 126.85 |
| 15 | 71.03 | 71.03 | 71.03 | 64.23 | 60.82 | 58.01 |
| 16 | 156.82 | 156.82 | 156.82 | 141.56 | 148.04 | 63.56 |
| 17 | 115.37 | 115.37 | 115.37 | 100.11 | 106.59 | 22.11 |
| Total distance | 3950.21 | 3950.21 | 3950.21 | 3522.21 | 3418.91 | 2338.46 |

BIOGRAPHY

Mr. Jongruk Rachsombut was born on June 9, 1986 in Sakon Nakhon, Thailand. He obtained the Bachelor's Degree (Biotechnology) in 2008 from the Faculty of Technology, Khon Kean University. He entered his master degree in the International Postgraduate Program in Environmental Management (Hazardous Waste Management), Inter-Department of Environmental Management at Chulalongkorn University in 2008.