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CHAPTER 1

INTRODUCTION

1.1 Introduction

A petrol filling station (PFS) poses potential hazards to the site and environment. Numerous hazards exist at petrol filling station. However, those that would affect the environment are the leakage of Underground Storage Tank (UST) that will contaminate groundwater [1], fire hazard evoked by open flame [2], static electricity [3], air pollution evoked by aromatic compound concentrations [4], and the traffic congestion due to vehicle queue to access the PFS [5].

A study by the U.S. Geological Survey shows that the petrol additive MtBE (Methyl-tertiary-butyl ether) has been detected in at least 40 percent of public wells. These samples were randomly taken from 225 water supply wells in Rockingham County in 2003. They also found a correlation between Methyl-tertiary-butyl ether concentration and the proximity to USTs [6]. USTs are used to store numerous chemicals including gasoline which have life span of 18 years, and prolonged exposure to the USTs elements will corrode the USTs [7]. Oil released from UST facilities is not the only groundwater contaminant. Small spills of fuel that routinely occur when fuel is being dispensed to vehicles are also a cause for concern [8].

The petrol refuelling process can also be extremely hazardous. Three probable causes for the ignition of the gasoline vapour at tank filler opening are (1) an open flame such as a lit cigarette lighter or match, (2) a spark from the engine compartment when the motor is running, and (3) a static electric discharge at the nozzle and filler opening due to fuel flow [3]. The highly flammable nature of petrol gives petrol station facilities the highest potential for fire breakouts to occur when compared with other non-industrial facilities [2].

Additionally, the additive MtBE that is extensively used to increase the octane level replacing lead-based anti-knock gasoline additives and reduces aromatic hydrocarbon has a potential health risk on humans. The refuelling process has a strong correlation with the concentration of MtBE in a downwind zone. The high concentrations of MTBE in the air is dangerous for people of the residential neighbourhoods [4].

The potential hazards that would occur from the petrol filling stations will affect the economy, human resources and the environment. Therefore, the suitability analysis of petrol filling stations is highly required. This research work moves towards the development of a suitability analysis of PFS sites in the Surabaya metropolitan area.

1.2 Problem Statement

Nowadays, the growth of petrol filling stations in Surabaya is very rapid. Surabaya has 90 PFSs in the metropolitan area. The Vice Mayor of Surabaya municipality, Arif Affandi, said that the existing PFSs still could not cater to the entire fleet of vehicles traversing the roads of the metropolitan. The number of motorcycles increases at a rate of 12% per year and the total number of vehicles including cars and motorcycles is almost 1.6 million [9].

Presently, the Surabaya municipality does not have any specific regulation for PFS siting that addresses the hazards mentioned earlier. That is why many PFSs are situated close to each other without any thought on the hazardous impact. They may also situated not in the suitable area. Therefore, there should be suitable regulation for PFS siting which should address issues such as the maximum number of PFSs within a specified area, the proximity to emergency services and the road safety.

1.3 Research Objectives

The main objective of this study is to assist the proper siting of PFSs by developing an approach of GIS-based suitability analysis to identify suitable sites for PFSs. More specific research objectives of this study are:

1. To investigate the contributing factors for suitability analysis of PFS based on hazards and site requirements of PFS.
2. To assess the suitability of PFS sites using spatial multicriteria decision analysis (GIS and AHP combination).
3. To validate the criteria ranking of suitable PFS areas using spatial sensitivity analysis.
4. To assess the factual condition of PFS distribution based on suitability analysis result.

1.4 Research Questions

To achieve the objectives above, this study attempts to answer these questions:

1. To investigate the contributing factors for suitability analysis of PFS based on hazards and site requirements of PFS.
    - 1.a What are the potential environmental hazards of PFSs?
    - 1.b What are the requirements for PFS sites?
2. To assess the suitability of PFS sites using spatial multicriteria decision analysis (GIS and AHP combination).
    - 2.a Who are the stakeholders that MUST have ability to assess the suitability analysis factors?
    - 2.b What are the level importance of each suitability criteria for PFSs
    - 2.c How is the result of suitability analysis shows based on stakeholder's priority ranking?
3. To validate the criteria ranking of suitable PFS areas using sensitivity analysis.
    - 3.a How is the recommended alternative (the output) affected by changes in the inputs (geographical data and the decision maker's preference)?

4. To assess the factual condition of PFS distribution based on suitability analysis result.
    4.a How many PFSs that are located not in highly suitable zone?

1.5 Research Scope and Limitations

The scope of this research work is limited to environmental concerns that focus on hazards identification related to PFSs. PFS locations of Surabaya is taken as a case study to obtain the real simulation of suitability analysis based on the perspectives of the city's stakeholders who are made up of the city planners, environmentalists, and government officers.

Although the research has reached its aims, there were some unavoidable limitations. First, due to time and human resource constraint, this research could not include dwellers as part of targeted stakeholders. Even in stakeholder analysis has mentioned that dwellers have low interest on determining PFS location, their opinion somehow valuable for the betterment of the study. Second, the criteria used for PFS suitability analysis is applicable only for urban area not for rural area since rural area have different characteristic especially for road safety criteria. Third, some area in Surabaya is considered as confidential area so it is appeared as blank or no data for data map layers. Forth, groundwater and private well data map layers are not available, since Surabaya does not use this water resources as drinking water so this condition do not give any effect to the result of this research.

1.6 Structure of the Thesis

The first chapter of this thesis discusses the overview and the introduction of the research. Furthermore, a detailed explanation on research background, problem statements, research objectives and questions, and conceptual framework has been elaborated for this research.

Chapter two discusses literature review related to two main topics: (1) criteria for suitability site selection and (2) previous studies related to spatial multicriteria decision analysis. In the first topic, construction of the PFS location criteria has been described using the hazards of the PFS to the environment and the site requirement of PFS. The second topic covers the comparison studies related to spatial multicriteria decision as suitability analysis tools.

Chapter three explains the data collection and methodology which is used to determine suitable area for PFS. Several tasks such as GIS data collection, AHP data collection, and pre-processing data are included for data collection. The Methodology section explains a combined approach using *Geographic Information System* (GIS) and *Analytic Hierarchy Process* (AHP) as decision analysis tools that used as the representation of spatial multicriteria decision analysis. However, sensitivity analysis is also conducted to get the robustness of spatial multicriteria ranking.

Chapter four explains the result and the analysis of the research. At the beginning of this chapter, the physical characteristics of Surabaya, review of the legislation procedure of PFS siting, the development of PFS, and existing problems with regards to the proximity of PFSs have been explained to depict the factual condition of geographical area being studied. In the next step, stakeholder analysis, weighted analysis, and spatial analysis have been conducted to obtain the spatial multicriteria decision analysis result. Once the spatial multicriteria decision analysis is accomplished, a sensitivity analysis is carried out to assess the robustness of the result.

Chapter five discusses the conclusions reached as an answer to the research questions and recommendations to potential PFS sites and possible further study.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the pertinent issues relating to petrol and petrol filling stations. The issues discussed include the characteristics of petrol, the general description of PFSs, health and environmental hazards related to petrol and PFSs. To further expound on the importance of PFS siting, matters relating to the inherent safe risks of PFSs and PFS site requirements are also elaborated. Finally, for comparison purposes, standards for PFS siting exercised in a two developing countries are highlighted.

2.1 Petrol

This research revolves around the PFS siting. However, the core component of any PFS is petrol. As such, this section will look at the physical and chemical properties of petrol as well as the hazards associated with petrol.

Petrol is a major hydrocarbon fuel. It is a mixture consisting mainly of hexane, octane and heptane which are extremely flammable [10, 11]. Petrol is able to give off vapour at temperatures as low as minus 40^oC. This vapour can cause fire and explosion when mixed with air [12]. Due to engine knock effect, many petrol companies add lead tetraethyl to slow the rate of combustion. However, this additive has been proven to give adverse impact to the earth's atmosphere and human health [13].

Petrol is particularly harmful to human health especially under these circumstances: excessive skin contact, aspiration, ingestion or vapour inhalation. As such, exposure to the liquid or vapour should be minimised. It has been reported that several harmful risk factors should be taken into account during the planning and design of a petrol filling station to account for the potentially harmful situations [10]. These various risk factors that can cause health problems are described in following sub-sections.

1. Inhalation

The respiratory tract in the human body can be affected by the exposure to petrol vapours that has a concentration range within 500 and 1000 ppm. If someone stays in such an environment for a long period of time he/she will experience a narcotic effect. The symptoms of this effect can be seen as headaches, nausea, dizziness and mental confusion [10].

2. Ingestion

Consumption of petrol may lead to the irritation of the digestive system that will further cause diarrhoea. This is because petrol has low to moderate oral toxicity. For adults, ingestion of petrol will only affect the digestive system but it can lead to death in children even if a small quantity is swallowed accidentally [10].

3. Aspiration

Breathing difficulties or even fatal chemical pneumonitis are the consequences when the aspiration of even small amounts of petrol happens. The ingestion of petrol usually followed by the aspiration of petrol directly into the lungs runs the risk of developing chemical pneumonitis [10].

4. Skin contact

Petrol is classified as Carcinogenic due to the presence of up to 5% benzene. At the initial stage, skin contact with petrol can potentially cause dermatitis effects. This is why petrol is also classified as a skin irritant. Repetitive skin contact with petrol will cause skin to dry and crack on the surface. In addition, it will also result in the skin to be susceptible to irritation and consequently penetration by other chemicals [10].

5. Eye contact

If liquid petrol comes into contact with the eyes it can cause moderate to severe irritation and conjunctivitis. However, it only normally has a transient effect and permanent injury is unlikely to occur [10].

2.2 Petrol Filling Station

PFS is a facility that commercially dispenses petrol or other fuels as well as providing maintenance and minor automobile repair services [14]. PFSs are widely known by terms such as fuel station, gas station, service station, filling station, and traffic station, and they typically include a wide range of facilities [15]. A few years ago, the design of PFS mainly focused on the islands where fuel would be dispensed. Nowadays, competition among owners has revolved around the modernisation of PFSs towards a store model that combines the idea of fast pay fuel islands complemented by convenience stores, car washes, automotive services, and food services [16]. This evolution has made PFSs more complex and has also made the provision of safe measures more critical due to increased risk of hazards. In general, the description of a typical PFS design is as follows (please refer to Figure 2.1 for a typical PFS design layout):

1. **Dispensing area:** where the dispensers are located. The dispensing area is usually covered by steel or concrete canopy and the size of the dispensing area depends on the number of dispensers and the size of the site.
2. **Underground storage tank area:** a vacant area where the tanks are located underground to store the fuel supply. Usually this area is indicated by manholes and venting pipes.
3. **Service area:** this area may contain a mini convenience store, car washes, automotive services, and/or food service which are located near the dispensing area.

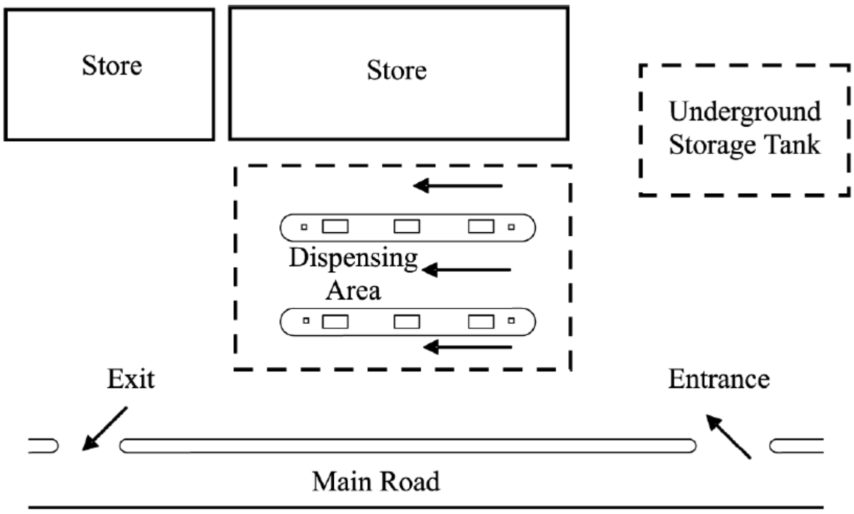


Figure 2.1 Typical Design Layout of Petrol Filling Station Facilities [2]

Improper design of PFS will lead to problems to the area within its vicinity. Hence, the development of PFS should be done with the consideration of the following criteria [17].

1. The location, design, and building materials of the PFS.
2. The impact of the proposed PFS on road network, traffic movement and road safety.
3. The impact of the proposed PFS on surrounding residents, and
4. Measures to be taken to prevent pollution.

2.3 Environmental Hazard Issue of Petrol Filling Station

A PFS can be a major source of pollutants that can contaminate the air, soil, and water in the areas surrounding the PFS [15]. Petrol contains complex mixture of hydrocarbon that has varying degrees of toxicity towards living organism [10]. Petrol could be released into the environment by incidents that have occurred as a result of damage or carelessness. The release of toxic materials at PFS due to spillage or leakage from underground storage tanks and pipes will result in a serious degree of soil and groundwater contamination [18]. In some cases, the pollutants can also contaminate surface water when the petrol soaks directly into the ground or flows into drains and culverts [10]. Because petrol floats on the surface of water it can be dispersed along the underlying water table. This will transport the hazard to quite far away areas from the source of the leak or spill. Those subsequent dispersions and movements are difficult to predict as petrol can migrate through soil, sewers, and water courses. These dispersions then can accumulate in the cellar or basement of a property posing a potential hazard to the occupants of the property [12]. A number of environmental crisis can occur as a result of human carelessness due to the following circumstances:

- petrol adsorbed onto soil particles or held in the soil pores
- petrol floating on the groundwater
- petrol constituents dissolved in the groundwater
- petrol floating on surface water (i.e. rivers and lakes)
- petrol at impervious ground layers such as clay
- petrol in drains or underground voids
- petrol vapours released from the above sources into the atmosphere or underground voids, etc.

2.3.1 PFS and Air Pollution

Petrol vapour is difficult to be dispersed by air due to its weight which is heavier than air. It tends to sink to the lowest level of its surroundings and may collect in tanks, cavities, drains, and pits. The accumulations of vapours in confined spaces and other poorly ventilated areas can stay for a long time without any visible sign of liquid [10].

Petrol vapour is released into the air during the refilling of storage tanks by tanker delivery personnel and customers refuelling their motor vehicles at their selected PFSs [15]. A certain concentration of petrol vapour affects the ozone in the lower atmosphere and can result in a phenomenon called photochemical smog. This photochemical smog affects respiratory systems of humans and animals. Sometimes it can also interfere with plant growth and also damage building exteriors [10]. The presence of organic additive compounds in petrol vapour further promotes the production of dangerous chemicals [19]. Mainly, this additive has to be used in order to increase the octane, replace the use of lead-based anti-knock gasoline additive, and reduce aromatic hydrocarbon [4]. A high usage of this additive has increased the potential hazards at PFSs. In other words, PFSs are considerably becoming emission sources of Volatile Organic Compounds (VOCs). Studies have been done to improve the design and evaluation of control systems in an attempt to diminish emissions [20, 21], relate the effects of VOCs on workers [22, 23] and evaluate associated air quality surrounding PFSs [24-27]. These studies have shown that a significant benzene concentration can have an influence in every PFS environment. Nevertheless, benzene concentration depends on the activity of the petrol station, the leaks of the fuel tanks and the meteorological conditions [28]. In another scenario, oxygenated fuels also could potentially have adverse health impacts to humans and animals. Exposure to these compounds can bring a variety of illnesses such as asthma, headaches, mucosal symptoms [29], and in some cases (e.g. benzene) may even result in an increased risk of cancer [30, 31].

2.3.2 PFS and Soil Pollution

PFS is one of the sources of soil polluting agents. Soil pollution originating from PFSs happens when petrol vapour is accumulated in the soil. This accumulation will bring a detrimental effect on the flora and fauna within the contaminated area due to the toxicity of the petrol vapour. Some of the most common posibilities that might cause the release of polluting agent to soil are [15]:

- leakage of USTs and underground pipes
- broken or leaking fuel dispenser
- overfilling by staff when refilling USTs
- overfilling due to customers refilling their vehicles
- the pavement of the dispensing area not oil-proof
- absence of drainage and oil separator at dispensing area

Petrol has a detrimental effect on living organism within the contaminated area due to its toxic nature when mixed with water and air. It has been reported that water solubility of the hydrocarbons, biodegradation, and soil absorption will influence the petrol subsequent dispersion into drinking water supplies. It can migrate through polyethylene water pipelines situated in heavily contaminated ground [10].

2.3.3 PFS and Water Pollution

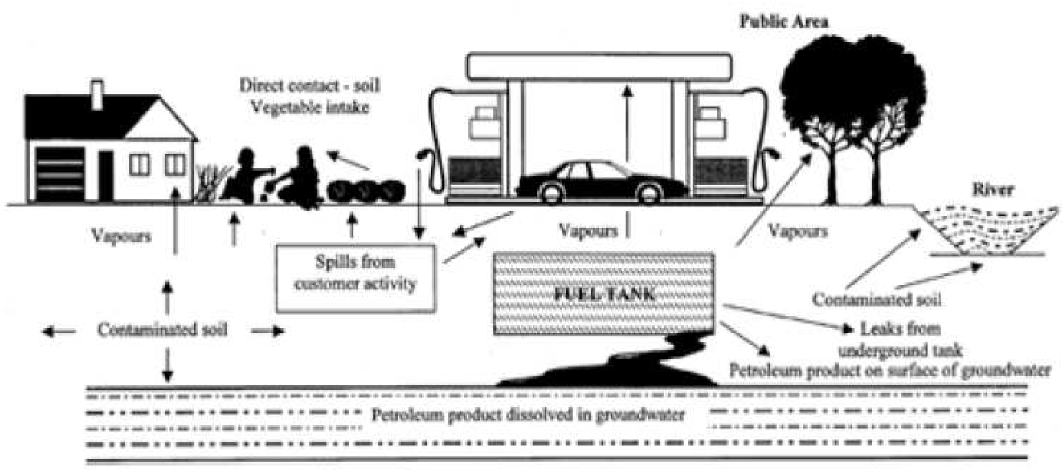
As mentioned earlier, petrol floats on water because of its lower density compared to water. As such, petrol can be carried a long distance away by water thus potentially posing hazards far away from the original point of the spill. In such a case, fire or explosion hazard can happen at a the place which is far away from the original source of occurrence [10].

The petrol spill dispersion mechanism into water is similar to its dispersion mechanism into the soil. The polluting agents are easily dispersed when rainwater washes into the soil. Harmful compounds such as VOC and BTEX (Benzene, Toluene, Ethylbenzene, And Xylenes) are borne in the water and may spread over the long distance. VOC compounds penetrate downwards into groundwater due to capillary action, gravity and adsorption. When the most harmful chemicals, MTBE and TAME, dissolve in a major groundwater area, that water containment area can be the source for the distribution of the fuel compounds [15].

Polluting agents not only contaminate ground water, but they also contaminate surface water such as rivers or lakes, especially in the areas where potable water is extracted. Many of the components of petrol have a significant solubility in water. Once they are dissolved in water, their biodegradation rate will be reduced. Hence, any contaminants in potable water will have to be removed by the relevant water supply companies. Petrol is not only toxic towards aquatic life, but also causes health problems to humans if ingested [10].

Figure 2.2, illustrates potential hazards that might occur in PFS. It shows that oil spill due to the leaking of underground storage tank or any human activity can lead into groundwater contamination, surface water contamination, and soil contamination.

Fuel Leaks and Spills



Source: DEFRA 2000

Figure 2.2 Environmental risk hazards of PFS [32]

Petrol stations are not only indispensable part of modern technological society but they also pose numerous risk and threats to the environment. PFS presents potential challenges to the health and safe of people and their surroundings. The major environmental risks involve release sources from petrol stations which will endanger the air, soil, and water.

Table 2.1 Major Environmental Risk and Release Sources at Petrol Station (to air, soil, and water) [33]

No.	***Risk and/or release source***	***Consequence of risk***	***Recommended action to limit environmental damage***
1.	Wall of UST's broken	Fuel product gets into soil and groundwater ➔ Contamination	1.1 2-wall storage tanks 1.2 Factitious compaction structure around tanks 1.3 Real time gauging system 1.4 Real time alarm system 1.5 Periodic inspections of tanks and control programme
2.	Underground pipes leak inside unsealed chamber	Fuel product enters soil and groundwater ➔ Contamination (Danger of explosion)	1.1 Sealed chamber 1.2 Real time alarm system 1.3 Periodic inspections and monitoring programme for pipes and chambers 1.4 Filling chambers; e.g with sand or mineral wool
3.	Underground pipes leak beneath dispenser	Fuel product enters soil and groundwater ➔ contamination (Possible danger of explosion if there are empty spaces beneath pump island or dispenser).	1.1 Factitious compaction structure under the forecourt 1.2 Pipe installation on the membrane 1.3 Sealed sumps 1.4 Periodic inspections and monitoring programme for pipes, dispenser, and sumps. 1.5 Filling empty spaces and/or sump; e.g with sand or mineral wool.
4.	Dispenser leaks from hydraulic sections	Fuel product enters soil and groundwater ➔ contamination	1.1 Factitious compaction structure under forecourt 1.2 Sealed sumps 1.3 Oil-proof pavement to the forecourt 1.4 Forecourt rainwater drainage to oil separator 1.5 Periodic inspections and monitoring programme for the dispenser
5.	Overflow when filling storage tank.	Fuel product enters soil and groundwater ➔ contamination	1.1 Overfill prevention 1.2 Filling wells 1.3 Oil-proof pavement to the fuel filling area 1.4 Filling area's rainwater

No.	*Risk and/or release source*	*Consequence of risk*	*Recommended action to limit environmental damage*
			drainage to oil separator 1.5 Factitious compaction structure under fuel filling area
6.	Overflow when filling customers' vehicles	Fuel product enters soil and groundwater ➔ contamination	6.1 Oil-proof pavement to the fuel filling area 6.2 Forecourt rainwater drainage to oil separator 6.3 Factitious compaction structure under forecourt
7.	Absence for overflow prevention	Overflow when filling the storage tank ➔ fuel product enters soil and groundwater ➔ contamination	7.1 Installation of overflow prevention 7.2 periodic inspections and monitoring programme for overflow prevention equipment. 7.3 oil proof pavement to the fuel filling area 7.4 factitious compaction structure under the fuel filling area.
8.	Absence of filling sump	Spillage when filling storage tank ➔ Fuel product enters soil and groundwater ➔ combination	8.1 Installation of filling sump 8.2 Periodic inspections and monitoring programme for filling sump 8.3 Oil-proof pavement to the fuel filling area 8.4 Factitious compaction structure under fuel filling area.
9.	Underground spaces beneath the filling area	Splashes when filling storage tank ➔ petrol vapour enters empty spaces ➔ Danger of explosion	9.1 Elimination of empty space under filling area 9.2 filling all spaces; 3.g with sand or mineral wool 9.3 Periodic inspections and monitoring programme.
10.	Lack of vapour recovery stage 1-system (or totally non-existent)	Vapour enters air ➔ Pollution Vapour enters underground spaces ➔ Danger of explosion	10.1 Installation of vapour recovery stage 1-system 10.2 Periodic inspections and programme
11.	Non-functioning alarm system	Petrol enters drainage ➔ Danger of explosion	11.1 Periodic inspections and monitoring programme

As a conclusion, PFS sites are associated with a number of risks and safe hazards such as fire, oil/gas leakage, and combustible oxides. Those risks will generate further adverse consequences such as soil contamination, groundwater and surface water contamination, as well as air contamination.

2.4 Safe Risk at PFS

The relative risks of pollution can be judged by reviewing the type and condition of the equipment on site and putting it in a site specific context (both in terms of surrounding neighbours and environment of petrol filling station). As mentioned in Table 2.2, several sources, pathways, and receptors can be recognized as pollutant linkages occurring in and around a PFS. Several sources of risks are identified based on guidelines for soil, groundwater and surface water protection, and vapour emission control at petrol filling station. According to *Institute of Petroleum*, if any of three components above is absent, then there is no pollutant linkage and the site may not pose a risk to the environment.

Table 2.2 Pollutant linkage [34]

Source	*Pathway*	*Receptor*
Leaking UST's	Permeable strata above water table	Groundwater in aquifer
Poorly maintained oil/water separator	Surface water sewer	Surface watercourse
Faulty pressure/vacuum vent on tank vapour manifold	Prevailing wind direction	Air quality in local residential area

Additionally, other sources of discharge-sites are infrastructure and equipment options as outlined by *Institute of Petroleum* [34]. Examples of these other sources are:

1. **Dispensers and under dispenser trays**

The most common form of containment failure at PFSs occurs due to the leakages on the dispensers (pumps). The leakages may occur in the air separators, dispenser valves or flexible couplings. The installations of dispensers are over open soil which further increases the risk of underground leakage.

2. **Pipe work**

Based on the experience, a large number of leakages occurred in underground pipes, particularly the ones linked to the storage tanks. In terms of damage percentage, leakages from these pipes are the principal source of soil and groundwater contamination beneath petrol stations.

3. **Storage tanks**

Virtually all corrosion of buried steel are caused by electrochemical mechanism. The measurement of soil conditions such as moisture, conductivity, pH, sulphides, chlorides, electrical activity, etc will assess the risk of external corrosion failure.

4. **Offset/direct fill pipes**

During delivery service, the underground offset or direct fill tank man-chambers are prone to the accumulation of small amounts of the product. If no significant amount of product accumulates but manchambers appear oily on the surface of the walls, it means the walls may be leaking and require remedial work.

5. **Delivery procedures**

Delivery procedures should include underground storage tank mandatory checks to avoid the possibility of tank overfills. Overfill contingency plans should be based upon product dispensing. This is to avoid the high risk of spill from manually decanting delivery hoses after the tank overfills.

2.4.1 Fire/Explosion Risk

Vehicle fuels are highly flammable and inappropriate storage/handling may result in dangerous fire or explosion that in turn may lead to severe injury, manpower loss, economical loss and destruction of the site and surrounding area. Therefore, experts highly recommend that in case of fire, action should be taken to control the fire at the early stage [2]. Furthermore, the site should be designed, constructed and operated according to relevant national and international safe standards. At the planning stage, factors such as the separation from nearby buildings, design and quality of fuel tanks, petrol pumps, underground pipe work and tanker offloading points should be thoroughly considered [35].

Several factors such as the presence of combustible gases and liquids, oxygen, and ignition have been found to be the potential elements that could contribute to fire and explosion hazards at PFSs. This may occur during unloading and dispensing activities where leaks and/or spills of flammable products can happen. Possible ignition sources include sparks associated with the build up of static electricity, lightning, and open flames. In addition, tank cutting activities associated with maintenance and decommissioning may also result in explosions [36]. In order to prevent the start of a fire, all sources of heat or ignition in PFSs should be analyzed and then reduced or eliminated. Furthermore, the mechanism used to take such explosive sources in direct contact with fuel should be careful considered [2].

Several known sources of heat and ignition occurring at PFS are categorized as follows [2] :

- Visible sources: such as cigarettes, welding inside or too close to the facility, and fire in nearby buildings.
- Electrical sources: such as lights, electrical receptacles, electrical wiring, and transformers.
- Mechanical sources: such as an engine of a car, and the operation of the pumping system inside the dispensers
- Static electricity sources: such as from the friction of a person moving out of the car. Static electricity can also be generated by the road tanker, which can become electrically ‘charged’ during the journey to the filling station; the flow of petrol through the delivery hose which goes into the USTs; and the personnel involved in the delivery process who could be charged with static electricity [11].

2.4.2 Fuel Leaks and Spills

The United States has approximately 5-6 million underground storage tanks used to store a variety of materials including petrol, fuel oil, and numerous chemicals. The average life span of these tanks has been reported to be about 18 years. Beyond this time range, exposure to the natural elements causes the tanks to corrode creating cracks and holes on the walls and joints of the tanks – which finally causes leakage. A study conducted in 1990 reported around hundreds of thousands of tanks were leaking [7]. The causes for the leakages can be divided into two categories: accidental and ordinary. Accidental leakages are due to a crash of some part of the UST system. On the other hand, ordinary leakages are due to the set of human activities that are performed above the soil [37].

The most significant environmental issues from PFS sites are the accidental release of stored or handled fuel due to leaks from USTs, piping systems, and fittings under fuel dispensers. The leaks from UST systems can lead to serious environmental problems. The most important of which is groundwater contamination. The main causes of groundwater contamination are faulty installations, leaking underground storage tanks and spillage from tank overfilling. Sacile in 2007 has monitored USTs for three years and results from that study shows an occurrence of leakages in USTs [37].

As mentioned earlier, aging is the factor that causes corrosion of steel components that may lead to the failure of tanks. Additionally, an improper installation of tanks may cause structural stress, and finally the failure [36]. Releases may also result from surface spills or overfills during delivery and fuelling. Damage to or misuse of dispensers and dispensing petrol into unsuitable containers may also cause spillage. Petrol is more likely to leak from tanks and pipework if equipment is poorly installed, inadequately maintained, or old [11]. Table 2.3 shows several sources of possible discharges due to leak and spill incidents.

Table 2.3 Source of discharges [34]

Possible discharges in runoff to surface watercourses	
Leaks from:	- under dispenser valves and flexible couplings - pipe work - tanks and offset fill pipes - faulty oil/water separator operation
Possible discharges to soak ways	
Spill during:	- customer refueling, including leaking car fuel tanks - filling of petrol filling station underground storage tanks directly or by below ground level offset fill points - filling of petrol filling station underground storage tanks via above ground level offset fill points. - Overfilling of portable containers.

Fuel that was released due to the leakage in UST will enter the soil directly beneath the site or around its perimeter. This is because the liquid product can flow downwards through soil towards the water table by means of floating or dissolving. As petrol is lighter than water, it floats on the water surface and is transferred to another place over long distances via drainage channels and other watercourses [35]. In such a way, accumulation of petrol may persist in water tanks and other ground water source. This contaminates a large percentage of drinking water which comes from underground. The impacts from such releases depend on factors including the amount of materials released and local geologic conditions. Another factor is proximity to environmental receptors such as subsurface utilities or building structures or water resources (e.g. groundwater, surface water) [36].

Therefore, proper planning on site selection and consultation from the Protection Environmental Agency (PEA) and other appropriate bodies before installation of USTs should be taken into consideration. During site selection, the consideration that has to be taken into account are as follows [18]

- The proximity of the installation to watercourses
- The site's geology and hydrogeology
- Subsurface pipes and structures
- Historical site activities (including the presence of existing USTs)
- The corrosive nature of the soil
- Groundwater conditions such as high acidity, sulphate content or saline conditions.

2.4.3 VOC Emissions

Volatile organic compounds (VOCs) belong to a very heterogeneous group of chemicals characterized by their relatively high vapor pressures. Exposure to these compounds will lead to a variety of adverse health effects such as asthma, headaches, mucosal symptoms [29] and may also lead to cancer [30, 31]. A concentration of VOC has been found to show high variability over time and location. Occurrence of VOC can be usually seen in specific microenvironments such as sidewalks along busy streets, within vehicles, parking garages, and petrol pumps [38].

VOC is generated during fuel use and its evaporation, in particular during delivery and dispensing operations. VOCs may also occur in the atmosphere during the refueling of vehicles. This is why PFSs are known to be one of the major sources of VOC emission [39]. Occurrence of VOCs can be minimized by the use of special fuel filter nozzles that provide the facility to recover vapor [35].

2.4.4 Traffic

Access and egress activities to and from the site need to be carefully considered in order to avoid issues of queuing and congestion. The location of a PFS is an important element in traffic obstructions. Locations that can cause congestion are such that are located near to an intersection, in a high traffic flow road, or near to grade crossing. Collision between vehicles using the PFS and pedestrian at both the entrance and exit points has also been known to occur due to the improper location of PFSs. Therefore, the layout of the site should be designed to provide clear lines of sight wherever possible. The other consideration is minimizing the crisscrossing of vehicles and pedestrians routes [35].

2.5 Site Requirement

Several factors related to site requirements should be taken into account while selecting PFS location. Dispensing or refueling activities at PFSs pose a number of risks. One of the major risks is called external or third party risk that effects the population of the surrounding area due to the exposure to hazardous substance coming from PFSs. In other modes, such risks also occur in plants, storage or transport systems such as pipelines, trains or trailer trucks. However, the explosion of these substances are more harmful when it originates from a PFS [40]. The following sections describe some of the factors that increase the third party risks.

2.5.1 Distance to Public Facilities

Petrol stations are usually located within the context of urban neighbourhoods which are near to public and residential properties. Hospitals and schools are sensitive facilities that need a special attention with regards to safe distances to PFSs. A distance guideline has been recommended for the different types of transport fuels to sensitive public facilities. In particular, safe distance for gasoline, CNG, and LPG are 20-25 m, 10-15 m and 15-25m respectively with the same order of magnitude. In case of LPG, safe distances for dispenser and underground buffer are 15m and 25m respectively. Besides this, safe distance for LPG tank trailer is 45–110m [41].

An incident of fire at a PFS must be controlled immediately to prevent the likelihood of explosion. Safe distance also matters to avoid static electricity. In this case, the location of the PFS should be in a certain distance to high voltage overhead line.

It has been reported that the special location of the small and medium size PFSs should have a distance of 100m from their surroundings such as school, residential, and hospital because both of them have similar impact. This states that a certain distance from a heavily populated area to a PFS should be considered for the safe. This can be helpful to establish a “belt” to avoid any mishap to nearby sensitive places such as schools and hospitals [19].

2.5.2 Distance to Water System

UST systems release gasoline constituents in the form of vapor leaks from ground water piping system. Furthermore, these vapor leaks may be carried off to another place that is far from the fueling area via water force. This will affect the ground water. The ground water should be highly protected because it is one of drinking water resources. Therefore, the location of PFSs should be restricted to the area where they cannot contaminate ground water [8].

Petroleum contamination in groundwater travel more than of 75 feet from its original source in more than 70% of PFS sites that have been studied. On the other hand, contaminants from 24% of the PFS sites studied travelled approximately 300 feet. Studies have also argued that considering a broad range of hydrogeological conditions and different product types, 76% PFS sites provide a significant result for the contaminants travelled distance up to 300 feet. This implies that the safe distance between USTs and groundwater should be set at 300 feet to offset any catastrophe in case of UST leakage [42].

A study was conducted in 2002 for the petroleum contamination travel distances at discharge sites in a state of New England (Maine). Outcomes of this study show that the average distance travelled by gasoline and diesel/fuel oil constituents was 295 feet and 140 feet respectively. Only few constituents such as one-third of MtBE contamination plumes, one-quarter of other gasoline plumes, and one-sixth of diesel/fuel oil plumes were found to travel more than 300 ft^2. As such, several rules for protecting water system by siting of UST systems at new locations should be the following [8]:

- 500 feet between gasoline USTs and public water supplies (PWSs)
- 250 feet between gasoline USTs and private wells

2.5.3 Proper land selection

The business profitability of PFS is influenced by the number of factors such as property maintenance and management, size of the site, neighbourhood business potential, grade of street and topography, visibility, compatibility of traffic flow, transient business potential, ease of approach, and special features of location [43]. In regards of topography, PFSs should be constructed on the land with a maximum 35% steep. This is because PFSs have a number of underground storage tanks that are used to store motor fuel. Since, USTs contain a huge amount of flammable fuel. Sometimes leakage in these tanks may cause fire to breakout. which will create great victims if it is located in residential area. That is why PFSs should be in commercial and/or industrial zones [5]. For compatibility of traffic flow inside site reason, the minimum land space used to place a PFS should be at least 1000 m^2.

2.5.4 Accessibility

The accessibility of a PFS is the ease of entry to and exit from the particular site. The PFS potential sales depend on the degree of accessibility to the site. As such, to achieve a high sale, a PFS site must be visible and easy to enter/exit for the motorist. As mentioned earlier, sites that are located near intersections or grade crossings definitely will cause traffic obstruction that will result in less number of motorists stopping to refuel their vehicles. Therefore, a strategic location for petrol station should avoid intersections and grade crossings to maximize accessibility.

According to PETRONAS criteria, the most suitable location for a petrol station is within a growth centre or an urban area. In a few cases, PFSs can also be situated in rural/ remote areas where the need exists. For the urban area, a minimum distance from the residential building to petrol station should be around 100 feet for the safe concerns. In a residential area, a landscaped open area of 10 feet wide shall be provided along the rear boundary of the site and 15 feet wide along the side. This will offer a convenience to motorist, draw public attention to the site, and permit handling of a larger volume of business [43].

2.5.5 Emergency Response Services

As discussed earlier, occurrence of fire at PFS is most dangerous and it is highly possible to happen. In case of fire, emergency response services such as city fire brigade should take immediate action. In most cities, these stations are located at a number of locations to respond to fire and other emergencies. A fire station should have full and quick access to potentially hazardous locations such as PFSs throughout the area of its jurisdiction. As such, the geographical factor, traffic patterns need to be analyze to achieve maximum efficiency. Geographic Information System (GIS) has the capability to visually observe the locations of the fire stations and calculate the drive times to respond to a particular site via different routes and different types of emergency vehicles used to reach that location.

The emergency services must be able to provide help not only to the PFS in trouble but also to contain the situation from spreading to nearby areas. In this case, emergency personnel must respond in the shortest time possible to provide effective services. Studies have shown that fires go through same stages with respect to speed of growth and length of burn time. Fire doubles itself every second of free burning that is allowed. Occurrence of this growth can be seen exponentially from the time and temperature curve. One particular stage of fire is “flashover” that occurs after temperature reaches 600ºC and after 4-10 minutes from the onset. This flashover marks a critical change in condition and should be taken into consideration to prevent fires. Flashover condition can be measured by the function of time and temperature as depicted in Figure 2.3 [44].

Figure 2.3 illustrates fire growth over time. It is also shown that flashover can occur in less than 2 or more than 10 minutes depending on the size of the site, contents at site, and available oxygen. Most frequently, flashover occurs between 4 and 10 minutes [44].

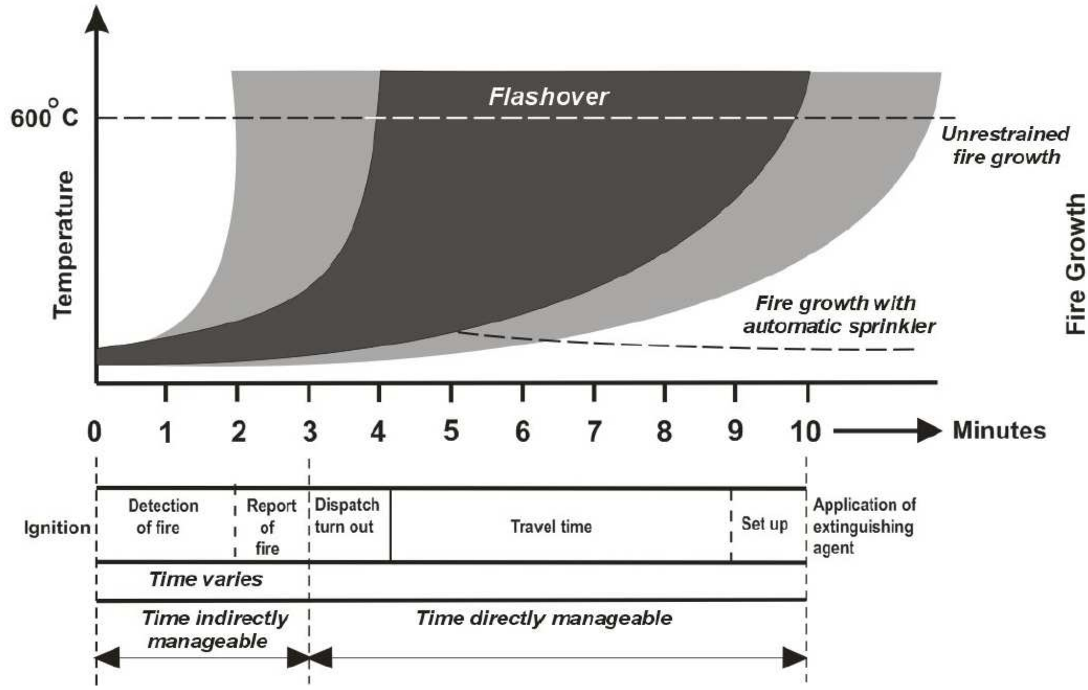


Figure 2.3 The Time and Temperature Curve of Flashover [44]

Based on National Fire Protection Agency (NFPA) 1710 [45], fire response time for fire department should be four minutes (240 seconds) or less for the arrival of the first responders (480 seconds) or less for the deployment of a full first alarm assignment at a fire suppression incident.

2.6 Standard Used in Some Countries

In this study, two standards have been used to create the PFS siting criteria for this research. The standards used are from National Environmental Protection Agency (NEPA) of the Republic of Jamaica and the Bhavnagar Area Development Authority of India.

2.6.1 National Environment Protection Agency, Jamaica

The NEPA of Jamaica has a list of considered criteria for petrol filling station siting [46].

1. Stations should be located within a growth centre or an urban area except in circumstances where it can be shown through appropriate studies that the need exists otherwise.
2. Land should be zoned for commercial/industrial use or be designated specifically for the purpose in a subdivision.
3. Stations should be located at a minimum of 500 ft. from any public institution such as schools, churches, public libraries, auditoriums, hospitals, public playgrounds, etc.
4. Area of land to be developed should be sufficient to allow manoeuvring of vehicles within its cartilage but should not be less than 12.000 sq. ft. with a minimum frontage of 300 ft. on the primary street.
5. Filling Stations will not be allowed in any area where the traffic situation is such that it will cause obstructions in entering or leaving a station, or on tight curves where visibility is not adequate.
6. Vehicular access/egress/crossover should be reasonably safe with adequate approach distances especially where main roads and intersections are involved.
7. Wherever possible, stations should be erected on level rather than sloping site to prevent rolling or discarded materials such as cans, drums, etc.
8. When sited in shopping centres, stations should be located in an isolated area of the development as long as planning criteria are met, example, set back.
9. Environmental impact on streams, lakes, ponds, aquifer, etc., will be taken into consideration. An Environmental Impact Assessment may be required from the applicant.
10. Buildings are to be located a minimum of 40 ft. from road property boundaries to provide adequate area for manoeuvring of vehicles in the service area.
11. Petrol pumps shall be located a minimum of 100 ft. from any residential building.

12. Fuel should be stored in double walled container to minimize leakage and prevent contamination of ground water.
13. Normally no access to nor egress from a filling station shall be closer than 150 ft. to any road intersection or 250 ft. from the intersection of two main roads.

2.6.2 Bhavnagar Area Development Authority, India

Bhavnagar Area Development Authority [47] has two PFS siting consideration aspects based on the space and traffic requirement. Space requirements for PFS are mentioned as follow.

1. The minimum size for the location of PFS shall be 30.00 m x 36.50 m.
2. Except in hilly terrain, the plot should be on level ground.

Traffic requirements are mentioned as follow:

1. A PFS is a major generator of traffic and as such present a degree of traffic hazard on the road on which it is sited. This potential traffic hazard determines the number of station that can be permitted in any section of the road or the highway or in a section of a city. The objective being to keep the traffic hazard to the minimum.
2. A PFS should not be located opposite a break or opening in the central verge on a dual carriage as this will encourage the traffic to cross the road while entering a filling station or filling cum service station.
3. A PFS preferably may not be sited too closed to an intersection to a traffic island on the main road. To assure satisfactory wearing distances. The minimum desirable distance between an access to a station and the tangent point of the traffic island or intersection should be 80.00 m.
4. In the case of main road provided along with a service road or a marginal access road. The access to the station should be provided from the service the marginal access road and not from the main road.
5. On road having heavy traffic it is desirable to provide one station on either side of the road so that vehicles are not required to cross the road. On roads the traffic can not support two filling station open on either side one may be

located on either sides provided the site is not close to a junction and confirm to the requirements of the above.

6. Siting of the stations on road curves or bends are a safe hazard and should be avoided located adjacent to the residential houses.
7. The minimum distance of the property line of the filling station from the central line of the road must not be less than 15.00 m or half the proposed right of way of the road.

Entrance and exit considerations

1. In all location of filling stations, the basic principle governing location as well as exit and entrance consideration is to minimize as much as possible interference with normal flow of traffic on the road.
2. For easy flow of the station a minimum frontage of 30.00 m. shall be provided with wide and easy entrance and exit kerbs. Vehicles entering and leaving the station should be fully visible to the traffic on the main road and there should not be any obstruction to view between the filling station pumps and the road.
3. The following minimum requirements for the ingress should be observed.
   i) Maximum width of the drive ways at the side walk: 9.00 m.
   ii) Minimum distance from any drive way to any exterior property line: 6.00 m.
   iii) Minimum distance from any drive way to any interior plot line 3.00 m.
   iv) Minimum distance between kerbs sites : 9.00 m.

2.7 GIS Application in Suitability Analysis

Previous studies which are mentioned in Table 2.4 have used several tools to find suitable location for facilities. It shows several tools that can be used for spatial multi criteria decision analysis that utilize the combination of GIS and AHP. These tools are used worldwide to conduct suitability analysis. The combination of GIS and AHP has been found to be an ideal tool to determine suitable location for certain facilities spatially while at the same time accommodating the willingness of stakeholders to state their opinions based on their expertise.

Those previous studies highlighted that GIS provides high efficiency in spatial analysis. The GIS is found to be a technique that has greater flexibility and accuracy for handling digital spatial data especially in suitability analysis. Nevertheless, GIS stand alone could not overcome the issue of inconsistency of expert opinion in decision making because it has limitation such as incapable to process multiple criteria and conflicting objectives. Furthermore, GIS could not integrate geographical information with subjective values/priorities imposed by the decision maker.

In regards of GIS limitations in decision making for suitability analysis, all those previous studies utilized an additional technique. This technique is multicriteria decision technique which can accommodate expert opinion for giving judgement and assigning relative importance to each of many criteria considered in decision making. This approach is highly dependent of the Experts preferences. However, the AHP as one of multicriteria decision method is superior method because it can deal with inconsistent judgments and provides a measure of the inconsistency of the judgment of the respondents.

As result, the integration of GIS and AHP creates similar output which is showing a classification of study area into several class of suitability analysis. However, all the studies do not explain further that the respondents' inconsistency judgement could give impact to spatial analysis output. In the efforts to overcome this problem, another additional technique should be taken to check the sensitiveness of final output. The technique is called as spatial sensitivity analysis. This technique is explained further on Chapter 3. The GIS applications in several suitability analysis researches are summarized by Table 2.4.

Table 2.4 GIS Application in Suitability Analysis Research

Previous Study ***Discussion***	***GIS-based Hierarchy Process for the Suitability Analysis of Nuclear Waste Disposal Site [48]***	***Site Suitability Analysis for Solid Waste Disposal [49]***	***GIS based Multicriteria Approaches to Housing Site Suitability Assessment [50]***	***GIS & AHP For Siting Water Harvesting Reservoirs [51]***	***Using GIS and AHP Technique For Land-Use Suitability Analysis [52]***	***Conclusion***
Objective	Selecting potential favourable sites for nuclear waste	Selecting sites, which are suitable for the disposal of solid wastes	Determining the optimum land suitability for housing	Locating and ranking suitable sites for water harvesting reservoirs on the basis on the overall suitability of each reservoir.	Integrating GIS and AHP in analyzing land-use suitability.	Several conclusion for those several study are: 1. Many previous researches used combination of AHP and GIS and supplemented with another method to construct suitability analysis. 2. GIS software are vary but three among five research using ArcGIS software to perform suitability analysis.
Methodology	**AHP** An Analytic Hierarchy Process (AHP) is applied to quantify the relative significance of each factor before determining the most suitable site. **GIS** ArcGIS is used to screen and analyze different datasets for generating suitability maps for each factor based on the above criteria.	**Decision Making** 1. Intelligence Phase 2. Design Phase 3. Decision Rules 4. Choice Phase The prime objectives of this research work the suitability of the sites were classified on the basis of different criteria: 1. Highly Suitable Site 2. Moderately Suitable Site 3. Less Suitable Site	The proposed process includes four steps: 1. Establishment of suitability criteria 2. Site screening 3. Establishment of the AHP evaluation criteria 4. Site evaluation	The study involved the development and application of a three-step Hydro-Spatial Analytical Hierarchy Process (HS AHP) 1. ArcGIS 2. Watershed Modelling 3. AHP	In this process, land-use types are selected based on local farming practices, opinions of farmers, scientists, and local district and province leaders. **AHP Technique** Using AHP technique these judgments on important of criteria are converted to criteria weights (w_i).	

Previous Study ***Discussion***	***GIS-based Hierarchy Process for the Suitability Analysis of Nuclear Waste Disposal Site [48]***	***Site Suitability Analysis for Solid Waste Disposal [49]***	***GIS based Multicriteria Approaches to Housing Site Suitability Assessment [50]***	***GIS & AHP For Siting Water Harvesting Reservoirs [51]***	***Using GIS and AHP Technique For Land-Use Suitability Analysis [52]***	***Conclusion***
	The process of integrated procedure: 1. Locating 2. Screening 3. Evaluating potential sites				**GIS** Each land-use requirement could be organized in form of one map layer in GIS.	3. The output of the research is suitability map that shows the hierarchy of area suitability assessment.
Tools	1. ArcGIS 2. Weighted linear combination	1. GIS software 2. Multicriteria ranking techniques	1. GIS Spatial analysis and 3D analysis using ArcView Model Builder (Arcview GIS 3.2) 2. AHP technique	1. ArcGIS 2. Watershed Modelling System (WMS) 3. AHP	AHP GIS	
Output	The output of suitability map can vary greatly based on the inputs of different factors and different weighting for each factor.	**Selection of Suitable Sites** There were seven suitable sites identified by the multi criteria evaluation method. Each of these plotted points has satisfied all the criteria adopted for highly suitable sites for solid waste disposal.	Suitability sites for housing with different criteria: 1. Extremely suitable 2. High suitable 3. Suitable 4. Less suitable 5. Unsuitable	The output of this research are: 1. Output maps showing the DEM for the study area and the sub watershed divisions. 2. Suitability ranking map for the sub watersheds.	Land use suitability map for coffee	

2.8 Summary of Criteria Use for PFS Siting

Many factors have to be considered for PFS siting. A list of criteria for petrol filling station consistent with environmental protection guidelines and site requirements as what have been discussed in all section of literature review are summarized in Table 2.5.

To achieve the research objectives which put the environmental issue as the main concern, several decisive factors are considered as guidelines. The criteria are water system protection from USTs leakages, vicinity area protection from petrol filling station's fire and explosion hazard, proper land selection, and access road selection due to in-out activities. Each of these criteria are further broken down into several sub-criteria. Subsequently, all sub-criteria are also broken down into several indicators. Those indicators are taken from several sources such as environmental agency like what have been mentioned on section 2.6, environmental city guideline (Maine, New Hampshire, Surabaya), PERTAMINA, and journals.

Table 2.5 shows the relationship between the criteria, sub-criteria and indicators. For the example of the water system protection from USTs leakages, Table 2.5 explains when a UST leaks, the petrol spilled then contaminates groundwater and when it dissolves and migrates to private wells or, even worse, rivers and lakes, drinking water sources of cities and towns will be contaminated.

Table 2.5 Criteria for Site Selection

Criteria	***Sub-criteria***	***Indicator***
Water system protection from USTs leakages	Groundwater	At least 300 ft from groundwater
	Seawater	At least 3.250 ft from saline water
	Rivers	At least 500 ft from rivers and lakes
	Public wells	At least 250 ft from artesis well
Vicinity area protection from PFS's fire and explosion hazards	Impact on the residential properties	At least 100 ft from residential properties
	Impact on nearby hospitals and schools	A least 500 ft from hospitals and schools
	Presence of electro static environment	At least 150 ft from High Voltage Areas
Proper land selection	Land availability	vacant land
	Proper HSE practises during UST construction	Less than 35% steep
	Land use	Located in commercial/industrial zone
Road safety due to in-out activity	Distance to Intersection	At least 250 ft from intersection
	Distance to road	At least 40 ft. from road property boundaries
	Distance to grade crossing	At least 820 ft from grade crossing
Emergency response services	Distance from Fire Station	Within 8 min. driving time
	Distance from Hospital	Within 8 min. driving time

CHAPTER 3

METHODOLOGY

The underlying idea of this research is suitability analysis using GIS tools that are supported with multi criteria decision analysis method. A brief overview of the principles of the method and its requirements were discussed in this chapter.

3.1 GIS and Suitability Analysis

A Geographic Information System (GIS) is a computer system that has the ability to capture, collect, store, retrieve, transform, analyze, and display geospatial data from the real world for a particular set of purposes [53, 54]. Several GIS softwares are available in the market such as ArcGIS®, GeoMedia, MapInfo, ERDAS, IDRISI, and AUTOCAD MAP. Among these, ArcGIS by Environmental Systems Research Institute (ESRI) [55] is the most popular. As such, several reasons ArcGIS is chosen to be utilized in this research is its popularity and also much easier to be integrated with AHP software Expertchoice 2000.

Land suitability analysis is the process of determining the fitness of a given tract of land for a defined use [56, 57]. In the other words, suitability analysis is the process to determine whether the land resource is suitable for some specific uses and to determine its suitability level. Its development and capability to overlay digital maps have made suitability mapping easier and quicker. Since suitability analysis deals with the analysis of several data sets, GIS can effectively be used in looking at the characteristics of land from a number of layers for each location to solve problems. GIS can process enormous data and have the powerful functions of displaying and outputting maps [58]. This capability is the main reason GIS is the preferred system for the suitability analysis in this study. In pursuance of these objectives, a conceptual diagram of the method is provided in Figure 3.1.

Figure 3.1 shows that four analysis has been utilized in this research to obtain the final result which is a single ranked map of PFS suitability analysis. At the beginning starts with stakeholder analysis followed by Analytical Hierarchy Process (AHP) analysis, spatial analysis, and sensitivity analysis subsequently.

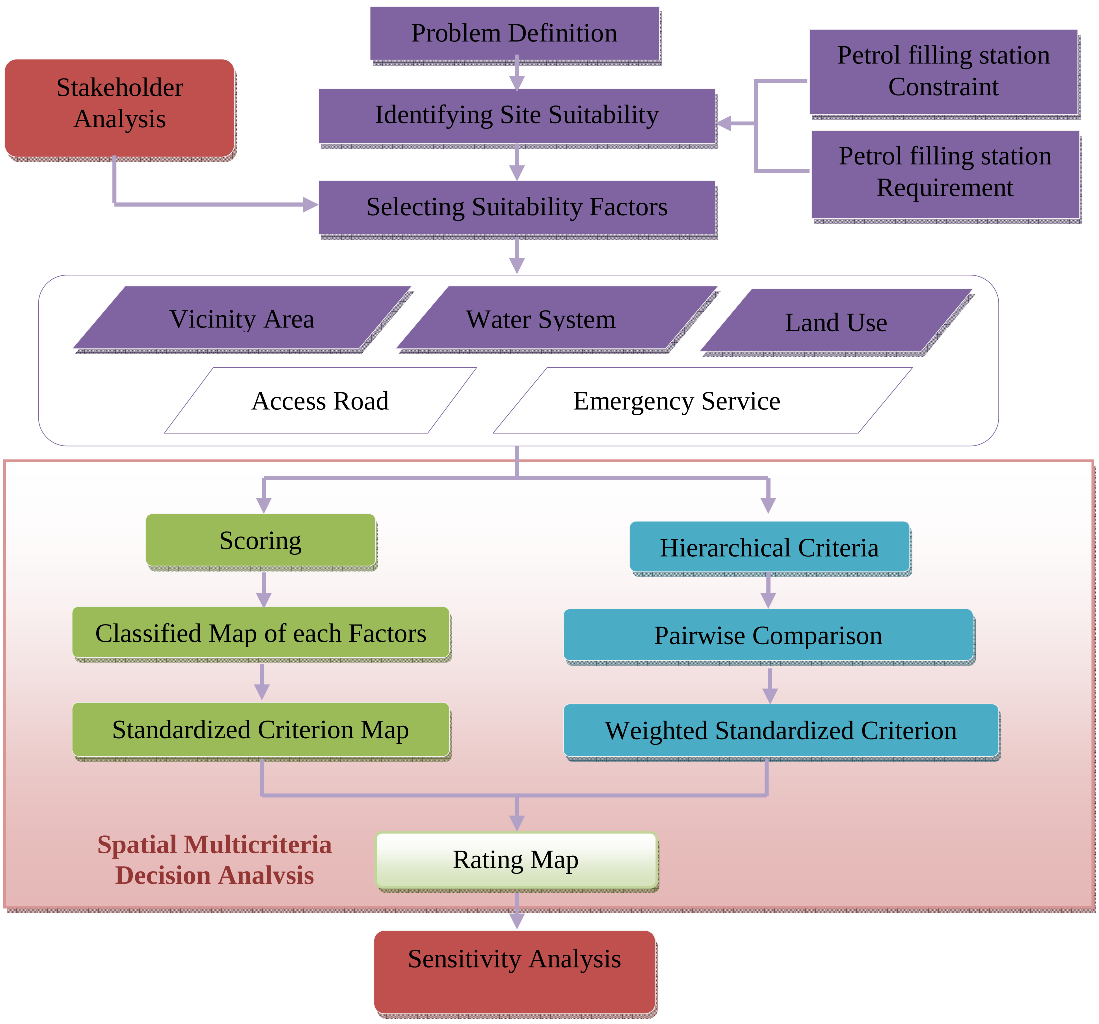


Figure 3.1 Flow-chart of Research Methodology

3.2 Stakeholder Analysis

Stakeholders are those whose interest are affected by the issue or those whose activities strongly affect the issue. Stakeholder analysis is used to identify people, groups and organisations that have significant interests in specific urban issues. This is a basic tool for achieving the understanding of potential roles and contributions of the many different stakeholders. Even opposition of the implementation of the policy or program can be detected. Therefore, using a stakeholder analysis, complemented by other key tools, as a guideline at the onset will increase the chances of success for any given policy or program [59].

Stakeholder analysis consists of three essential steps: 1) Identifying the key stakeholders and their interests (either positive or negative) in the project; 2) Assessing the influence of, importance of, and level of impact upon each stakeholder; and 3) Identifying how best to engage stakeholders [60]. Figure 3.2 shows that a stakeholder who has high degrees of both importance and influence is the stakeholder who stands to lose or gain significantly from the project and whose actions can affect the project's ability to meet its objectives. A stakeholder who has high importance but low influence is the stakeholder who stands to lose or gain significantly from the project but whose actions cannot affect the project's ability to meet its objectives. A stakeholder who has low importance but high influence is the stakeholder whose actions can affect the project's ability to meet its objectives but who does not stand to lose or gain much from the project. Finally, a stakeholder that has low importance and low influence is the stakeholder who does not stand to lose or gain much from the project and whose actions cannot affect the project's ability to meet its objective.

Figure 3.2 shows the mapping of stakeholder using stakeholder analysis matrix based on their importance and influence.

Degree of Influence

High Influence ← Low Influence

High Importance ↑ Degree of Importance ↑ Low Importance

Box A **Stakeholders who stand to lose or gain significantly from the project AND whose actions can affect the project's ability to meet its objectives.** The project needs to ensure that their interests are fully represented in the coalition. Overall impact of the project will require good relationships to be developed with these stakeholders.	**Box B** **Stakeholders who stand to lose or gain significantly from the project BUT whose actions cannot affect the project's ability to meet its objectives.** The project needs to ensure that their interests are fully represented in the coalition.
Box C **Stakeholders whose actions can affect the project's ability to meet its objectives BUT who do not stand to lose or gain much from the project.** They may be a source of risk; and you will need to explore means of monitoring and managing that risk.	**Box D** **Stakeholders who do not stand to lose or gain much from the project AND whose actions cannot affect the project's ability to meet its objectives.** They may require are of low priority. They are unlikely to be the subject of activities or involved in project management.

Figure 3.2 Stakeholder Analysis Matrix [61]

3.3 Spatial Multi-Criteria Decision Analysis

A Spatial Decision Support System (SDSS) is an interactive, computer-based system designed to support a user or a group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem [62]. The difference between SDSS and a traditional decision support system (DSS) is the particular nature of the geographic data which depicts spatial problems and the high level of its complexity.

Spatial multi criteria analysis requires information on criterion values as well as the geographical locations of alternative sites. Additionally, preferences of a set of evaluation criteria chosen by the decision makers will also aid in suitable analysis.

This means, the analysis results not only depends on the geographical distribution of attributes, but also on the value judgments involved in the decision making process. Two available techniques that provide a significant contribution in spatial multi-criteria decision analysis are: (1) the GIS component and (2) the Multi Criteria Decision Making (MCDM) analysis component [63, 64]. In solving spatial decision problems, GIS and MCDM techniques support the decision makers to achieve greater effectiveness and efficiency of decision making.

Figure 3.3 shows the framework of integrating GIS and MCDM analysis consists of several stages such as problem definition, evaluation criteria, generating alternatives, assessing criterion weighting, choosing decision rules, and testing sensitivity analysis.

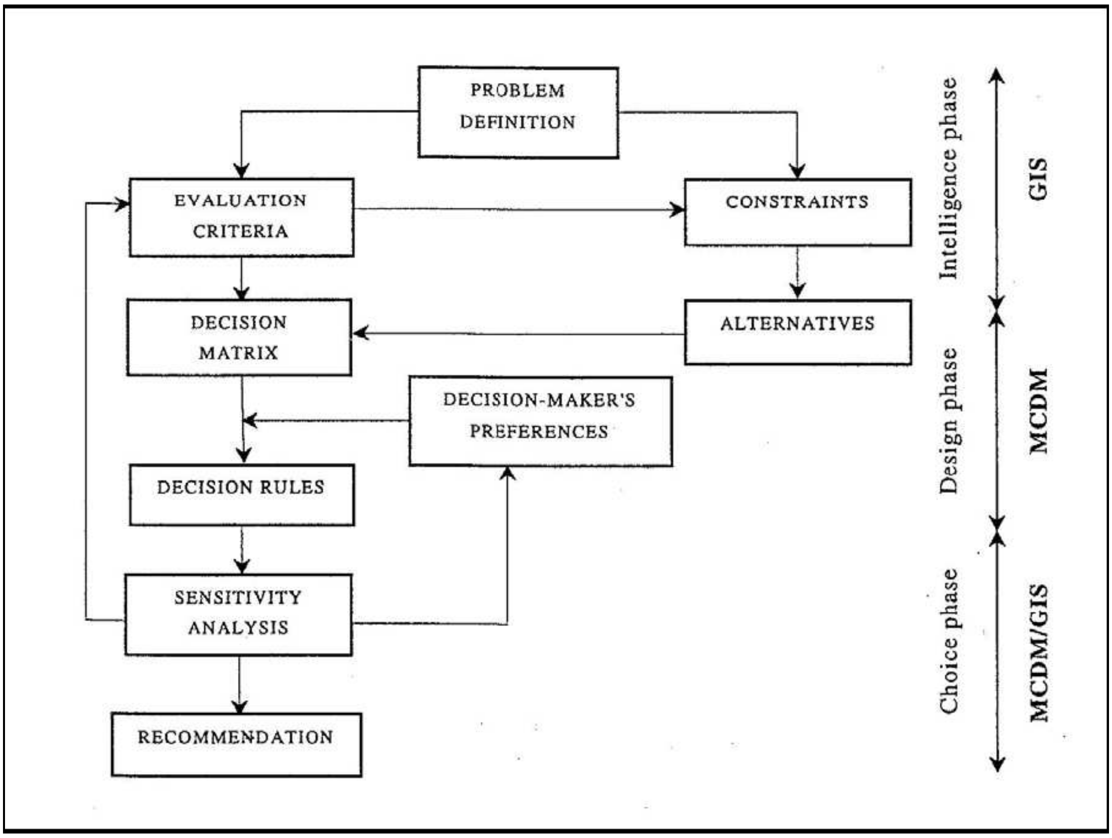


Figure 3.3 Integrating GIS and MCDM Analysis [65]

Overviews of those stages are explained as follows:

1. Problem Definition

   The difference between desired and existing states of a system is perceived as a decision problem. It is a “gap” between the desired and existing states as viewed by a decision maker. The GIS capabilities for data storage, management, manipulation, and analysis offer major support in the problem definition stage.

2. Evaluation Criteria

   The spatial multicriteria analysis focuses on the set of evaluation criteria (objectives and attributes) once the decision problem has been identified. This step involves two specification processes: 1) specifying a comprehensive set of objectives that reflects all concerning the decision problem, and 2) specifying measures (or attributes) for achieving those objectives. A measurement scale must be established for each attribute. The degree to which the objectives are met is the basis of comparing alternatives.
3. Alternatives

   The process of generating alternatives should be based on the value structure and be related to the set of evaluation criteria. Each alternative is assigned a decision variable. Variables are used by the decision maker to measure the performance of alternative decisions, which is also called attributes.
4. Criterion Weights

   The purpose of criterion (objective or attribute) weight is to express the importance of each criterion relative to other criteria. The derivation of weights is a central step eliciting the decision maker’s preference. The input data can be organized in the form of a decision matrix or table once alternatives, attributes, and associated weights are already built.

5. Decision Rules

   Eventually, the unidimensional measurements (geographic data layers) and judgements (preferences and uncertainty) must be integrated to provide an overall assessment of the alternatives. An appropriate decision rule or aggregation function will be accomplished for alternatives' assessment. Decision rules dictate how best to rank alternatives or to decide which alternatives are preferred to another.

6. Sensitivity Analysis

   Sensitivity analyses should be performed to determine robustness after obtaining a ranking of alternatives. It is defined as procedure for determining how the recommended course of action is affected by changes in the inputs of the analysis. It aims at identifying the effects of changes in the inputs (geographical data and the decision maker's preference) on the outputs (ranking of alternatives). As a result, either one of two conditions will prevail. Firstly, the ranking is considered to be robust if the changes do not significantly affect the outputs. Alternately, information about the output to return to the problem formulation step may be used if the current result is found to be unsatisfactory.

3.3.1 Weighting Analysis using Pair-wise Comparison Method

The purpose of criterion weighting is to express the importance of each criterion relative to other criteria. Weighting of criteria can be done in several ways: ranking method, rating method, pair-wise comparison method, trade-off analysis method, and comparing method. However, empirical applications suggest that the pair-wise comparison method is one of the most effective techniques for spatial decision making including with GIS-based approaches [66].

The pair-wise comparison method was developed by Saaty in the context of the Analytic Hierarchy Process (AHP) [67]. The analytical hierarchy process (AHP) method is based on three principles: decomposition, comparative judgment, and synthetic of priorities [65]. This method involves pair-wise comparisons to create a ratio matrix. It takes as an input the pair-wise comparisons and produces the relative weight as output. Specifically, the weights are determined by normalizing the eigenvector associated with the maximum eigen value of the (reciprocal) ratio matrix. The AHP could be further divided into:

1. **Development of the AHP Hierarchy**

Decomposing the decision problem into a hierarchy is the first step in AHP procedure. The hierarchical structure consists of four levels: goal, objectives, attributes, and alternatives. The alternatives are represented in GIS databases. Each layer contains the attribute values. These attribute values are assigned to the alternatives, and each alternative is related to the higher-level elements. The attribute concept links the AHP method to GIS-based procedures.

2. **Comparison of the Decision Elements on A Pair-wise**

Pair-wise comparison method incorporates three steps. The first step is to develop pair-wise comparison matrix by inputting an underlying scale with values from 1 to 9. This is to rate the relative preferences for two criteria. Table 3.1 shows the intensity of importance that has been used for pairwise comparison matrix.

Table 3.1 Pairwise Comparison Matrix [67]

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

Secondly, the criterion weight is computed by: (a) summing the values in each column of the pair-wise comparison matrix; (b) dividing each element in the matrix by its column total (the resulting matrix is referred to as the *normalized pair-wise comparison matrix*); and (c) computing the average of the elements in each row of the normalized matrix that can be achieved by dividing the sum of normalized scores for each row by 3 (the number of criteria). Resulting average values will provide an estimate of the relative weights of the criteria being compared. Table 3.2 shows the calculation for each step to determine the relative criterion weight.

Table 3.2 Determining the Relative Criterion Weight [65]

Criterion	**Step I**			**Step II**			**Step III**
	P	**S**	**V**	**P**	**S**	**V**	**Weight**
Price (P)	1	4	7	0.718	0.769	0.538	(0.718 + 0.769 + 0.538)/3 = 0.675
Slope (S)	1/4	1	5	0.179	0.192	0.385	(0.179 + 0.192 + 0.385)/3 = 0.252
View (V)	1/7	1/5	1	0.102	0.039	0.077	(0.102 + 0.039 + 0.077)/3 = 0.073
	1.393	5.200	13.0	1.000	1.000	1.000	1.000

The third step is to determine the consistencies in the comparison by estimating the consistency ratio. This requires the following steps [65]: (a) determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pair-wise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, and finally, sum these values over the rows; and (b) determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously. Table 3.3 shows the two staged calculation for third step to determine the consistency ratio.

Table 3.3 Determining the Consistency Ratio [65]

Criterion	**Step I**	**Step II**
Price (P)	(0.675)(1) + (0.252)(4) + (0.073)(7) = 2.194	2.194/0.675 = 3.250
Slope (S)	(0.675)(0.250) + (0.252)(1) + (0.073)(5) = 0.786	0.786/0.252 = 3.119
View (V)	(0.675)(0.143) + (0.252)(0.2) + (0.073)(1) = 0.220	0.220/0.073 = 3.0149

The last step is to determine the average values of the consistency vector that is so called lambda (λ) and the consistency index (CI) which provides a measure of departure from consistency.

The value for lambda (λ) is simply the average value of the consistency vector. Calculation of CI will depend on the careful consideration that λ is always greater than or equal to the number of criteria under consideration (n) for positive, reciprocal matrixes. Should the pair-wise comparison matrix be a consistent matrix, lambda is simply equal to the number of criteria under consideration ($\lambda = n$). Therefore, a measure of $\lambda - n$ is believed to be a valuate of the degree of inconsistency. This measure can be normalized as follows:

$$CI = \frac{\lambda - n}{n - 1} \tag{1}$$

Further, we can calculate the *consistency ratio* (CR), which is defined as follows:

$$CR = \frac{CI}{RI} \tag{2}$$

Where RI is the random index or so the consistency index of a randomly generated pair-wise comparison matrix. Random index depends on the number of elements being compared. The ratio obtained from the measurement of consistency ratio (CR) shows the performance of judgements. A ratio less than 0.10 ($CR < 0.10$) indicates a reasonable level of consistency in the pair-wise comparison. On the other hand, a ratio of 0.10 or more ($CR \geq 0.10$) indicates the inconsistent judgements. In case of inconsistency, original values in the pair-wise comparison matrix should be reconsidered and revised [65].

3. Construction of an Overall Priority Rating

The final step in weighting analysis using pair-wise comparison method is to aggregate the relative weights of the levels obtained in the second step. This is done by means of a sequence of multiplications of the matrices of relative weights at each level of the hierarchy. The composite weight obtained in second step represents rating of alternatives or decision alternative scores used to make a decision with respect to the overall decision analysis. The overall score R_i of the *i*th alternative is the total sum of its ratings at each of the levels and is thus computed in the following way:

$$R_i = \sum_k w_k r_{ik} \tag{3}$$

Where w_k is the vector of priorities associated with the *k*th element of the criterion hierarchical structure, $\Sigma\ w_k = 1$; and r_{ik} is the vector of priorities derive from comparing alternatives on each criterion. Maximum value of R_i (i = 1, 2, …., m) can be identified as the most preferred alternative.

Overall rating of alternatives can be obtained by combining the attribute weights with the data. Since the attribute data can be represented as map layers, the AHP method can be incorporated into a GIS. A GIS environment has the capability to process the attributes (map layer) data and assigning the weights of AHP results to the attributes would enable priority rating in GIS.

Figure 3.4 shows the integration part between AHP and GIS-based rating of alternatives.

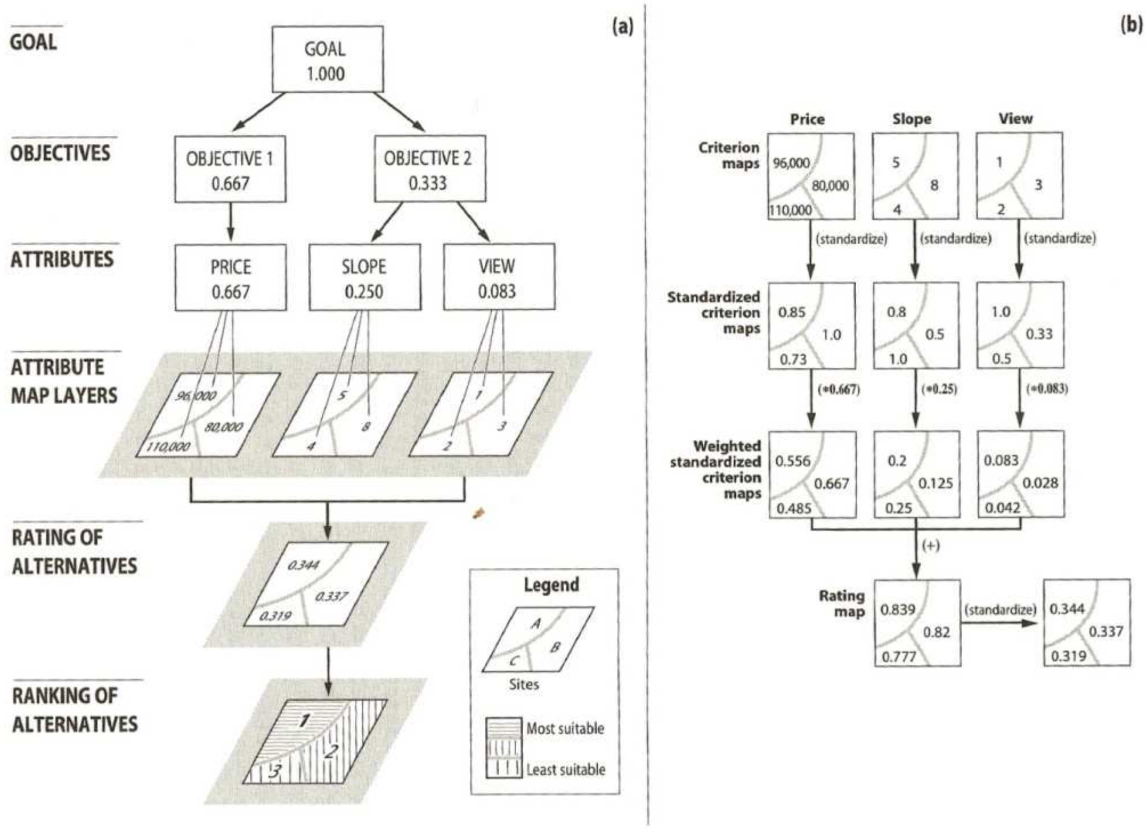


Figure 3.4 Analytic hierarchy process (AHP) method: (a) AHP procedure; (b) GIS-based rating of alternatives [65]

Fortunately, computer programs can perform all the necessary calculations. EXPERT CHOICE is one of the most popular software packages for the pair-wise comparison procedure [68]. It is also as advantageous that the method can be easily implemented in spreadsheet environment [69]. Furthermore, the pair-wise comparison method has been incorporated into GIS-based decision making procedures [64, 70].

Table 3.4 shows that among the methods for assessing criterion weights, pair-wise comparison supported by Expert Choice Software has a lot of advantages compare to other weighting methods.

Table 3.4 Summary of Methods for Assessing Criterion Weights [71-73]

Feature	**Method**			
	Ranking	Rating	Pairwise Comparison	Trade-off Analysis
Number of judgments	*n*	*n*	*n(n-1)/2*	*< n*
Response Scale	Ordinal	Interval	Ratio	Interval
Hierarchical	Possible	Possible	Yes	Yes
Underlying Theory	None	None	Statistical/heuristic	Axiomatic/deductive
Ease of Use	Very Easy	Very Easy	Easy	Difficult
Trustworthiness	Low	High	High	Medium
Precision	Approximation	Not precise	Quite precise	Quite precise
Software Availability	Spreadsheets	Spreadsheets	Expert Choice (EC)	Logical Decisions (LD)
Use in GIS environment	*Weights can be imported from a spreadsheet*	*Weights can be imported from a spreadsheet*	*Component of IDRISI*	*Weights can be imported from LD*

3.3.2 Spatial Analysis

Spatial analysis model is required to create the backbone of GIS operations for this research [6]. The process for determining the suitable parcel for PFS in this study is performed by a GIS Spatial analysis using ArcGIS Model Builder. In the model builder, the process ‘to convert vector themes to grid themes using the vector conversion process’ was carried out. Models are represented as sets of spatial processes, such as buffer, classification, reclassification and overlay techniques.

Figure 3.5 show the steps for spatial analysis to obtain single ranked map using weighted overlay analysis method.

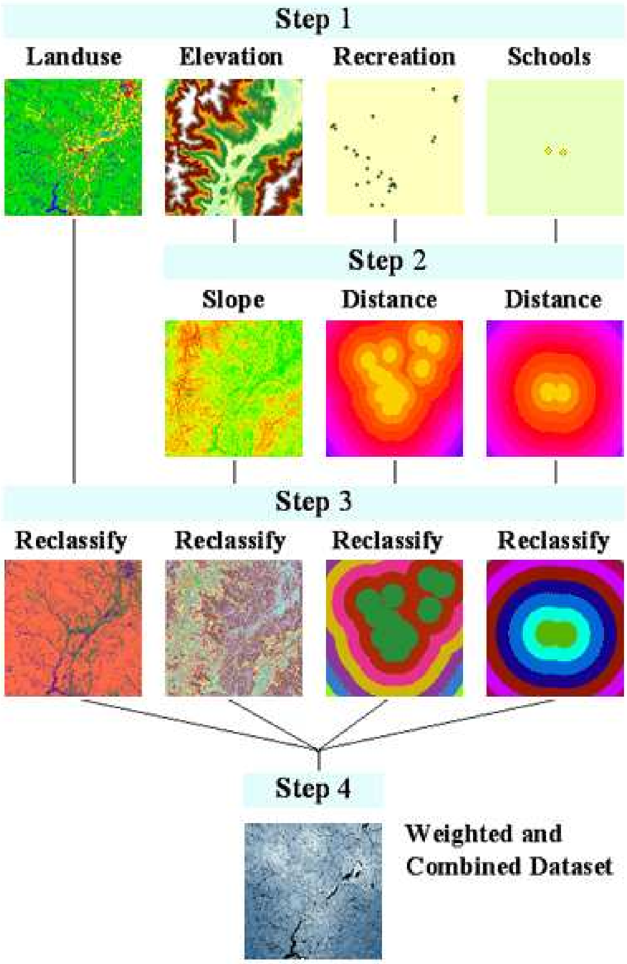


Figure 3.5 Spatial analysis for Weighted Overlay Analysis [74]

Four analysis tools that have been utilized for spatial analysis are rasterization, eculicean distance, reclassification, and weigted overlay. The explanation for each analysis tools are mentioned as follows:

1. Rasterization

The conversion of vector data to raster data is called rasterization and this method uses different computer algorithms [75]. The first step sets up a raster with a specified cell size to cover the area extent of the vector data and initially assigns all cell values as zeros. The second step changes the value of those cells that correspond to points, lines, or polygon boundaries. The cell value is set to 1 for a point, the line's value for a line, and the polygon's value for a polygon boundary. The third step fills the interior of the polygon outline with the polygon value. Errors from rasterization are usually related to the design of the computer algorithm, the size of raster cell, and boundary complexity [76, 77]. Figure 3.6 shows the conversion from vector to raster data.

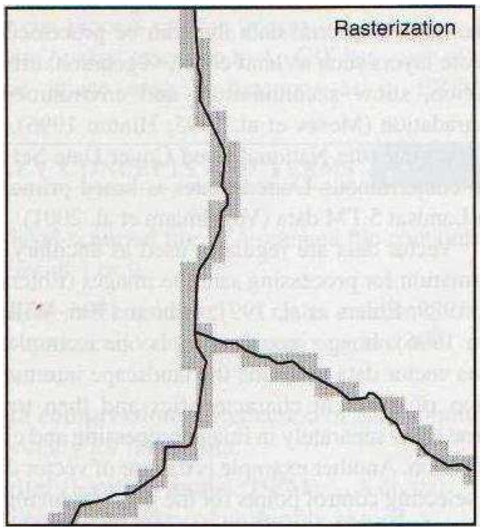


Figure 3.6 Conversion from vector to raster data [53]

In a raster representation, space is divided into an array of rectangular cells. All geographic variation is then expressed by assigning properties or attributes to these cells. The cells are sometimes called pixels (short for picture elements).

2. Euclidean Distance Analysis

Distance may be expressed as physical distances or cost distances in GIS projects. The physical distance measures the straight-line or Euclidean distance. Physical distance measure operations calculate straight-line distances away from cells designated as the source cells to a specified maximum distance [53]. It is shown on Figure 3.7 a buffers from source cells with wavelike continuous distances over the entire raster or to a specified maximum distance.

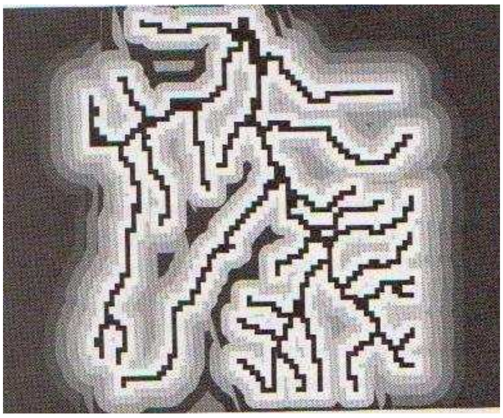


Figure 3.7 Continuous distance measures from a stream network [53]

3. Reclassification Analysis

The purpose of reclassification is to assign numeric values to classes with each map layer, so they have equal importance in determining the most suitable location. Reclassification is also referred to as recoding, or transforming, through lookup tables [78]. Two reclassification methods may be used. The first method is a one-to-one change, meaning that a cell value in the input raster is assigned a new value in the output raster. The second method assigns a new value to a range of cell values in the input raster [53]. By assigning numeric values to classes for each map layer, equal importance is given so it is easy to determine the most suitable location.

The reclassification by individual value function changes one value to another in a one-to-one change. For an example, on the task of performing a deer habitat analysis, the values on a land use raster need to be changed to a preference range 1 to 10 — to make each land use type meaningful to the deers. The types of land that is preferred by deers are reclassified to higher values while those less preferred to lower values. For instance, the forest land use is reclassified to 10, the low-density residential land use to 5, and the industrial to 1. The following illustration depicted by Figure 3.8 reclassifies the original values from Base Raster to new reclassified values. The output range of values is from 1 to 20.

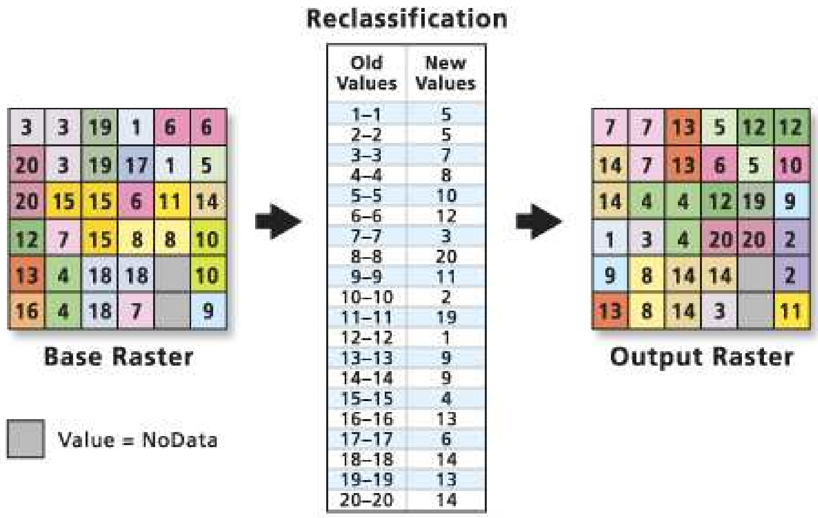


Figure 3.8 Reclassification [74]

4. Weighted Overlay Analysis

Research has shown that index values can be computed using the weighted linear combination method. This method involves evaluation at three levels as described in the analytic hierarchy process proposed by Saaty [67].

At the first level, the relative importance of each criterion, or factor, is evaluated against other criteria. Many studies have used expert-derived paired comparison for evaluating criteria [67, 79-82]. This method involves performing ratio estimates for each pair of criteria. The paired comparison method derives a weight for each criterion using criterion matrix of ratio estimates and their reciprocals as the input. Finally, the criterion weights are expressed in percentages, with the total equalling 100 percent or 1.0

At the second level, data for each criterion has to be standardized. A common method used for data standardization is the linear transformation. For example, the formula in equation 3 can convert interval data into a standardize scale of 0.0 to 1.0:

$$S_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \quad (4)$$

where S_i is the standardized value for the original value X_i, X_{min} is the lowest original value, and X_{max} is the highest original value.

At the third level, the index value is calculated for each unit area by summing the weighted criteria values and dividing the sum by the total of the weights as described in equation 4:

$$I = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \qquad (5)$$

where I is the index value, n is the number of criteria, w_i is the weight for criterion i, and x_i is the standardized value for criterion i [53].

Figure 3.9 shows a flow diagram of a sample for finding the best location for a school. The input base layers are land use, elevation, recreation sites, and existing schools. The derived datasets are slope, distance to recreation sites, and distance to existing schools. Each raster is then reclassified on a scale of 1 to 10. The reclassified rasters are added together with distance from recreation sites and other schools having higher weightage.

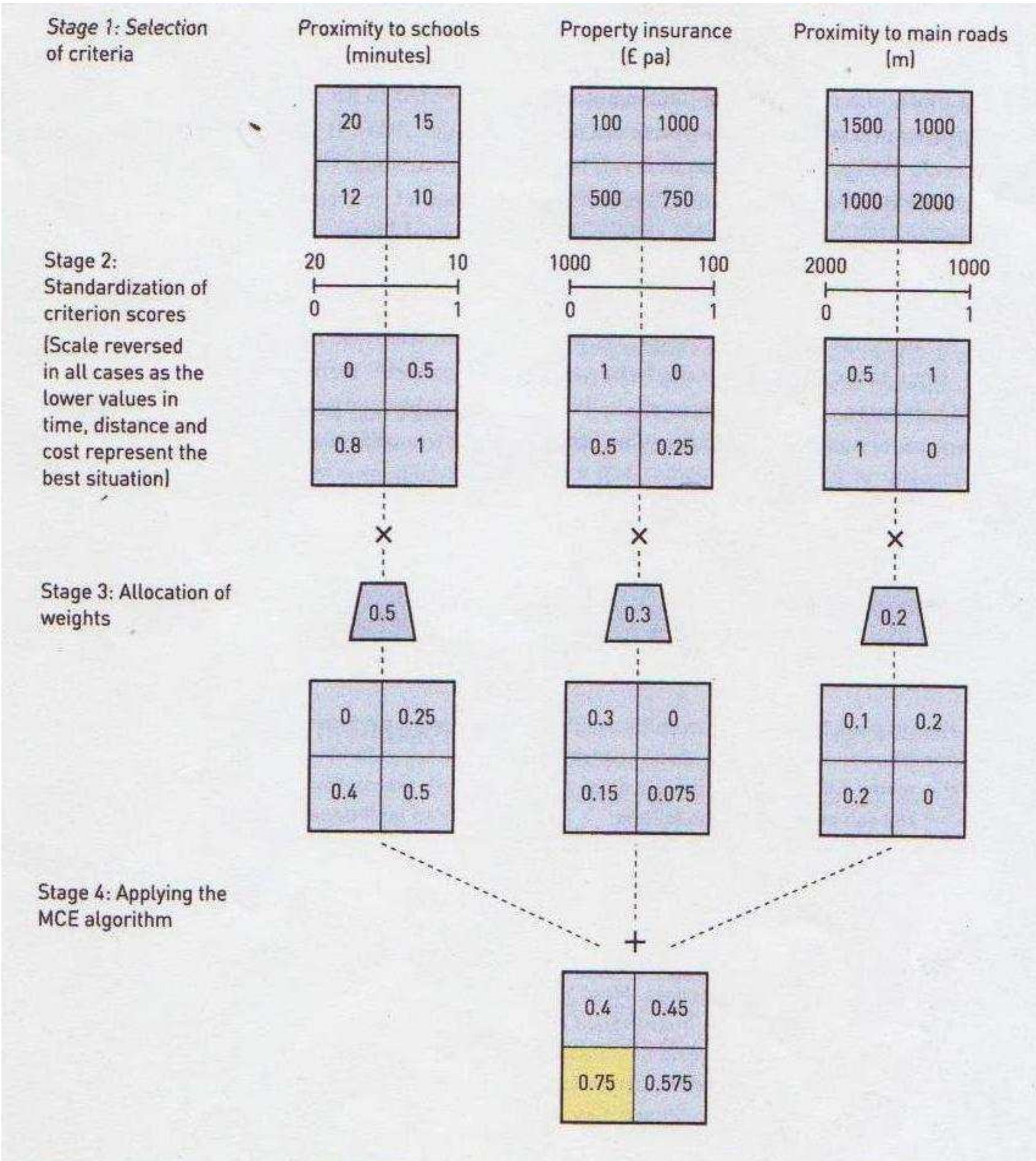


Figure 3.9 Applying a simple linear weighted summation model in raster GIS [83]

3.4 Spatial Sensitivity Analysis

In multi criteria decision analysis, *Sensitivity Analysis* is a process of ascertaining use for evaluating how sensitive the spatial multicriteria model output depends upon the small changes in the input values [65, 84]. The analysis provides insights into the robustness of the recommended solution.

Criterion weight and criterion (attribute) value are the two most important elements to consider in sensitivity analysis. Between the two of them, sensitivity attribute weight is perhaps more important. The method to do sensitivity analysis is by imposing some perturbation on the weights of criteria. We attempt to determine the degree to which the output of the added weighting procedure will change. Accordingly, a ± 0.1 perturbation to the weights is imposed and this is carried through the added weighting procedure. If there is a big change of priority ranking to the alternative criteria results, it means that the resultants indicate sensitivity of some areas to the weighting scheme. If the rankings remain unaffected as the weights are varied, errors in the estimation of attribute weights can be considered insignificant. If the ranking of alternatives proves to be sensitive to one or more weights, the accuracy in estimating weights should be examined carefully [65]. Sensitivity analysis is usually conducted via a series of test in which the modeller use different input values that vary around a central value within certain bounds to see how change in input causes a change in the model output [84].

3.5 Summary of Methodology

In the previous sub-section, we have identified several analysis tools including Descriptive analysis, Expert Choice 2000 and ArcGIS 9.3. In summary, there are five analyses stakeholder analysis, AHP, spatial multi-criteria decision analysis, sensitivity analysis, and network analysis as described in previous section. To perform these analyses, we require three analysis tools including Descriptive analysis, Expert Choice 2000 and ArcGIS 9.3. A description of several analyses, their importance/purpose and the available tools are summarized in Table 3.5.

Table 3.5 Analysis Tools

Analysis	Sub Analysis	Purpose	Tools
Stakeholder Analysis		To find stakeholders that are affected by the issue or whose activities strongly affect the issue of PFS siting	Descriptive Analysis
AHP		To rank the level of importance of each PFS siting criteria	Expert Choice 2000
Spatial Multicriteria Decision Analysis	Rasterization	To transform CAD form into a matrix of cells (or pixels) where each cell contains a value representing information	ArcGIS 9.3
	Euclidean Distance Analysis	To measure distance from every cell to the nearest source to get buffer result	ArcGIS 9.3
	Reclassification Analysis	To assign numeric values to classes with each map layer, so they have equal importance in determining the most suitable location	ArcGIS 9.3
	Weighted Overlay Analysis	To create one single rank map by assigning a weight influence based on its importance result from previous multi-criteria decision analysis	ArcGIS 9.3
Spatial Sensitivity Analysis		To evaluate how sensitive the spatial multicriteria model output is to small changes in input values	Expert Choice 2000

3.6 Software Determination of Analysis Tools

This research has three main phases; design of the suitability criteria, multicriteria decision analysis, and GIS modelling in spatial and network analysis with assistance from several software such as AutoCAD 2007, ArcGIS 9.3, and Expert choice 2000 which will be used collaboratively.

Physically, there are four possible modes to integrate GIS and multicriteria analysis tools: (i) no integration, (ii) loose integration, (iii) tight integration, (iv) full integration. This study is implementing loose integration strategy or loose coupling strategy whereas the integration of GIS software and a stand-alone multicriteria analysis software application is made possible by the use of intermediate system. The intermediate system permits the reformulation and restructuring of the data obtained from the overlapping analysis performed through GIS, and is converted into a form that is convenient to the multicriteria analysis software interface [62].

The integration of ArcGIS 9.3 and Expert Choice 2000 was developed using the loose coupling strategy. The integrated system has three components: a GIS module, MCDM module, and file exchange module. Expert Choice 2000 is an interactive computer program based on Analytic Hierarchy Process – AHP [67].The program uses the hierarchical structure of criteria and pair-wise comparisons among the criteria to establish criterion weights. The additional transformation function of the weighted summation approach is used to calculate a final score for each alternative. The size of decision problem accepted by Expert Choice has no limit. The DM's preferences on criteria are represented by cardinal weights [64].

3.7 Data Processing

Two set of data are required to perform spatial multicriteria decision analysis. First data set is the compilation of spatial data collection and the second data set is Analytical Hierarchy Process (AHP) data. The spatial data collection has been done through formal request to respective department and also self observed from Google Earth 2010. Meanwhile, the AHP data collection has been done through primary survey by distributing questionnaire form to the respective stakeholders.

The following are the list of spatial data which are required to perform spatial analysis:

1. Land use map
2. River map
3. High voltage electricity network map
4. Slope map
5. Road network map
6. Railway network map
7. Coastal area information
8. Hospital, school, and fire station location map

9. Groundwater map
10. Private well map

The data source is provided by Department of Housing and Urban Planning, Surabaya Municipality 2005 through formal request. All data are available on AutoCAD maps (dwg files). In addition, the projection used for this model simulation is WGS 1984 UTM Zone 49S. Unfortunately, several data such as groundwater and private well maps are unavailable due to no research have been done before. Nevertheless, since Surabaya does not use this water resource as drinking water so this condition does not give any effect to the result of this research. The questionnaire can be found at the appendix of this thesis.

Once the criteria for selecting PFS location are established, questionnaires utilized pairwise comparison method has been distributed to the city stakeholders. The stakeholders are selected using stakeholders analysis method and purposive sampling method. Thirteen questionnaires were distributed to selected stakeholders and being processed by Expertchoice 2000 software to obtain criteria suitability ranking. The questionnaire can be found at the attachment of this thesis.

After reclassification analysis the result of spatial analysis data processing will be integrated with the final result of AHP. The result of AHP is a list of weighting coefficient for each criteria which subsequently will be inputted into GIS weighted overlay analysis work sheet so weighted standardized criterion map can be resulted.

The sensitiveness of weighted standardized criterion map further will be tested using spatial sensitivity analysis method which is also utilizing Expertchoice 2000 software. By imposing some perturbation value on the weight of criteria, spatial changes might be occurred to the spatial model criteria output. If there is a big change of priority ranking to the alternative criteria results, it means that the resultants indicate sensitivity of some areas to the weighting scheme and should recheck the pairwise comparison result. If there is no significant changes for spatial model output, so the model can utilize further to evaluate the factual condition. The entire data processing is illustrated by diagram on Figure 3.10.

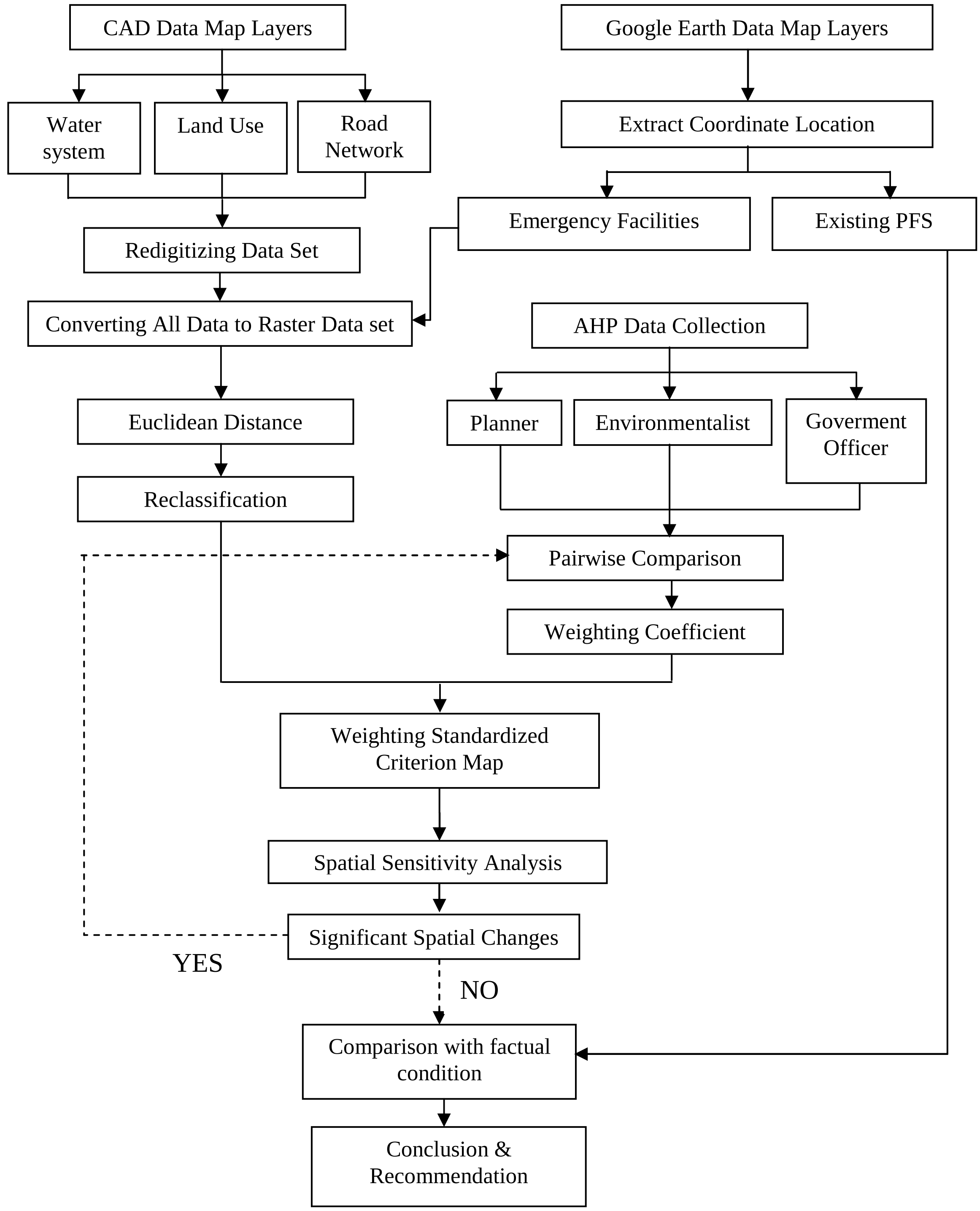


Figure 3.10 Data Processing

3.7.1 GIS Data Processing

As it has been mentioned above that, all data set are available in CAD therefore raw data needs to be converted into raster data set. Some of the data are in format compatible for importing to the GIS. However, some data map layers have to need additional processing before they can be incorporated. Table 3.6 shows the pre-processing data map layers to imported to ArcGIS.

Table 3.6 Pre-processing Data Map Layers

Thematic Data Map Layers	**Process (in biref)**
Distance to coastal	Redigitized from Land use map, imported into ArcGIS, projected, and rasterised using 30m cell size.
Distance to Rivers	Ready vector-line data from River data map, just need to be imported into ArcGIS, projected and rasterised.
Distance to residentials	Redigitized from Land use map, imported into ArcGIS, projected, and rasterised using 30m cell size.
Distance to hospitals and schools	Redigitized from Land use map, imported into ArcGIS, projected, and rasterised using 30m cell size.
Distance to High voltage overhead line network	Ready vector data from High voltage overhead line network data map, just need to be imported into ArcGIS, projected and rasterised.
Land availability	Ready vector-polygon data from Land availability data map, just need to be imported into ArcGIS, projected and rasterised.
Slope	Ready vector-polygon data from Slope data map, just need to be imported into ArcGIS, projected and rasterised.
Land use	Ready vector-polygon data from Land use data map, just need to be imported into ArcGIS, projected and rasterised.
Distance to Intersection	Redigitized from Road network map, imported into ArcGIS, projected, and rasterised using 30m cell size.

Thematic Data Map Layers	Process (in biref)
Distance to road	Ready vector-line data from road network data map, just need to be imported into ArcGIS, projected and rasterised.
Distance to grade crossing	Ready vector-line data from road network data map, just need to be imported into ArcGIS, projected and rasterised.
Distance from Fire Station	Obtained coordinate point of fire station location from Google earth using open source software “Zonum Solutions” then converted kml file to shp file, imported the shape file to ArcGIS then projected.
Distance from Hospital	Obtained coordinate point of hospital location from Google earth using open source software “Zonum Solutions” then converted kml file to shp file, imported the shape file to ArcGIS then projected.

The basic data pre-processing has been explained on table 3.6. First, it needs to create a new personal geodatabase by ArcCatalog in the ArcGIS 9.3 software. Secondly, it imports the original CAD map to geodatabase to generate shape file. All CAD data should be converted into raster so that they can be incorporated with another data set. All data sets should be rasterized in a specified cell size which, in the case of this research, is 30m by 30m.This procedure of setting all CAD data into raster data set is called data pre-processing.

Once all data map layers are in shape file format, it is ready to be proceed further in ArcGIS using analysis tools such as raster tools, Euclidean analysis tools, reclassification tools, and weighted overlay tools. Each data map layers have different step of processing way like what have been explained in Table 3.7.

Table 3.7 Processing Data Map Layers in ArcGIS

Data Map Layers	**Feature Type**	**Attribute**	**Process in ArcGIS**
Distance to coastal	Line	Length	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Distance to Rivers	Line	Length	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Distance to residential	Line	Area	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Distance to hospitals and schools	Polygon	Area	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Distance to High voltage overhead line network	Line	Length	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Land availability	Polygon	Area	Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Slope	Polygon	Area	Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Land use	Polygon	Area	Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Distance to Intersection	Point	Name	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Distance to road	Line	Length	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay

Data Map Layers	Feature Type	Attribute	Process in ArcGIS
Distance to grade crossing	Line	Length	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Distance from Fire Station	Point	Name	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay
Distance from Hospital	Point	Name	Rasterization ➔ Euclidean Distance ➔ Reclassification ➔ Weighted Overlay

Figure 3.11 shows the data collection arrangement in ArcCatalog and ArcMap using ArcGIS 9.3

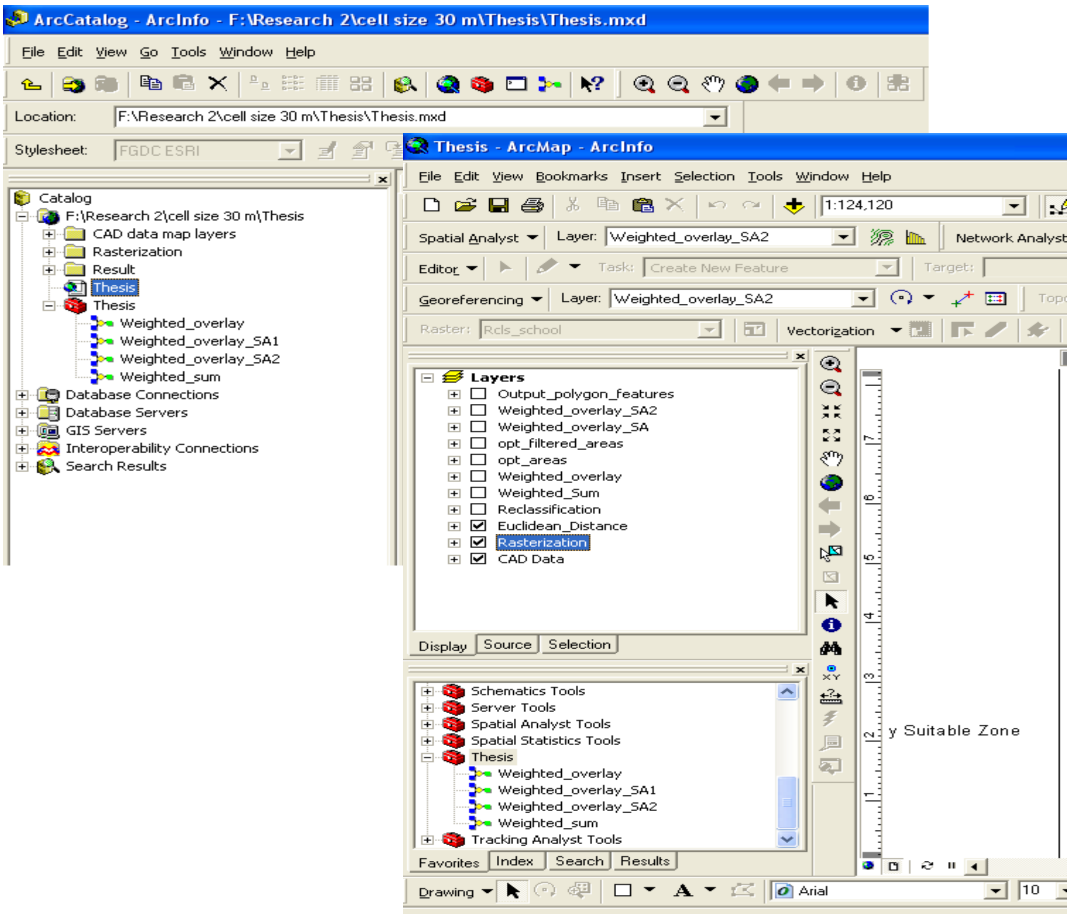


Figure 3.11 Data Collection Arrangement in ArcCatalog and ArcMap

3.7.2 AHP Data Processing

Once we collect back the questionnaire, we create the AHP hierarchy model which contains goal, objective, and attribute. The AHP hierarchy model is shown on Figure 3.12. This hierarchy model has been inputted to Expertchoice 2000 together along with the nine degree scale comparison result onto pairwise comparison worksheet. There should be two value comparison resulted, first is comparison value between the objective with respect to goal. Second, is comparison value between attribute with respect to objective.

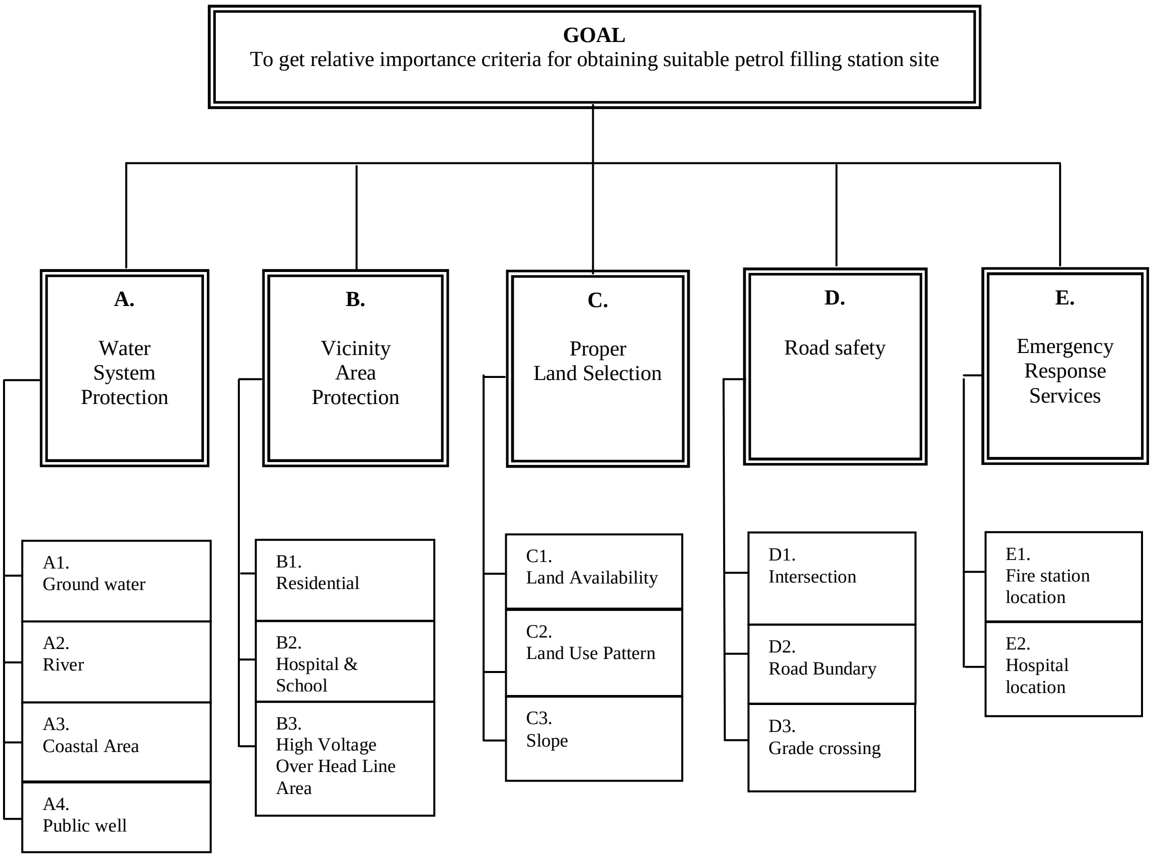


Figure 3.12 Analytical Hierarchy Process (AHP) Hierarchy Model

Figure 3.13 shows the nine degree scale pairwise comparison matrix. By dragging the grey bar under the range of nine degree scale value, the respected value according to stake holder preference could be inputted to the pairwise comparison matrix.

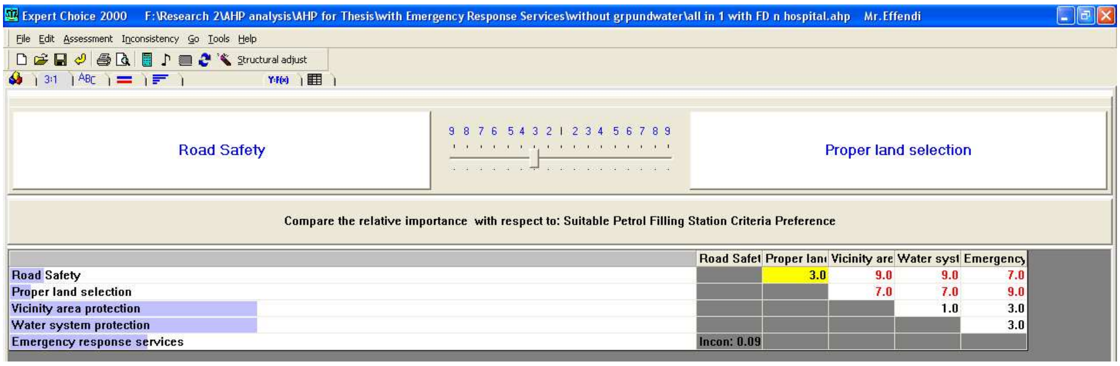


Figure 3.13 The Nine-degree Scale Pairwise Comparison Matrix

Figure 3.14 shows the priorities preferences of objective with respect to goal. The road safety yielded 0.047 of total preference. It means that the road safety criteria only have 4.6% preference value compare to total criteria value. This figure also shows that the consistency ratio of this matrix is 0.09 which is less than equal to 0.1 (CR ≤ 0.1). It means that the ratio indicates a reasonable level of consistency in the pair-wise comparisons.

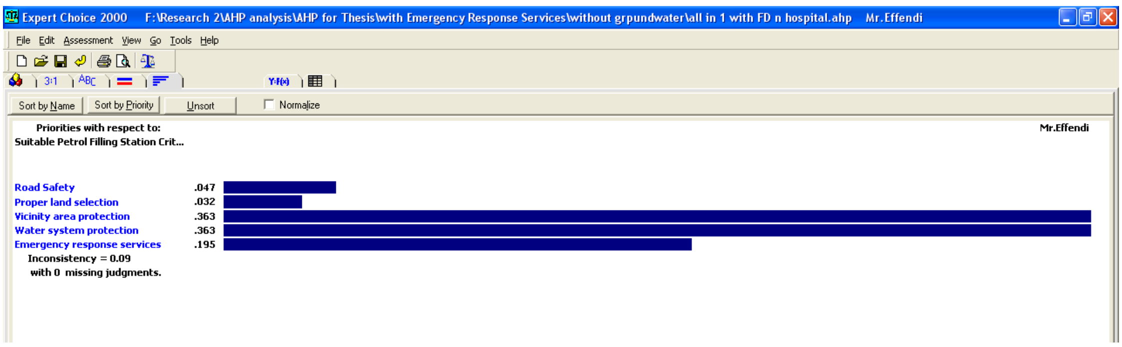


Figure 3.14 The Priorities Preferences of Objective with Respect to Goal

3.7.3 Spatial Sensitivity Data Processing

As it has been mentioned before that, the spatial multicriteria model output should be evaluated by the spatial sensitivity analysis to check its sensitivity to small changes in input value. By imposing some perturbation value (a ± 10%) to the weights of criteria, the priority ranking of alternatives might be changed. If there is a big change of priority ranking to the alternative criteria results, it means that the resultants indicate sensitivity of some areas to the weighting scheme. If the rankings remain unaffected as the weights are varied, errors in the estimation of attribute weights can be considered insignificant. The changing of criteria weight due to the imposed of perturbation value will be used to determine the weight of alternative using dynamic sensitivity analysis. Table 3.8 shows how the perturbation value as much as ± 10% to the weight of criteria can change the alternative ranking.

Table 3.8 The Result of ± 10% Perturbation to The Weight of Criteria

No.	Alternative	%	MDTAR (a)		PLU (b)		PVA (c)		PWS (d)		ER (e)	
			(a +10%)	(a -10%)	(b +10%)	(b -10%)	(c +10%)	(c -10%)	(d +10%)	(d -10%)	(e +10%)	(e -10%)
1	Land use pattern	**.... (1)**	**.... (2)**	.... (1)	.... (1)	.... (1)	.... (1)	.... (1)	**.... (3)**	.... (1)	.... (1)	.... (1)
2	Distance to river	**.... (3)**	.... (3)	**.... (4)**	**.... (5)**	.... (3)	.... (3)	.... (3)	**.... (1)**	.... (3)	.... (3)	.... (3)
3	Distance to residential	**... (6)**	**... (7)**	... (6)	... (6)	**... (4)**	... (6)	**... (7)**	... (6)	... (6)	... (6)	... (6)
4	Distance to school	**... (5)**	... (5)	... (5)	**... (3)**	... (5)	... (5)	... (5)	... (5)	... (5)	**... (4)**	... (5)
5	Distance to high voltage area	**... (7)**	**... (6)**	... (7)	... (7)	... (7)	... (7)	**... (6)**	**... (13)**	... (7)	... (7)	... (7)
6	Land availability	**... (4)**	... (4)	**... (3)**	... (4)	**... (6)**	... (4)	... (4)	... (4)	... (4)	**... (5)**	... (4)
7	Distance to railway	**... (9)**	... (9)	**... (10)**	... (9)	... (9)	**... (10)**	... (9)	... (9)	**... (11)**	... (9)	**... (11)**
8	Distance to intersection	**... (10)**	... (10)	**... (9)**	... (10)	... (10)	**... (9)**	**... (12)**	... (10)	... (10)	... (10)	... (10)
9	Distance to road boundary	**... (12)**	... (12)	... (12)	... (12)	... (12)	... (12)	**... (10)**	... (12)	... (12)	... (12)	... (12)
10	Slope	**... (11)**	... (11)	... (11)	... (11)	... (11)	... (11)	... (11)	... (11)	**... (9)**	... (11)	**... (9)**
11	Distance to coastal Line	**... (13)**	... (13)	... (13)	... (13)	... (13)	... (13)	... (13)	**... (7)**	... (13)	... (13)	... (13)
12	Distance to fire station	**... (2)**	**... (1)**	... (2)	... (2)	... (2)	... (2)	... (2)	... (2)	... (2)	... (2)	... (2)
13	Distance to hospital	... (8)	... (8)	... (8)	... (8)	... (8)	... (8)	... (8)	... (8)	... (8)	... (8)	... (8)

Dynamic Sensitivity analysis is used to dynamically change the priorities of the objectives to determine how these changes affect the priorities of the alternative choices. In Figure 3.15 by dragging the objective's priorities back and forth in the left column, the priorities of the alternatives will change in the right column. If a decision-maker thinks an objective might be more or less important than originally indicated, the decision-maker can drag that objective's bar to the right or left to increase or decrease the objective's priority and see the impact on alternatives.

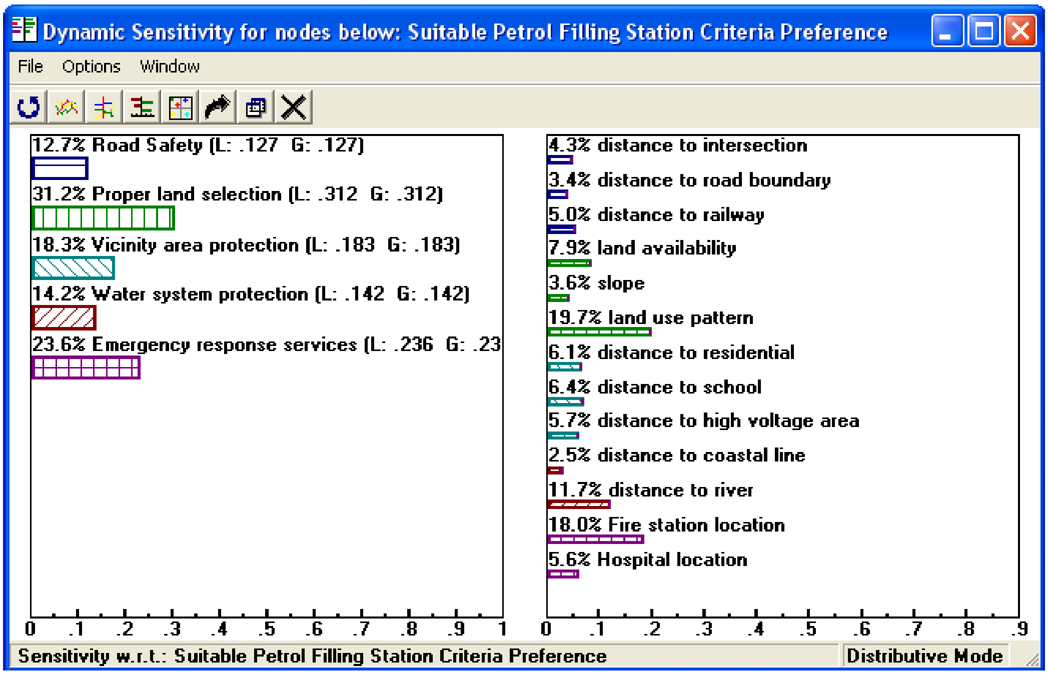


Figure 3.15 Dynamic Sensitivity Analysis

Any changes of alternative priorities in dynamic sensitivity analysis should be recorded on table of perturbation. Once it has been recorded, the changing of alternative ranking could be observed. Focus only to extreme changes of alternative ranking, for example for at the first place A alternative got first ranking then suddenly drop to fifth ranking then spatial analysis is needed to evaluate further. By inputting new alternative priorities into influence column in weighted overlay analysis work sheet at ArcGIS 9.3 software, the new spatial model output resulted.

If the new spatial model outcome indicates significant changes compare to the previous one, it means that spatial sensitivity analysis indicates that alternative priorities ranking is not robust. In this case, we have to recheck the pairwise comparison matrix. Figure 3.16 shows the weighted overlay work sheet to input new alternative priorities resulted by dynamics sensitivity into influence column.

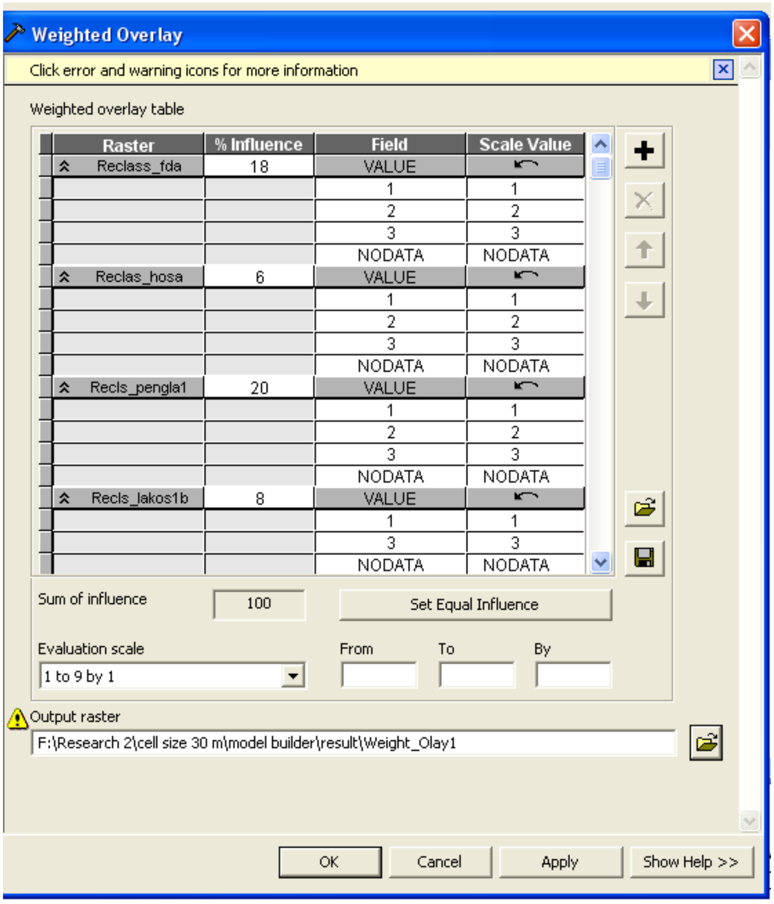


Figure 3.16 Weighted Overlay Work Sheet to Input the New Alternative Priorities

CHAPTER 4

CASE STUDY OF SURABAYA METROPOLITAN

4.1 Study Area: Surabaya Metropolitan

In geographic context, Surabaya is located between 112°30 ’ to 113° E longitude and 7°0’ to 7°30’S latitude. It has quite vast area of 327.41 km^2 and is divided into 31 districts. Surabaya is a seaport city which is supported by the existence of Madura Straits lying in the west part of the city [85].

As the second largest city in Indonesia, Surabaya plays an important role for the development of the eastern part of Indonesia. The main economic activities are manufacturing and trading which utilize major air and seaport facilities. The presence of the seaport generates an economic chain which influences the economic growth in the eastern part of Indonesia.

4.1.1 Physical Characteristic

In this section, the physical characteristics of the Surabaya Metropolitan are discussed. The Physical characteristics discussed are topography, land use and the water system.

<u>Topography</u>

The topography of Surabaya is divided into two areas: the lowland plain and the rolling plain [85]. The southern, eastern, and northern parts of the city have lowland plain areas which have elevations up to 5m above the tide level and prevailing slopes are within 0-2%. The western part of the city is considered as mostly rolling plain area. The elevation in these rolling plain areas reach more than 5m above low tide level and the prevailing slope is within 2-15%. Due to this natural condition, the most inundated areas in Surabaya are the Eastern and Northern part.

Land Use

The dominant land use in Surabaya is residential and commercial areas [85]. The remaining area is occupied by industrial, office, public facilities, green open space, and fish pond areas. Previously, the urban area is scattered in the southern and northern parts of the city. Nowadays, the urban development is expanding to the western and eastern parts of the city as well. In 2001, the city made up 63% of the land area in Surabaya.

Water System

Rivers: The Wonokromo River and the Mas River are the two main rivers that divide the city of Surabaya [85]. Mas River flows northwards through downtown and ends at the End of Ujung Perak (Madura Strait.) While Wonokromo River flows eastwards but also ends into Madura Strait.

Ground Water: Surabaya does not have enough ground water reservoirs that can be used as a clean water resource [85]. Three types of ground water that can be found are scattered productive aquifer area, the unproductive aquifer area, and scarce ground water area. The scattered productive aquifer area is in the northern, central, south, east and west of Surabaya. The unproductive aquifer area is in the west and south of Surabaya. While the scarce ground water area ranges from the west to the southern part of the city of Surabaya.

Coastal: Coastal area encompasses Northside and Eastside of Surabaya. By the ecological condition, the coastal area in The Eastside is a preserved area which includes areas of the coastline, river, and mangrove. In general, the thickness of the mangrove vegetation in this area ranges between 5-10 meters with the dominant mangrove species being Avicennia, Sonneratia and Rhizophora [85].

4.1.2 Review of the Legislation Procedure of Petrol Filling Station Site Permit

Only two regulations have been found to govern the permission for PFS establishment. Based on the Minister of Energy and Mineral Resources regulation 1454 k/30/mem/2000 governing technical guidelines for the application and approval to build PFSs, only a general requirement must be fulfilled such as: company profile, location map, data of storage capacity, data of distribution estimation, inventory of equipment and facilities used, and recommendation from PERTAMINA. PERTAMINA is an Indonesian government-owned corporation which extracts and refines the country's oil and gas reserves. No requirement is mentioned in detail regarding environmental considerations.

Recommendation from PERTAMINA will be given once the applicant fulfils several requirements such as follows:

1. The minimum width for PFS site is 1,000 m^2.
2. The minimum distance between building and plot boundary is 3 m.
3. The minimum distance between road and pump island are based on transportation impact assessment.
4. The distance between the PFS to another PFS is determined by the turnover of 20 or 30 Kilo Litre.
5. The minimum distance of the underground storage tank to the surface is 1 m. The minimum distance between UST's location with another is 1 m.
6. The minimum distance between UST with the main hole is undetermined, as long as the gravity flow of fuel remains smooth.
7. The distance between pump island and the building(s) on the PFS site is based on vehicle manoeuvrability inside the site.
8. Shape and size of the pump island depend on the pump model used.
10. The PFS site must be equipped with a fire extinguisher. Types used are fire extinguishers with powder. In addition, managers must provide sand filling stations in the area of the site.
11. The location of the site must have adequate lighting. Types of lighting used are Highlight, Glamox, Mini 300, and T5 (80 Watt lamps).
12. All building materials of the PFS should be of fire resistant materials.

4.1.3 The Petrol Filling Station Growth in Surabaya

The total numbers of PFSs that have been built in Surabaya are 104. From those total numbers, 86.5% have been operational and 13.46% PFSs are still waiting for permission to begin operations. Most of these PFS are located at East Surabaya. Table 4.1 shows that the number of PFS in Surabaya falls into two categories they are operational and yet to be operational.

Table 4.1 Recapitulation of The Number of PFSs in Surabaya [86]

No	Region	Number Per Site		
		Operational	Yet to be operational	Total
1	East Surabaya	27	3	30
2	West Surabaya	16	3	19
3	Central Surabaya	14	2	16
4	South Surabaya	16	3	19
5	North Surabaya	17	3	20
	Total	90	14	104
	Percentage (%)	86.54	13.46	100.00

By the help of Google Earth 2010 and open source software Zonum Solutions, the coordinate location of those 90 PFSs can be detected. Figure 4.1 shows the distribution of existing PFSs in Surabaya according to coordinate points recorded from Google Earth 2010.

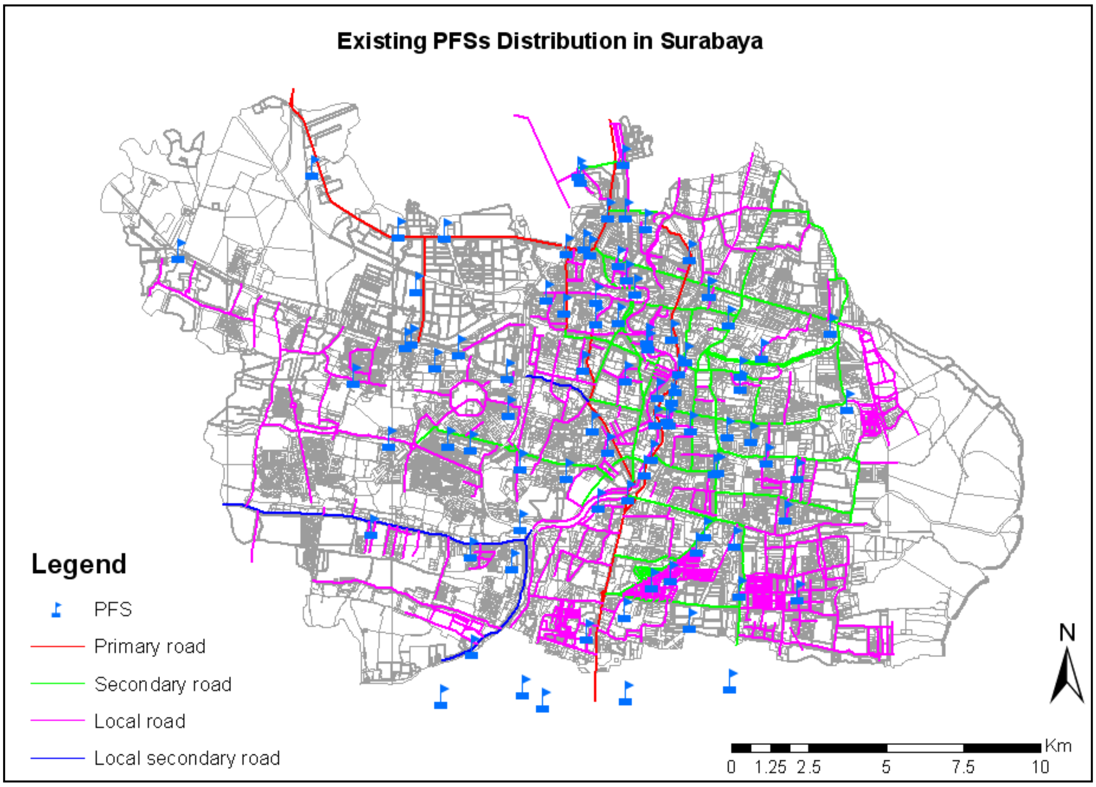


Figure 4.1 Existing PFSs Distribution in Surabaya City

4.1.4 Problem in Vicinity of Petrol Filling Station

Since no technical regulations that consider environmental safe are specified, many PFSs are built adjacent to residential areas. Furthermore, to capitalize on the economic benefits, many owners built their PFSs close to one another at the same strategic sites. This has lead to a situation where so many PFSs are clustered in one particular area. When PFSs are sited close to each other it will generate several problems such as congestions and domino effect in case fire accidents were to occur.

The following are problems existing in area being studied based on the initial survey:

<u>Location</u>

Most PFSs are located near to residential areas. This has led to many complaints from communities that live around the PFSs. The most common problems are noise, traffic congestion, and fear of fire hazard in case of fire or explosion.

Traffic

The location of PFSs near to junctions or crossings may lead to the collision of vehicles on the access road and vehicles passing in and out of PFS sites. PFSs that are located near main roads are more likely to cause traffic congestions as the access and egress activities to and from PFSs are interfered by passing vehicles on the main road. The location of PFS near grade crossings also will lead to accidents for vehicles that will access PFS.

Fire and explosion hazards

Residents living near PFSs are very concerned with the risk of fire occurrences or explosion hazard, whether caused by mishap in the storage system and/or fuel distribution. Furthermore, the existence of High Voltage Overhead Line is feared to generate static electricity that can cause fires.

4.2 Stakeholder Analysis for AHP

Four stakeholders are identified as having importance and influence in determining PFS sites. The stakeholders are urban planners, environmentalists, local government, and local residents. Each of them has different levels of importance and influence depending on how their interests and activities are affected by or affect the issue. Table 4.2 shows the identification of importance and influence for each stakeholder for determining PFS location issue.

Table 4.2 Stakeholder Analysis Matrix

Stakeholders	Importance	Influence
Planner	Planner as city consultant will work with government to design spatial plan for city development.	Planner can determine suitable site for PFS based on location criteria.

Stakeholders	Importance	Influence
Environmentalist	Environmentalist would oversee the preservation of the city's environment.	Environmentalist is just able to give recommendations to the government about PFS that might pose environmental hazard.
Local Government Officer	Local government has authority to give site permit for PFS.	Local government is able to push many parties to investigate the suitability of a PFS location.
Local Residential	Local resident can only voice out their opinions about the conditions they perceive from living near to PFS at the time of the environmental assessment.	Residents do not aware about PFS environmental issue and do not have adequate knowledge to give justification for PFS location.

4.2.1 Planner

Five urban planners were invited to the group discussion. This group provided the most vivid discussion, mostly about the potential of locating PFS sites in safe areas since it is one of city infrastructure when it is misplaced can lead to traffic congestions and other hazards. Overall, the group accepted that problems exist in the PFS sitings because systematic planning is almost non-existent and no environmental consideration was taken as the basis of a suitable analysis. Therefore, the urban planners had the responsibility to solve these problems by planning suitable locations for PFSs. They later acknowledged that in previous years they had seen that land used was unsuitable for PFS because it is located very near to the access road, some of them located near to grade crossings, coastal lines, high density residential areas and other sensitive facilities such as schools and hospitals. Planners as city consultants work with the local government to design spatial plan for the city's development. Hence, the planners can determine suitable sites for PFS based on location criteria.

4.2.2 Environmentalist

The group of environmentalists interviewed comprised of four individuals. They were mostly concerned about the hazards of PFS such as ground and surface water contamination, soil contamination, air pollution, and danger of explosion. As such, a new suitable location analysis of PFSs should be determined by considering the existence of surface and ground water, appropriate slope and land use. Concerns were also expressed about the conflicts between economic benefits and ecological benefits. This conflict will arise in a situation where the only strategic location for a PFS is also the most environmentally fragile (e.g. close to a ground water source). Environmentalists are obliged to keep their eyes on the city's environment. However, environmentalists are only able to give advice to the government about PFS that might pose the environmental hazards of PFS locations. Without any clear policy as guidelines, the voices of the environmentalists will only fall on deaf ears.

4.2.3 Local Government Officer

This group is represented by four officers. Overall, the group admitted that there is no detailed criterion for PFS site selection especially one that is specifically addresses environmental safe. At the present time, the only requirement the applicant has to meet is the PFS cannot be built on green open space areas. The other requirements are based on PERTAMINA's recommendations. Once the applicants complete the requirement provided by PERTAMINA, the location permit can be processed. As such, this group of officers are looking forward to this research to outline the requirements for a suitable location especially one that includes the criteria for environmental safe since the hazard of PFS is real and inevitable. However, they were also concerned that a healthy balanced between economic benefits and ecological benefits will not be considered in future plans, since PFS not only poses a risk to the environment but also plays an important role for city revenue. Even though the local government has authority to give site permit for PFS they are also able to push many parties to investigate the suitable place for PFS.

4.2.4 Local Resident

The group of residents generally said that PFS played an important role in transportation aspect but some of the existing PFS locations possibly pose hazards to the environment, especially for those located very near to residential areas or any other sensitive facilities such as hospitals and schools. They are worried that in the event of an explosion, for example, will damage the environment and even worse will cause the loss of lives. However, they felt it was not their responsibility to talk to PFS owners. In their opinion, that is the responsibility of the local government officials. Local residents believe that their opinions should be considered during the environmental assessment prior to the approval of a PFS site.

Figure 4.2 clearly shows that local government officers are the party that strongly affect the issue. Government officers have high influence and high importance to determine where PFSs should be sited.

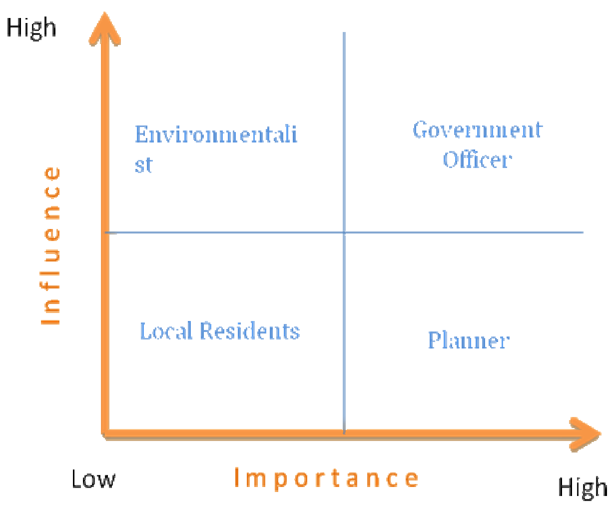


Figure 4.2 Stakeholder Matrix

4.3 Weighted Comparison Analysis Result

As previously explained, several stakeholders are involved in the decision regarding the criteria ranking. Those who are involved are those who have significant contribution for determining PFS sites. They are urban planners, environmentalists, and local government officers. As such, the original thirteen stakeholders including five urban planners, four environmentalists, and four local government officials were invited to make the pair-wise comparison according to a nine-degree comparison scale. Residents were excluded in this invitation mainly because of their low influence and low importance in the stakeholder matrix, which would make it difficult for them to use the nine-degree scale to make the pair-wise comparison between the suitability factors.

The hierarchical structure consist of three levels: goal, objective, and attributes [67]. In this research, the goal is the site suitability PFS criteria ranking preferences. The considered objectives to reach the goal are water system protection, vicinity area protection, proper land selection, access road selection, and emergency response services. Firstly, we create the pairwise comparison matrix by each group of stakeholders to examine the preference of each group. Secondly, we combine the entire pairwise comparison matrix to obtain the final preference of PFS suitability criteria based on all stakeholders perspective.

4.3.1 Urban Planner

Five urban planners were invited to the group discussion. Most of them deplored the location of PFS that are located in residential zone and nearby sensitive facilities such as schools and hospitals. The existing PFSs tend to be unevenly distributed and in some cases too close to each other. One of the urban planners suggested that the scale and area or the size of the petrol station should be proportionate to the size of the road since traffic is one of main considerations in selecting a suitable site. On the other hand, high voltage overhead line areas should be also considered as dangerous due to the increased risk of static electricity accident.

Referring to AHP model hierarchy, the comparison value between attribute with respect to objective is called as Local (L) comparison. Meanwhile, the comparison value between attribute with respect to goal is called as Global (G) comparison. For attribute, the L value is indicated the comparison value of attributes with respect to objective which have total value "1". Meanwhile the G value is indicated the comparison value of attributes with respect to goal which also have total value "1" or same with the G value of objectives.

Figure 4.3 shows the pair-wise comparison of suitability criteria based on the urban planners' perspectives. Based on pairwise numerical comparisons, proper land selection is the most important criteria for suitable PFS location determination with a weightage of 0.325. The other criteria such as emergency service response facility, access road selection, vicinity area protection, and water system protection have weightages of 0.209, 0.188, 0.177, and 0.101 respectively.

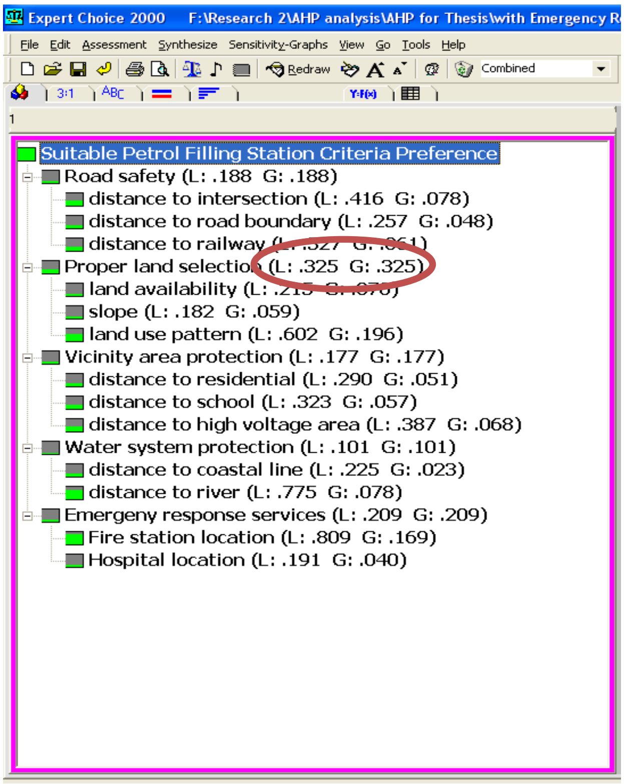


Figure 4.3 Pairwise Comparison of PFS for Urban Planners' Perspective

The consistency ratio (CR) is designed in such a way that if CR < 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparison; if, however, CR ≥ 0.10, the values of the ratio are indicative of inconsistent judgments [4]. The urban planners' pairwise numerical comparison for PFS suitability criteria shows an consistency ratio of 0.03. This means that their judgment for criteria weighting is consistent. Meanwhile, the priorities preference like what is seen in Figure 4.4 shows that land use pattern, fire station location, and distance to intersection are the top three most important criteria that have to be considered as determined by the urban planners for the PFS location selection.

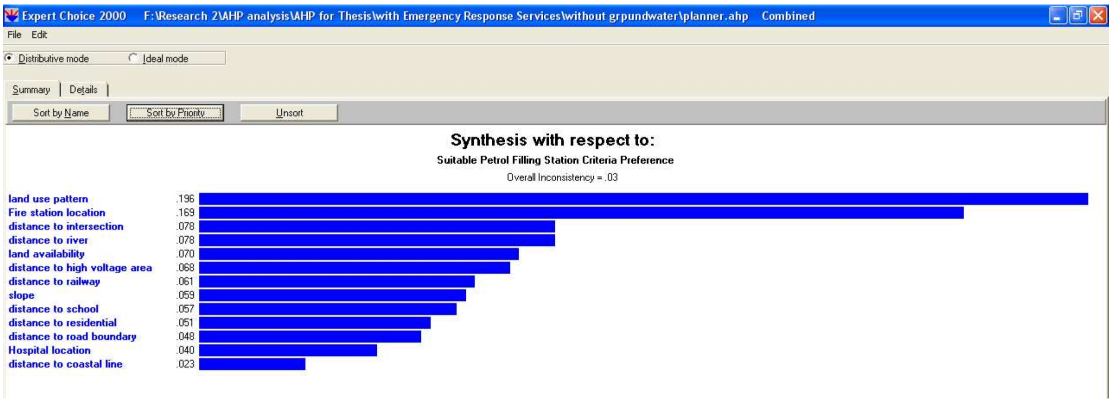


Figure 4.4 Priorities Preference of PFS for Urban Planners' Perspective

4.3.2 Local Government Officer

The group of local government officers comprised of four individuals. Most of them are concerned about the possibility of USTs leakage which can contaminate soil and water. Moreover, the existing condition that depicts the close proximity of residential areas to PFSs are the most obvious threat should any mishap happen.

Figure 4.5 shows the pair-wise comparison of suitability criteria based on local government officers' perspectives. Based on the pairwise numerical comparisons, proper land selection is the most important criteria for suitable PFS location determination with a weight of 0.311. The other criteria such as emergency response service facility, vicinity area protection, water system protection, and access road selection have weightages of 0.181, 0.175, 0.174, and 0.159 respectively.

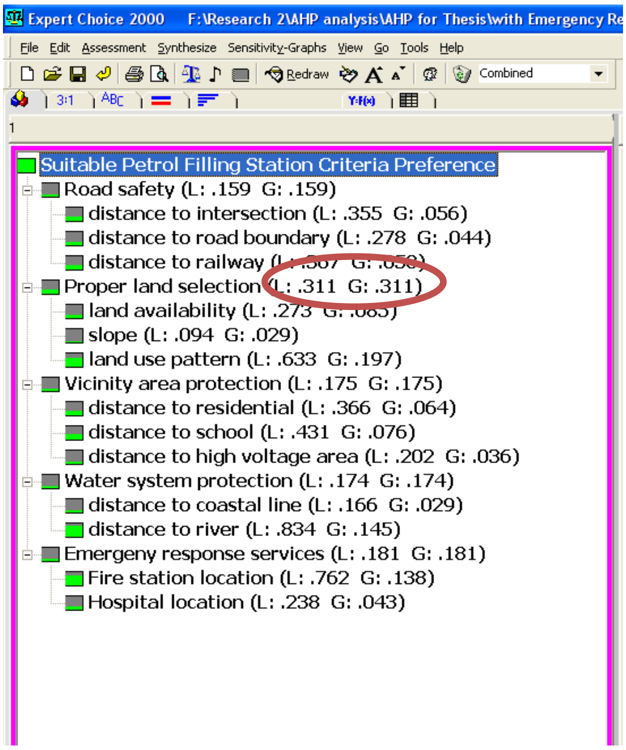


Figure 4.5 Pairwise Comparison of PFS for Local Government Officers' Perspective

The local government officers' pairwise numerical comparison for PFS suitability criteria shows consistency ratio of 0.01. This means that their judgment for criteria weighting is consistent. Meanwhile, the priorities preference seen in Figure 4.6 describes that land use, distance to river, and fire station location are the top three most important criteria that have to be considered for PFS location as determined by local government officers.

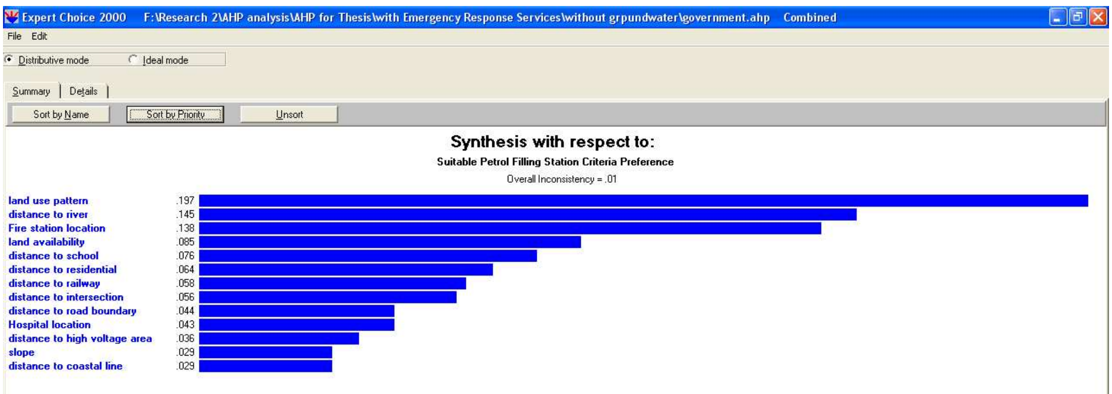


Figure 4.6 Priorities Preference of PFS for Local Government Officers' Perspective

4.3.3 Environmentalist

This group comprised of four individuals. The environmentalists strongly disagree with PFSs that are situated very close to residential areas. One of the main activities within residential areas is cooking which involves the use of fire. Therefore, this brings fear for residents should in any case open flame happens and causes an explosion to the next door PFS. On another hand, the existence of high voltage overhead lines within close proximity to the PFS also causes concern to the residents' safe.

Figure 4.7 shows that the pair-wise comparison of suitability criteria based on the environmentalists' perspectives. Based on the pairwise numerical comparisons, emergency service facility is the most important criteria for suitable PFS location determination with a weight of 0.324. The other criteria such as proper land selection, vicinity area protection, water system protection, and access road selection have weights of 0.273, 0.183, 0.163, and 0.057 respectively.

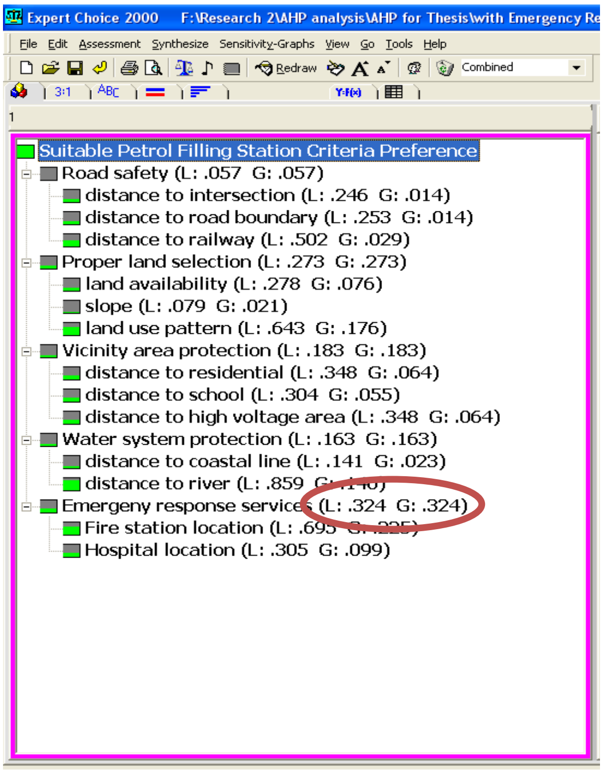


Figure 4.7 Pairwise Comparison of PFS for Environmentalists' Perspective

The pairwise numerical comparison for PFS suitability criteria based on the perspective of the environmentalists shows consistency ratio of 0.01. This means that their judgment for criteria weighting is consistent. Meanwhile, the priorities preference, as shows in Figure 4.8, describes that fire station location, land use, and distance to river are the top three most important criteria that have to be considered for determining PFS locations chosen by the environmentalists.

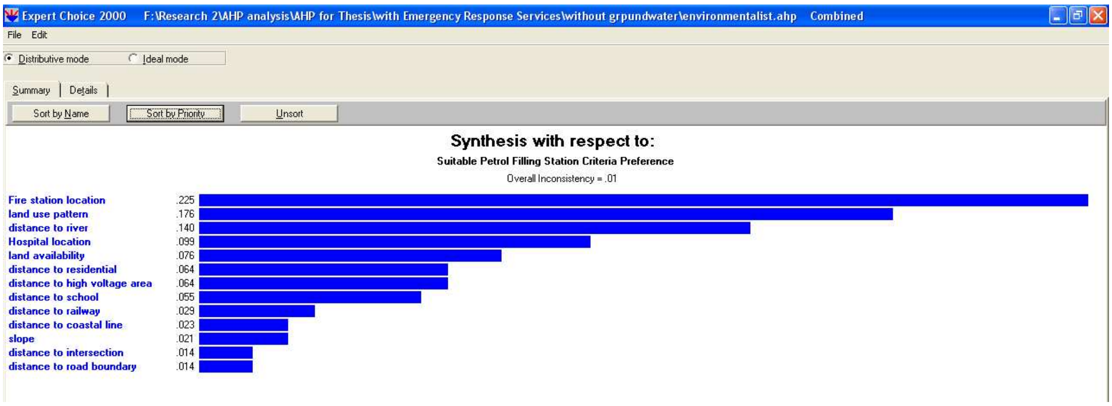


Figure 4.8 Priorities Preference of PFS for Environmentalists' Perspective

4.3.4 Summary Overall

This study has shown that among all the stakeholders, land use is the most important criteria compared to other criteria. PFS is one of the city's commercial infrastructures that should be placed in commercial zones and have safe distances to residential areas and other sensitive facilities. Moreover, fire hazards or even explosion is the most obvious threat that should be taken into account by considering the nearest emergency response facility (such as fire department and hospital) should accidents happen.

Figure 4.9 shows the pair-wise comparison of suitability criteria based on every stakeholder's perspective. Based on pairwise numerical comparisons, proper land selection is the most important criteria for suitable PFS location determination with a weight of 0.312. The other criteria such as emergency response service facility, vicinity area protection, water system protection, and access road selection have weightings of 0.236, 0.183, 0.142, and 0.127 respectively.

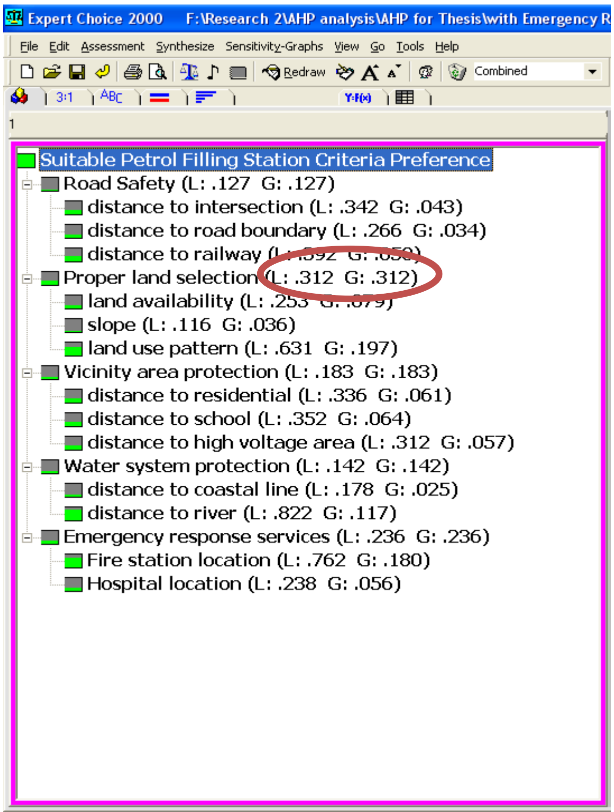


Figure 4.9 Pairwise Comparison of PFS for Overall Perspective

Meanwhile, the priorities preference shown in Figure 4.10 shows that land use, fire station location, and distance to rivers are the top three most important criteria that have been chosen as consideration for the PFS location by all stakeholder. Based on priority preference for PFS siting criteria land use criteria yielded an 19.7% influence to the priority preference of desirable locations. This is the highest influence compared to other criteria.

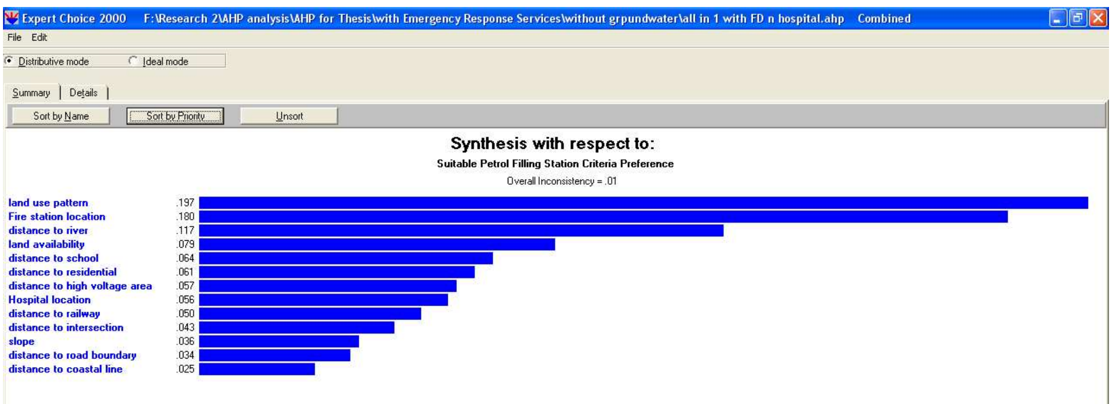


Figure 4.10 Priorities Preference of PFS Criteria for Overall Perspective

The pairwise numerical comparison for PFS suitability criteria on the perspective of overall stakeholders shows consistency ratio (CR) is 0.01. This means that their judgement for criteria weighting is consistent.

4.4 PFS Site Candidates Selection and Result

The summary of chapter two outlined several criteria that are used to determine or to select suitable sites of PFSs. These criteria focus on the protection of the environment from the hazards associated with PFSs such as water system protection, vicinity area protection, road safety, and proper land selection.

4.4.1 The PFS Site Suitability Criteria Implementation

This sub chapter not only explains about each criterion but also the minimum requirement of each of the criteria, such as the minimum requirement of safe distance.

a. Water system protection

Protecting the water system is one of the criteria that aim to protect surface and groundwater from the possibility of UST leakage. The examples of surface water are rivers, lakes, and private/public wells. In some other case, USTs near coastal areas had been experiencing leakages as well due to corrosion by the intrusion of sea water. As such, coastal line is taken into consideration as one of criteria for protecting water system. In this research, the availability of data is somehow limited because data for groundwater and private/public well are unavailable.

Figure 4.11 shows the rasterization figure from previous coastal line CAD data set. Once all data set had been rasterized, a minimum requirement measurement is set as the implementation of safe distance, which is depicted as straight lines from the designated cells. These straight lines essentially buffers the source cells with wavelike continuous distances over the entire raster or to a specified maximum distance [53].

For protecting water system the minimum requirement for coastal line is 3,250 feet and a minimum 500 feet from rivers.

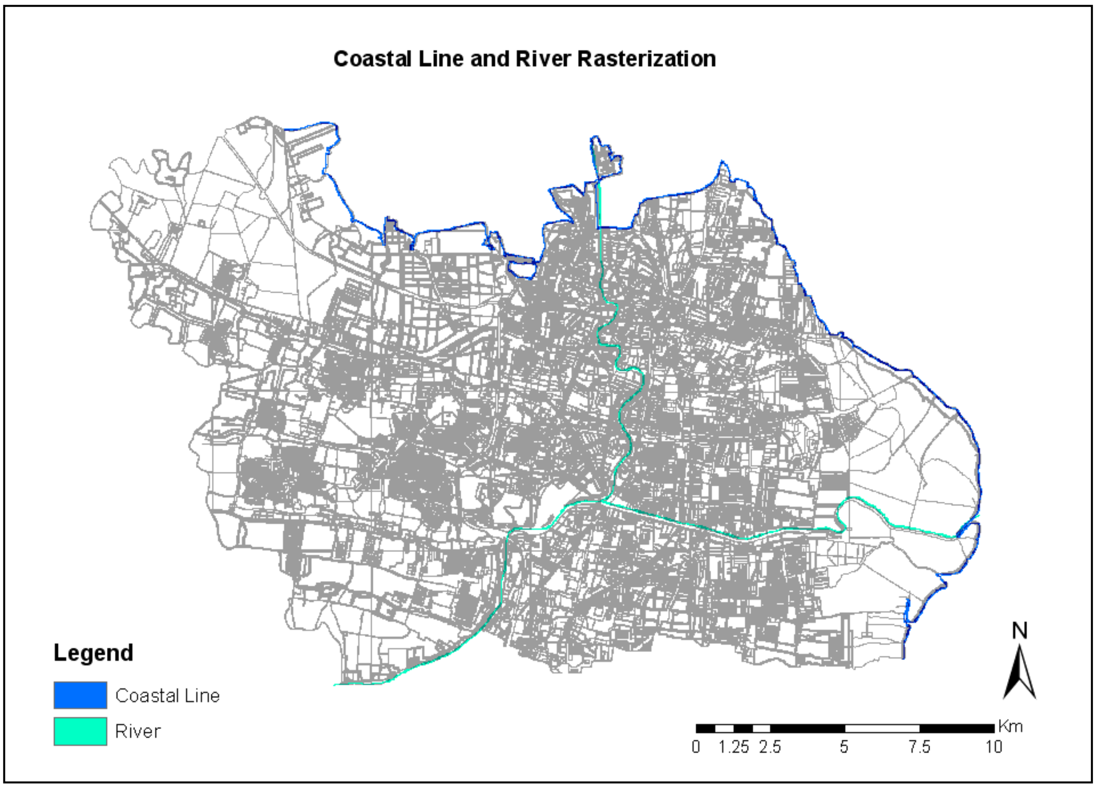


Figure 4.11 River and Coastal Line Rasterization

The safe distance from coastal line to depict areas that are prone to sea water intrusion that can cause leakage to USTs is shown by Figure 4.12. Meanwhile, Figure 4.13 shows the safe area for two big rivers in Surabaya. This area is measured 500 feet from the body of the rivers which means no PFS should be sited in these areas.

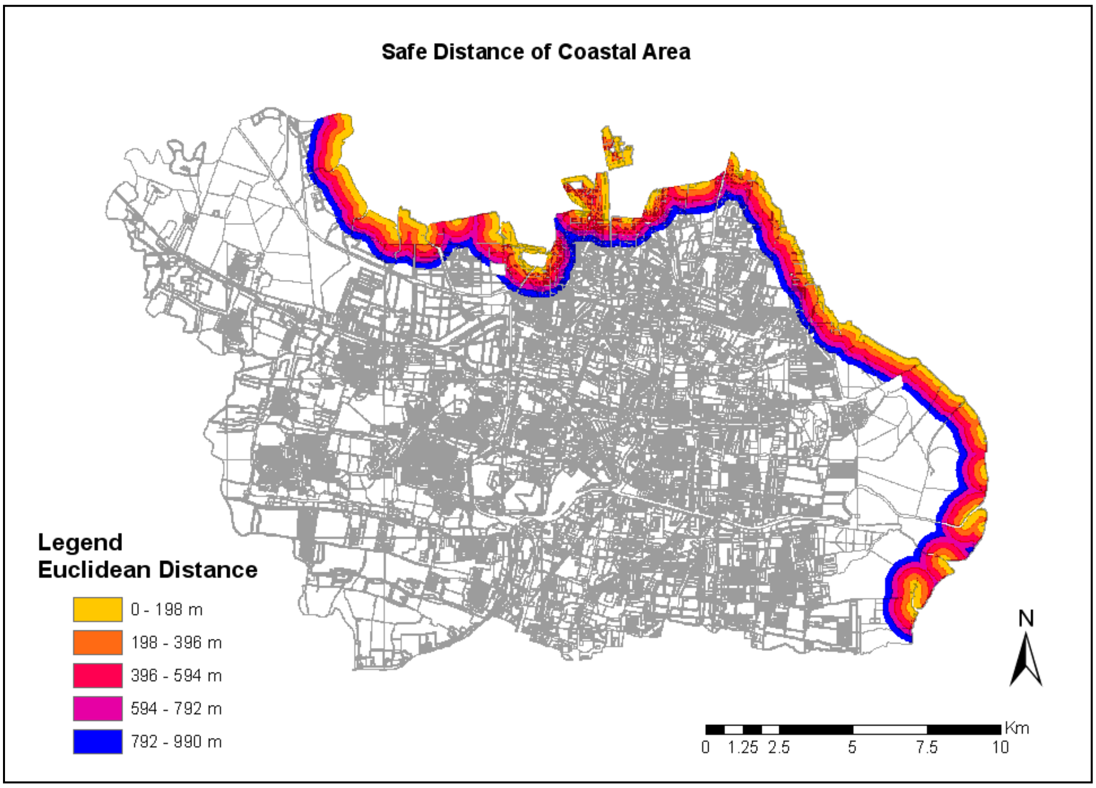


Figure 4.12 Safe Distance of Coastal Area

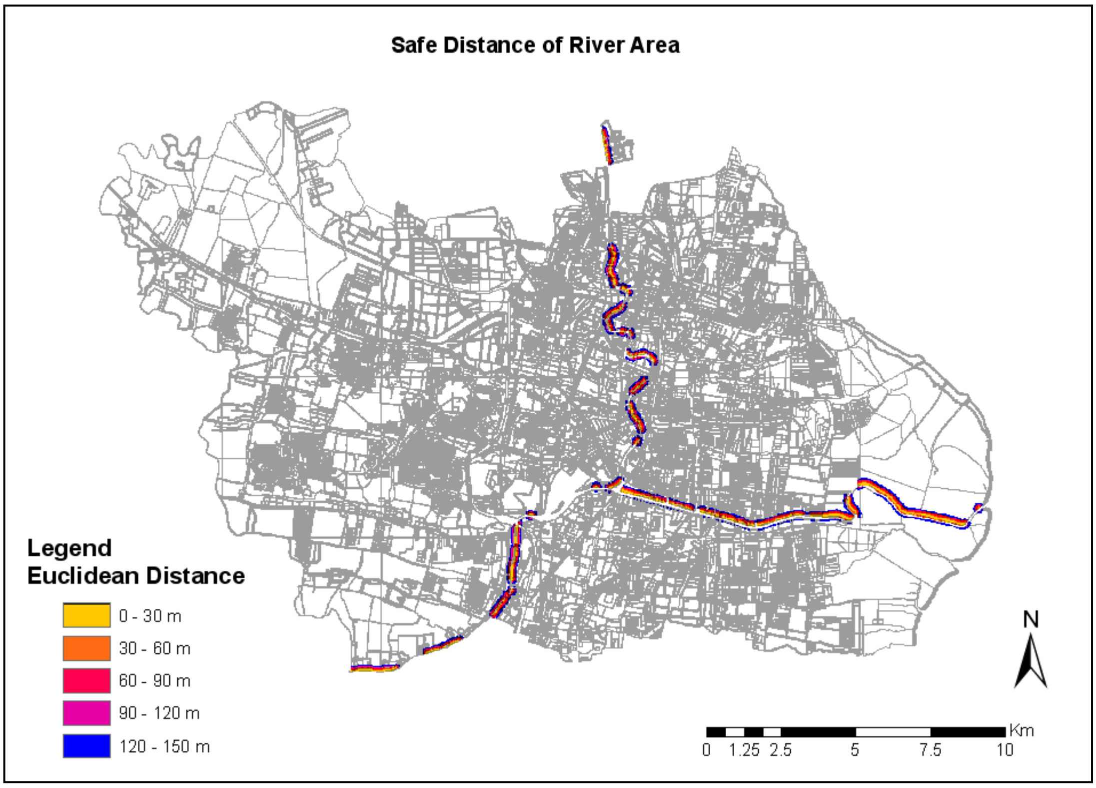


Figure 4.13 Safe Distance of River Area

b. Vicinity area protection

Protecting the vicinity area is one of criteria that aim to protect sensitive facilities in the vicinity of a PFS from the possibility of a fire break out. These sensitive facilities are hospitals and schools. In the effort to protect the vicinity area, the minimum requirement of safe distance for residential properties is 500 feet from a PFS and a minimum 100 feet for schools or hospital facilities. Figure 4.14 shows the safe distance area surrounding sensitive facilities (hospitals and schools). Meanwhile, Figure 4.15 shows the safe distance area surrounding residential area in Surabaya.

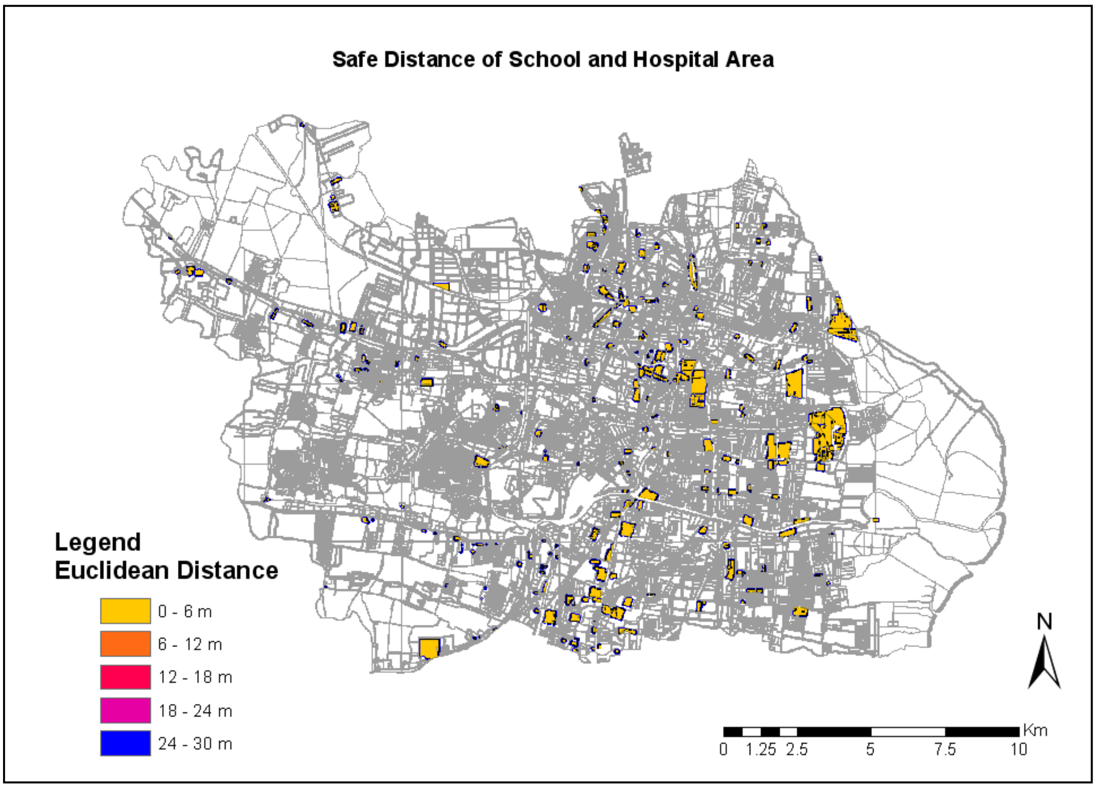


Figure 4.14 Safe Distance of Sensitive Facility

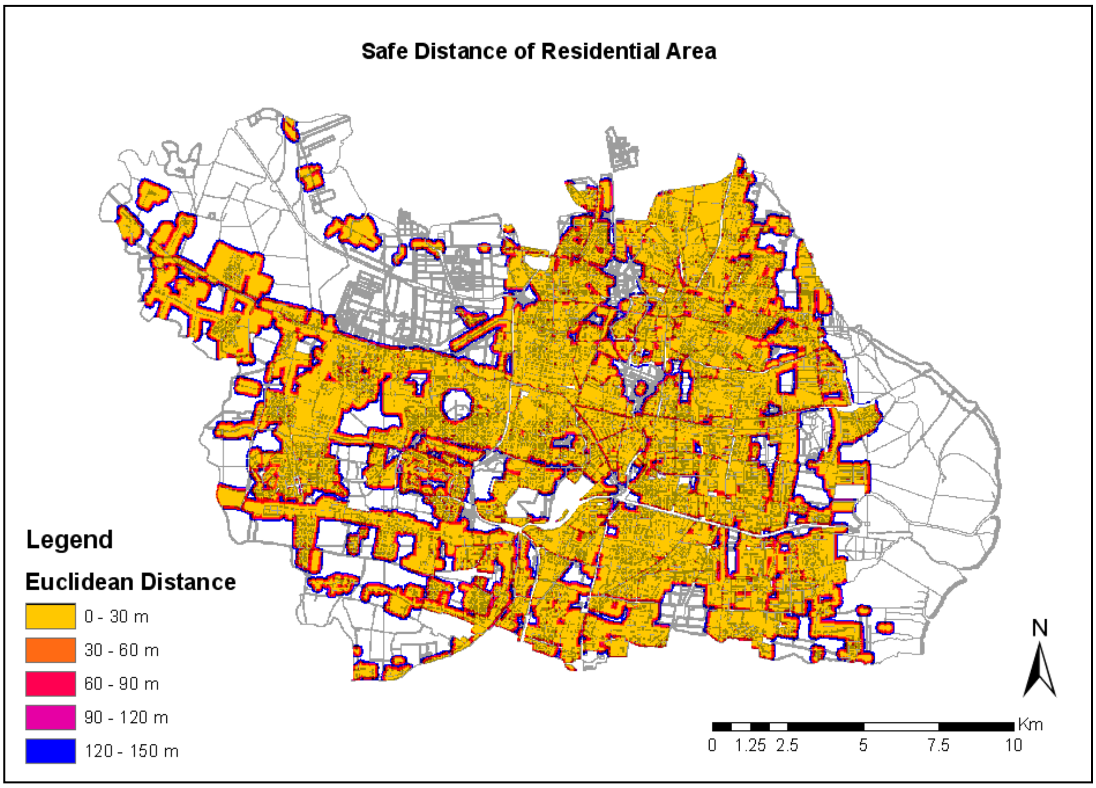


Figure 4.15 Safe Distance of Residential Parcel

Another facility considered as a sensitive facility is the high voltage overhead line area. In some cases, all areas located under or close to this facility could experience static electricity environment. The minimum requirement that is considered as safe distance is 150 feet from high voltage overhead line areas, which means, area in the 3D radius of 150 feet from high voltage overhead line area should not be occupied by PFSs. Figure 4.16 shows safe area near high voltage overhead line.

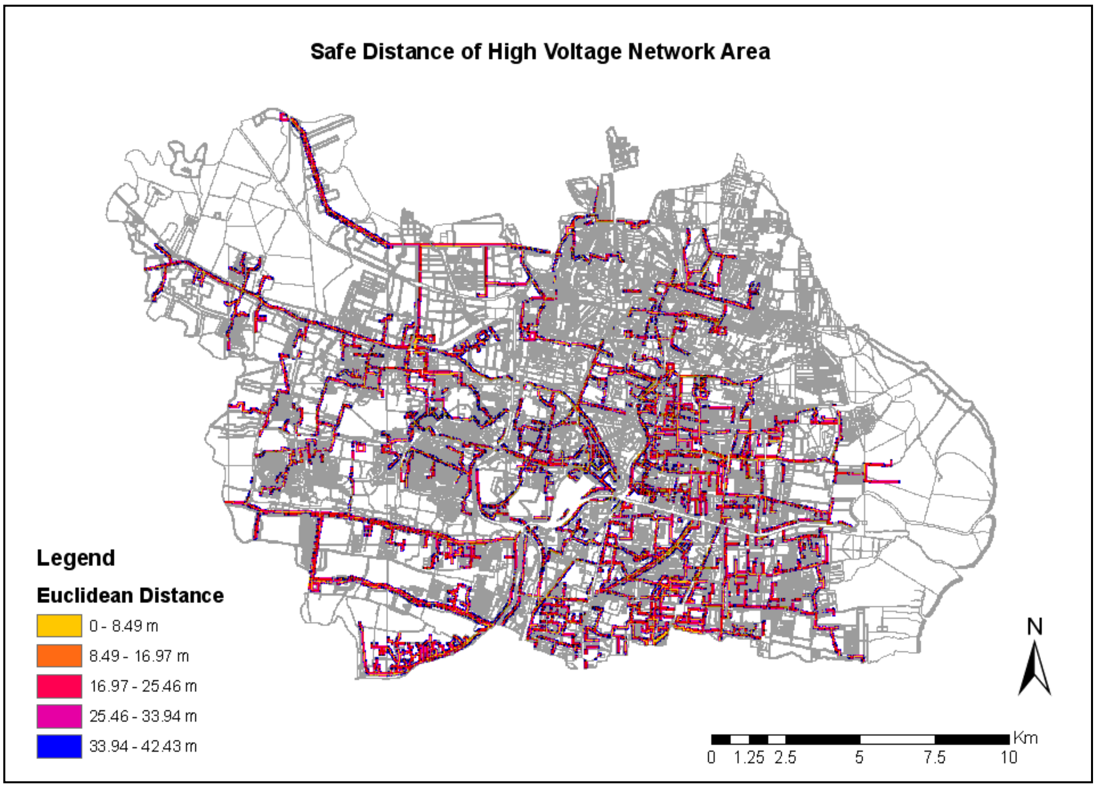


Figure 4.16 Safe Distance of High Voltage Network Area

c. Road safety

Avoiding road obstruction is one of criteria that aim to reduce the possibility of traffic congestions or even accidents associated with the location of PFSs that might be close to traffic intersections or even grade crossings. Petrol stations have high traffic attraction so they are able to cause obstructions on access roads due to vehicles entering and/or leaving the stations. The road capacity also determines the traffic situation when most of high rise buildings are situated in the periphery which means a safe distance requirement from PFS site to the nearest road boundary should be implemented to avoid traffic jam due to access and egress activities. However, the criteria used for road safety is applicable only for urban area not for rural area since road classification for rural area have different characteristic. According to the NEPA guideline, the road safety criterion only covers major roads.

To avoid traffic congestions and accidents, several minimum requirements of safe distances should be set. A PFS should be located a minimum 40 feet from the road boundary, a minimum 820 feet from grade crossing, and a minimum 250 feet from road intersections. Figure 4.17 and Figure 4.18 show safe areas of road intersections and road boundaries that should be not occupied by any PFS. Meanwhile, Figure 4.19 depicts the safe area of grade crossings.

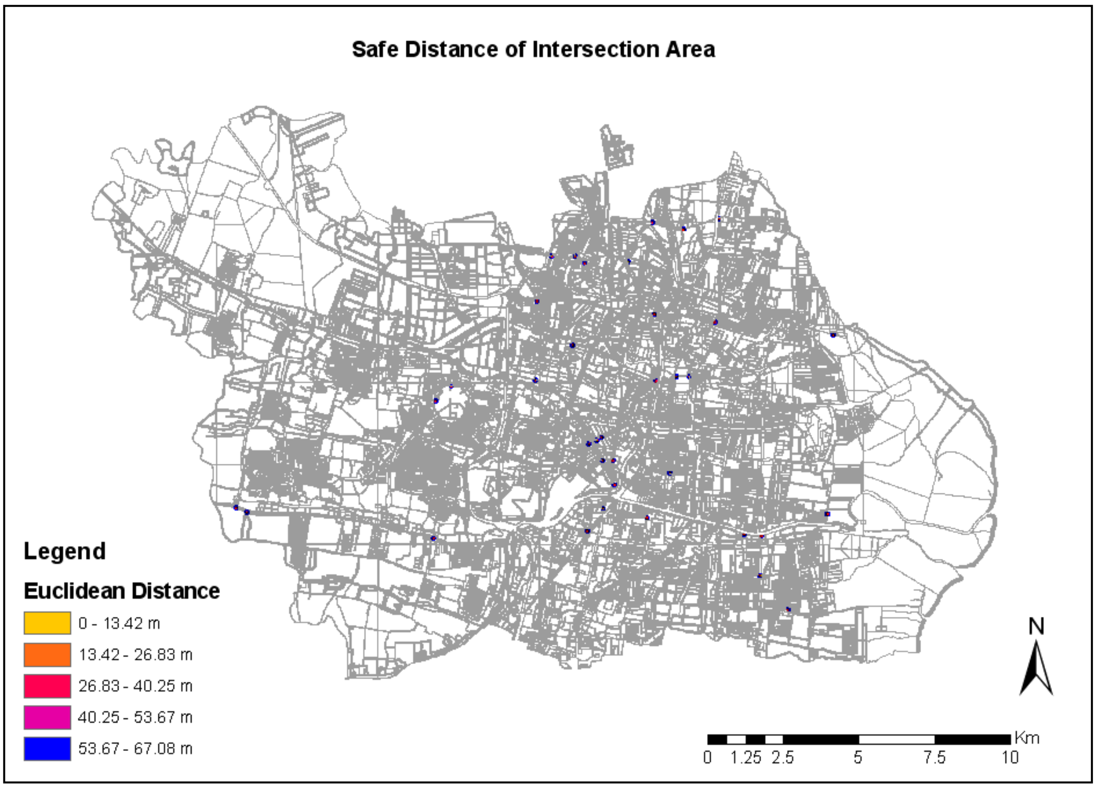


Figure 4.17 Safe Distance of Intersection Area

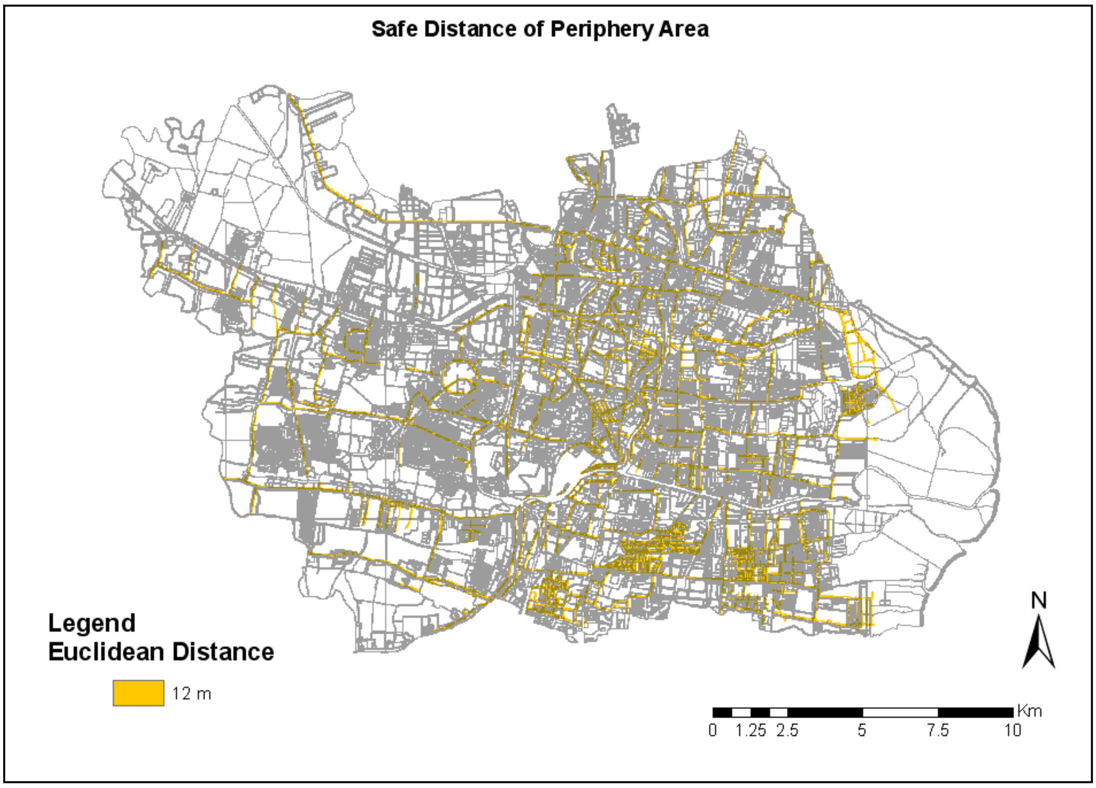


Figure 4.18 Safe Distance of Periphery Area

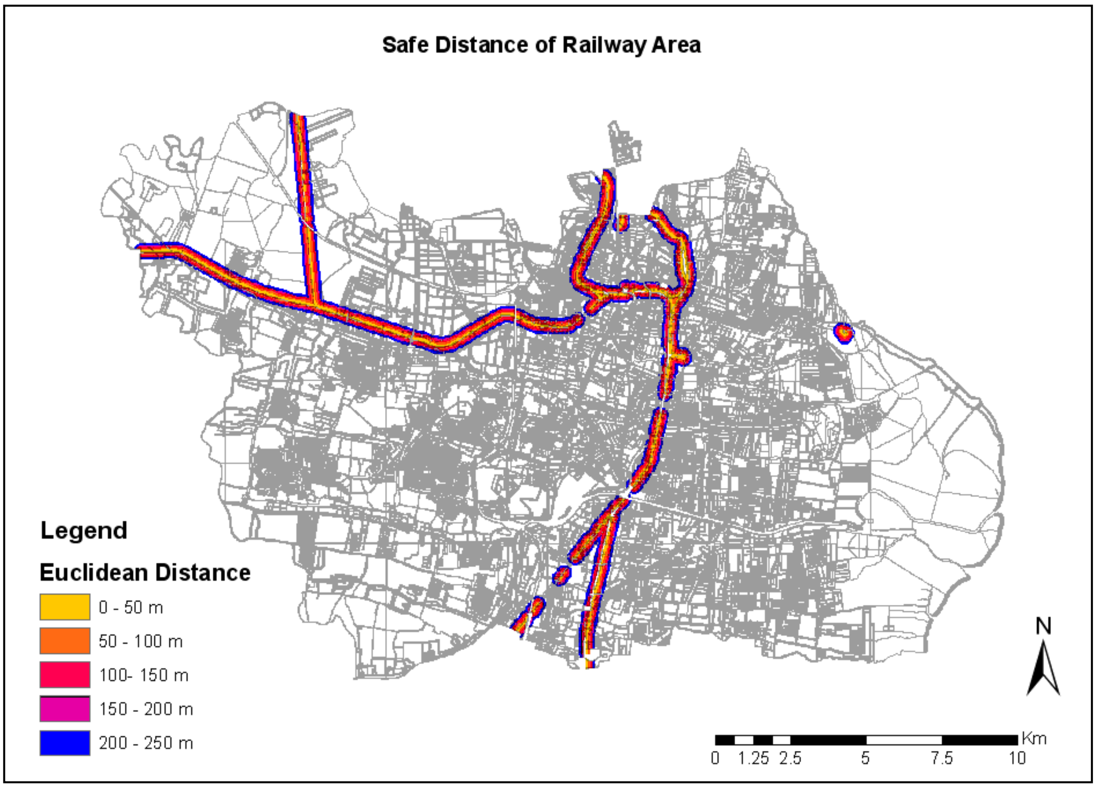


Figure 4.19 Safe Distance of Railway Area

d. Proper Land Selection

Selecting proper type of land is one of criteria that aim to choose suitable type of to locate the PFS. Due to environmental safe, the topography, zoning, and availability of vacant parcel of land that has the appropriate width should be considered in determining the location of a PFS.

The width of vacant land or land that is supposed to be developed as a PFS site should be sufficient to allow manoeuvring of vehicles within its cartilage but should not be less than 1000 m^2. Figure 4.20 shows the availability of vacant land in Surabaya. The figures show that vacant lands are available in the western part of Surabaya.

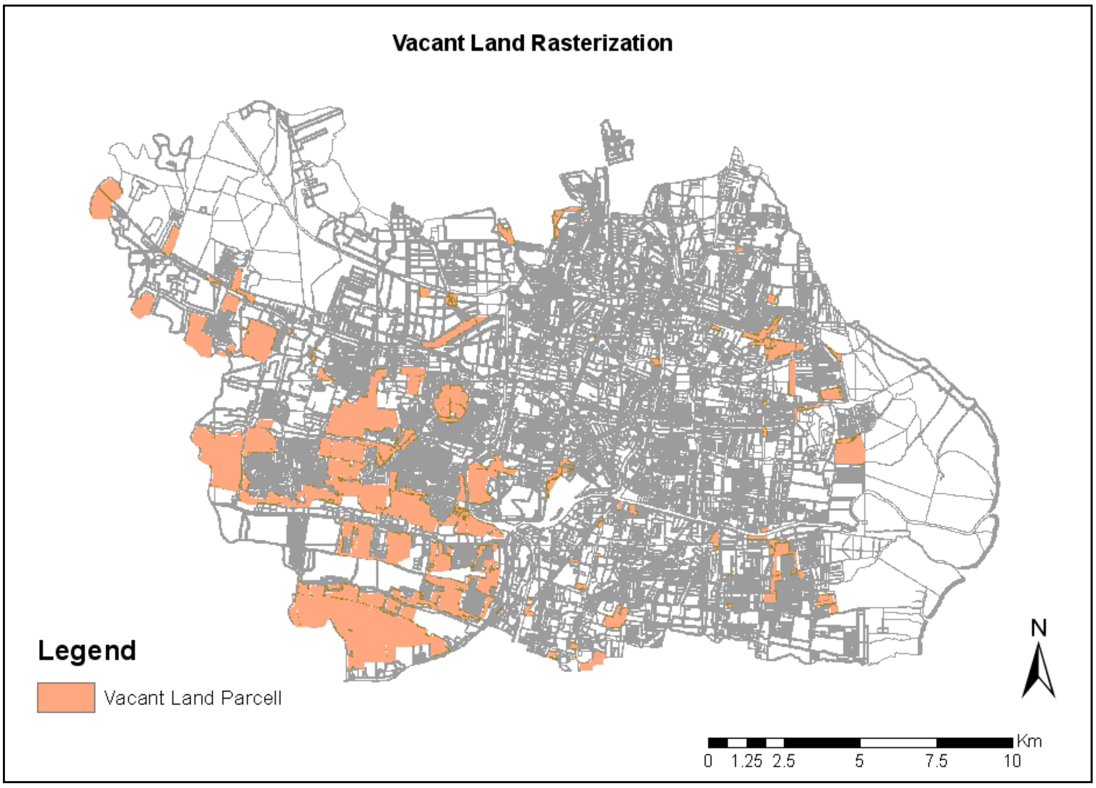


Figure 4.20 Vacant Land Rasterization

Figure 4.21 shows the coverage area of slopes in Surabaya city. It clearly shows that Surabaya is a low land area which does not have a great difference of land elevation. Most parts of Surabaya are in the slope of 1-10% steep and in the slope of 1-15% steep which are considered safe for the construction of PFS USTs.

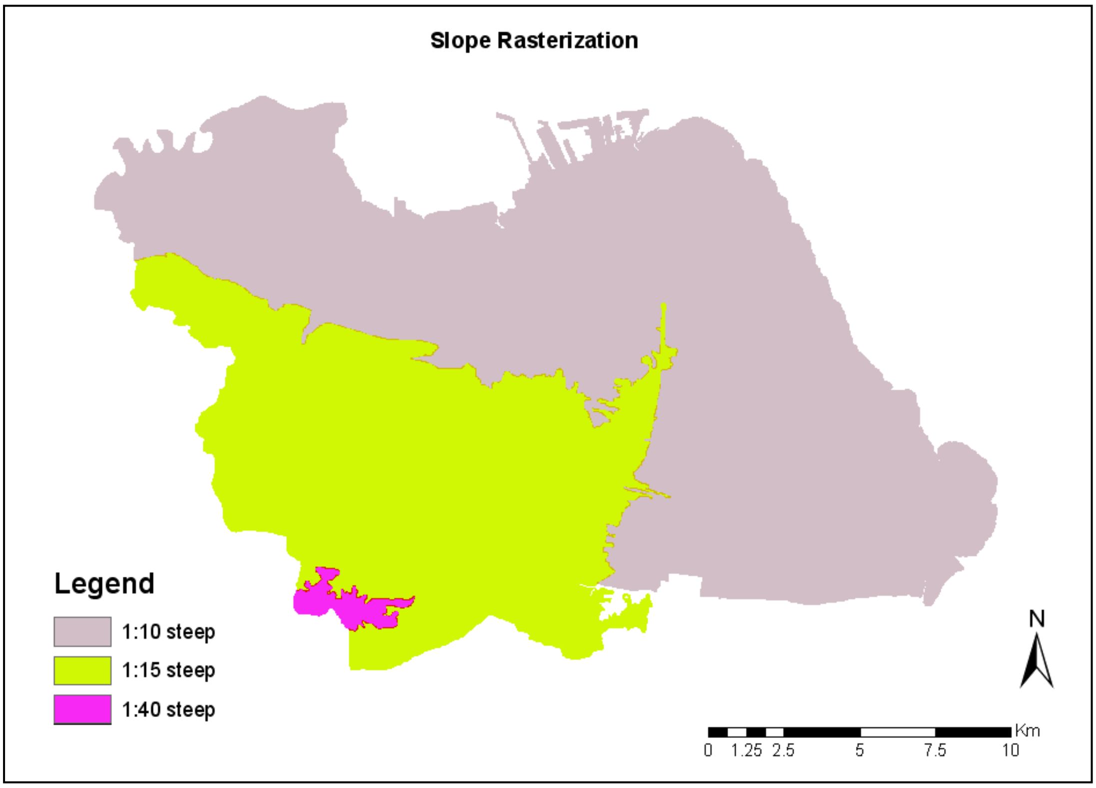


Figure 4.21 Slope Rasterization

On the other hand, PFSs should be located in commercial/industrial zones or be designated specifically for the purpose in a subdivision. Several requirements indicate the suitability of land use. Fish ponds and green open spaces are considered as land use that is not suitable for PFS construction. Any site constructions in these areas are forbidden not only for PFSs. Figure 4.22 shows the distribution of land use in Surabaya. Most of the land used is occupied by residential properties.

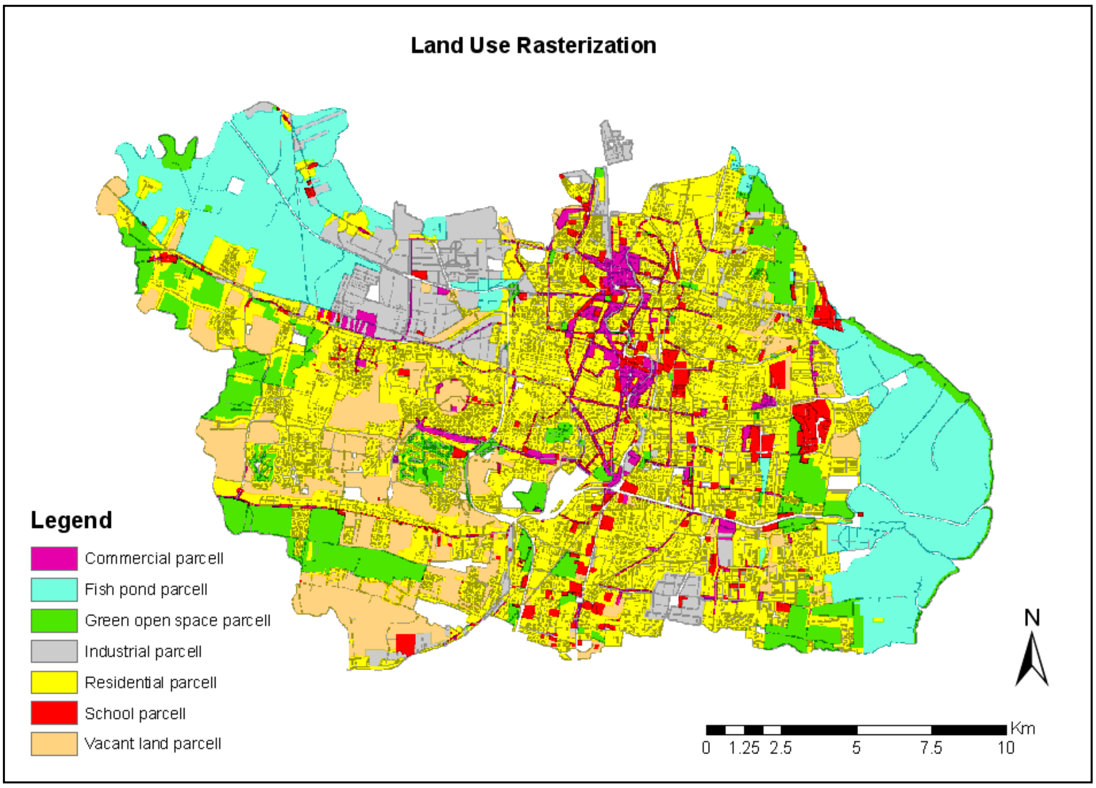


Figure 4.22 Land Use Rasterization

e. Emergency Response Services

Emergency response service is another important criteria to be considered when deciding the location of a PFS in the advent of any mishap happening. These emergency response facilities are fire stations and hospitals. Surabaya has eight fire stations and twenty eight hospitals which are unevenly distributed throughout the city.

City fire stations are located throughout the city to respond to fires and other emergencies that fall within its jurisdiction. To effectively serve the general public, service areas need to be established to provide coverage and response times from the stations to the emergency site(s) need to be analyzed [44]. In this case, Geographic Information System (GIS) is a means to visually observe the locations of the fire stations in the city and calculate the drive times of the variety emergency vehicles to the PFSs in the event of fire hazards. Based on NEPA 1710 [87], fire response time for fire departments should be four minutes (240 seconds) or less for the arrival on the scene of the first rescuers an eight minutes (480 seconds) or less for the deployment of a full first alarm assignment at a fire suppression incident.

Eight fire stations are unevenly distributed in Surabaya. Five of those fire stations are located in the northern part of the city. The remaining is distributed in the southern and western parts of the city. Figure 4.23 shows that each fire station has emergency response times of four minutes, six minutes, and eight minutes. Four fire stations which are located in the northern part share their four minutes coverage time because they are located too close to each other. The close distance between two fire stations can be assumed due to the densely populated surrounding areas. Compared to the actual conditions, 65 PFSs are located completely within the 4-minute emergency response service coverage time for each fire station. This means that 72% of the PFSs are covered by emergency response services in the event of any mishap.

Meanwhile, twenty eight hospitals are located centrifugally within the radius of the city centre. The medical service areas were designed based on the fire station response time to arrive quickly at an emergency location in any part of the city. In addition, the expected maximum time for an ambulance to reach an incident site is within 8 minutes. Figure 4.24 shows 28 hospitals located throughout the city. Based on the distribution of the hospitals, it may observe that within 0-8 minutes range time there 84 PFSs are within the ambulance services 0-8 minute coverage time. This means that another six (6) PFSs are not within the optimum hospital emergency response range.

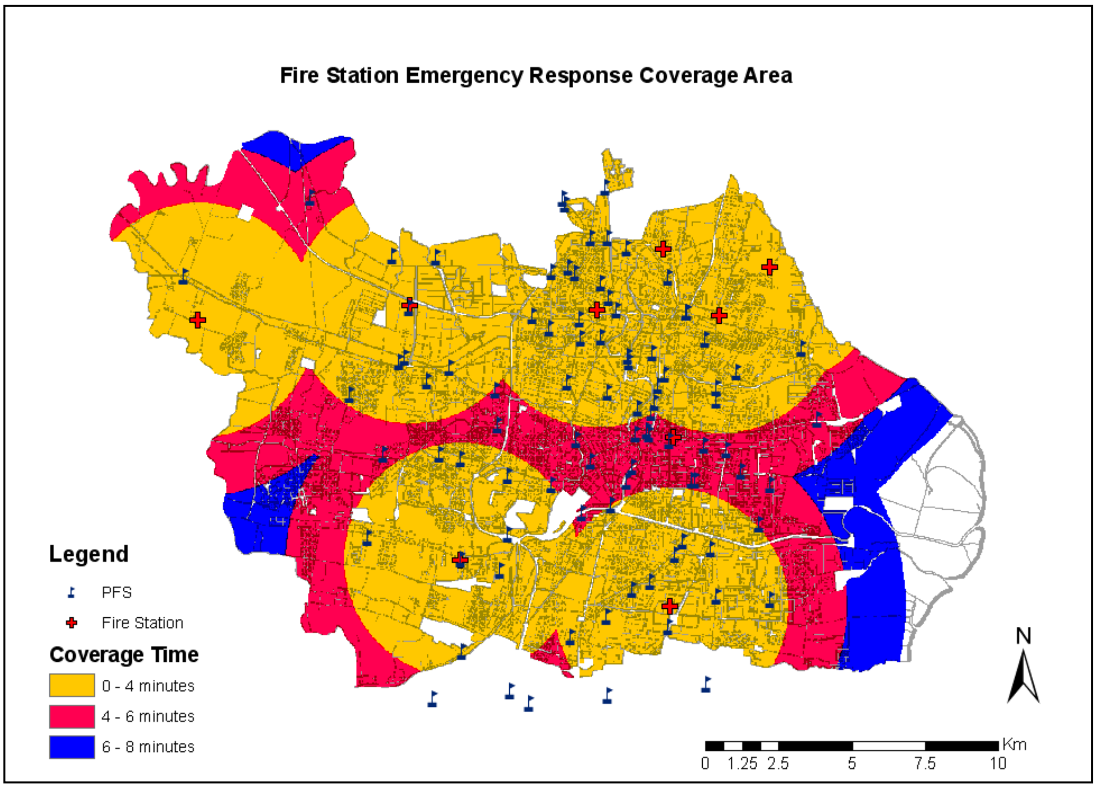


Figure 4.23 Fire Stations Emergency Response Coverage Time

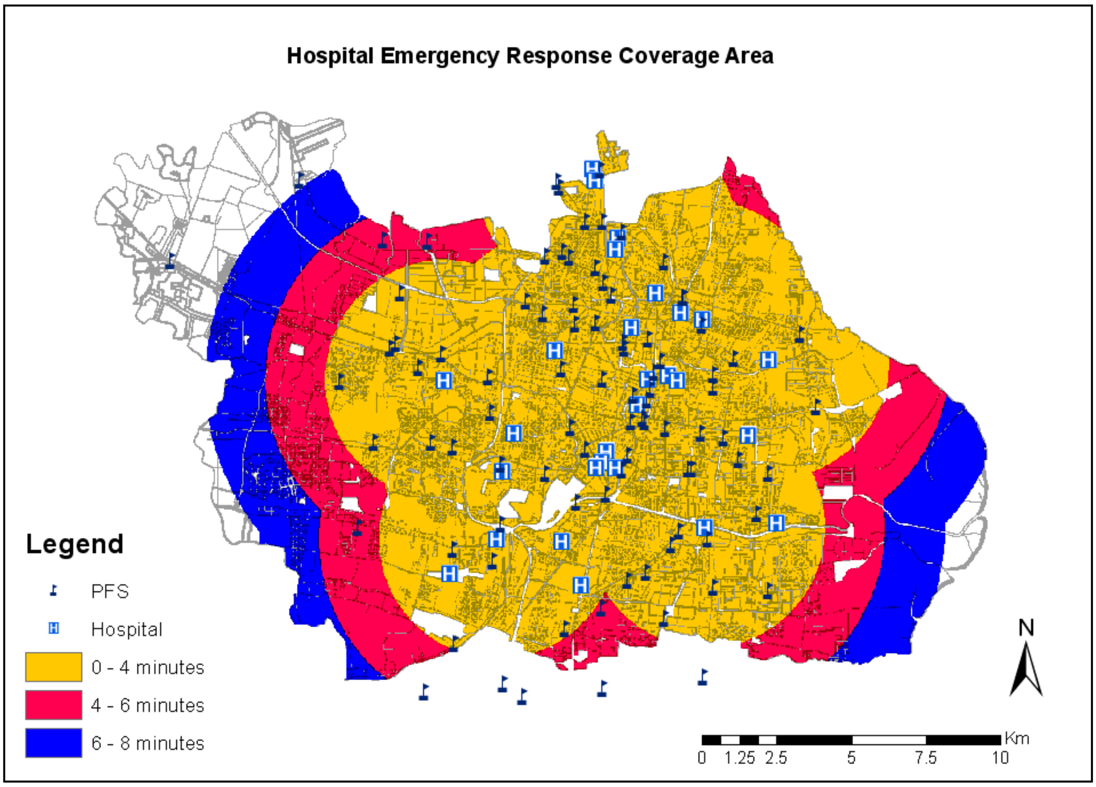


Figure 4.24 Hospitals Emergency Response Coverage Time

4.4.2 Reclassification Data Map Layers

To create a single ranked map of potential areas to site PFS we have to compare the values of classes between layers by assigning numeric values to classes within each map layer. This technique is called reclassification [74]. Having all the measurements on the same numeric scale gives them equal importance in determining the most suitable locations. Hence all data map layers will be reclassified into new numeric value or scoring as ‘3’,’2’, ‘1’and ‘0’. These numerical scores are used to identify the differences among highly suitable sites, moderately suitable sites, less suitable sites, and non suitable. Table 4.3 shows the classification of criteria into three different categories: no suitability, less suitability, moderate suitability, and high suitability.

Table 4.3 Classification of Criteria

Criteria	**Classification of Criteria**			
	No Suitability	**Less Suitability**	**Moderate Suitability**	**High Suitability**
	0	**1**	**2**	**3**
Distance to Coastal Line	-	< 3.250 ft	-	> 3.250 ft
Distance to River	-	< 500 ft	-	> 500 ft
Distance to Residential Properties	-	< 500 ft	-	> 500 ft
Distance to Hospital and School	-	< 100 ft	-	> 100 ft
Distance to High Voltage Area	-	< 150 ft	-	> 150 ft
Distance to Intersection	-	< 250 ft	-	> 250 ft
Distance to Road Property Boundaries	-	< 40 ft	-	> 40 ft
Distance to Grade Crossing	-	< 820 ft	-	> 820 ft
Slope	-	1-40%	1-15%	1- 10%
Land Use	Green open space	Fish pond	Residential School	Industrial Commercial
Land availability	-	Non vacant land	-	Vacant land
Distance to Fire Station	> 8 min. driving time	Within 8 min. driving time	Within 6 min. driving time	Within 4 min. driving time
Distance to Hospital	> 8 min. driving time	Within 8 min. driving time	Within 6 min. driving time	Within 4 min. driving time

Suitability class of each criterion is divided into three classifications which are less suitability, moderate suitability, and high suitability. No suitability is assigned by 0, Less suitability criteria is assigned by 1, moderate suitability criteria is assigned by 2, and high suitability criteria is assigned by 3 [88].

From Table 4.3, we can see that this suitability of PFS is primarily based on the point of environmental benefit because the ultimate goal of this determination of PFS is to minimize the possibility of contamination or danger to the site and vicinity area. As such, the PFS should be best located in the areas that are a minimum of 500 feet from the nearest surface water to prevent water contamination, a minimum of 500 feet from residential properties in case of explosions and occurrences of open flames, on a slope with 1-10% gradient, and within 5 minutes driving time from nearest emergency response services such as hospitals and fire stations.

a. Water system protection

Two classification areas are identified for coastal area and river area. Less suitable area is depicted by the pink barrier colour and highly suitable area is depicted by the dark purple colour. The pink barrier area is a safe area which is measured 3,250 feet from the coastal line (see Figure 4.25). As for the river area, the pink barrier is measured 500 feet from the river body (see Figure 4.26).

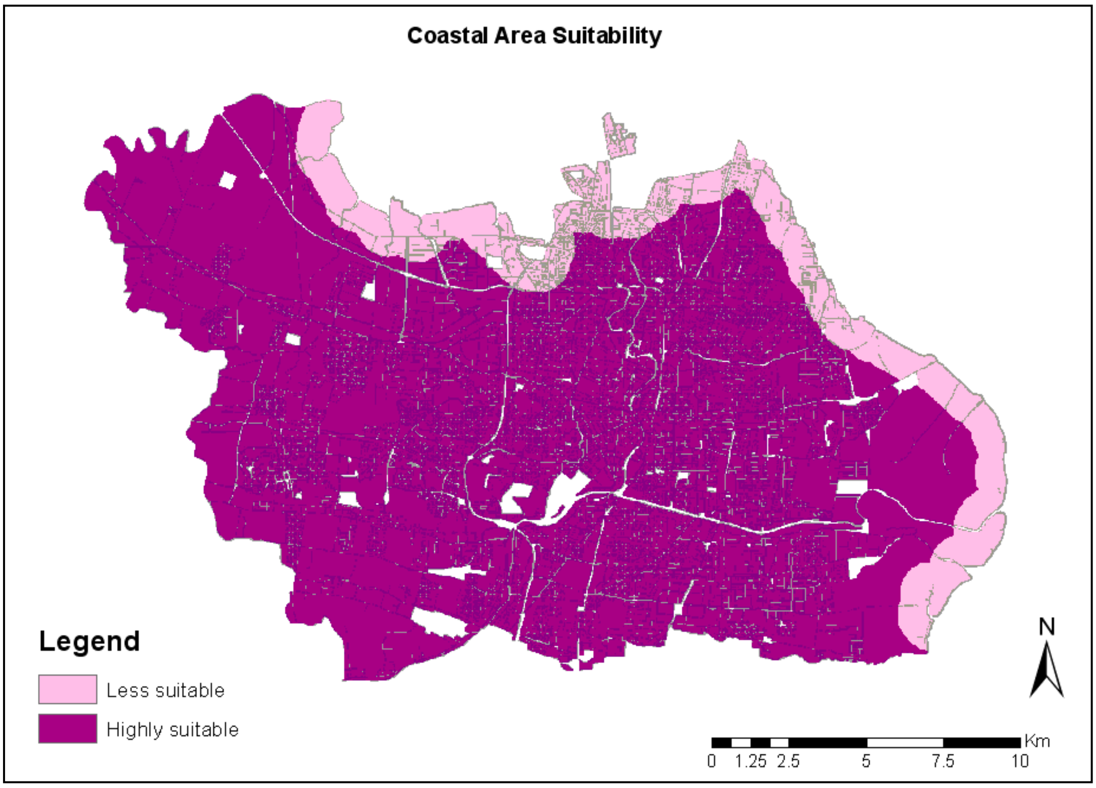


Figure 4.25 Coastal Area Reclassification

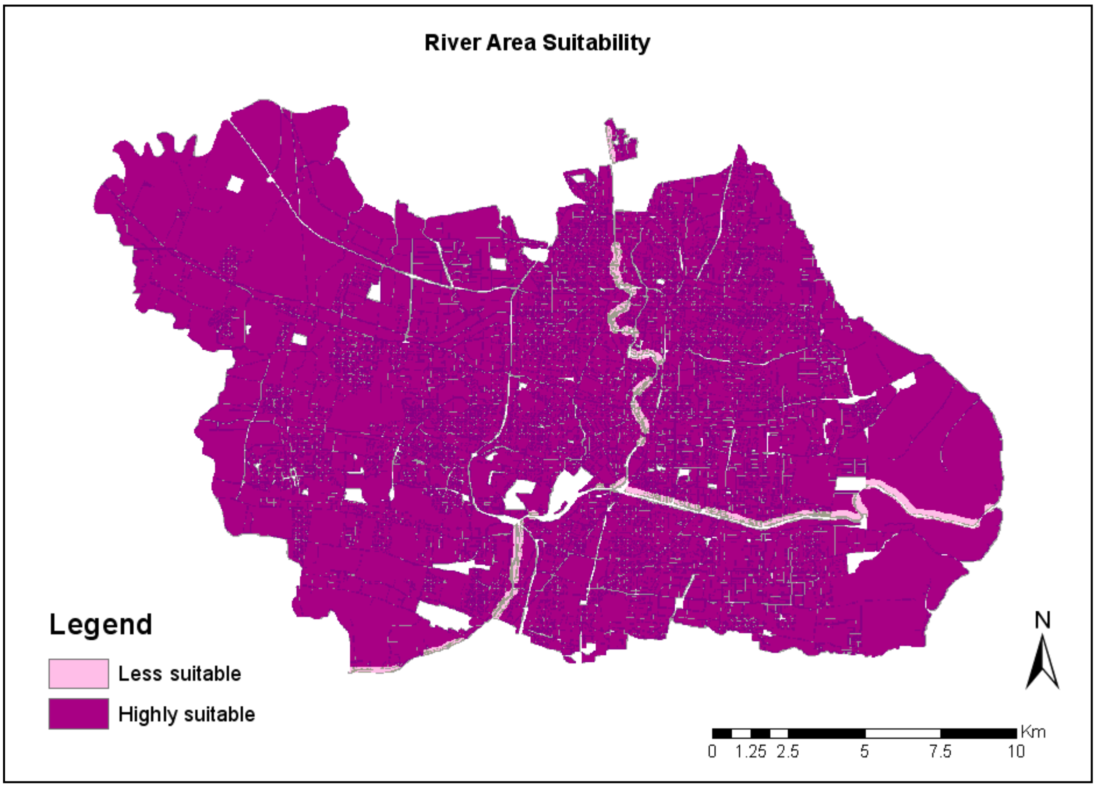


Figure 4.26 River Area Reclassification

b. Vicinity area protection

Areas within 500 feet from residential area, 100 feet from sensitive facilities, and 150 feet from high voltage overhead line areas are classified as less suitable areas for PFS construction. Figure 4.27, Figure 4.28, and Figure 4.29 show the suitability classification of residential area, sensitive facilities area, and high voltage network area, respectively.

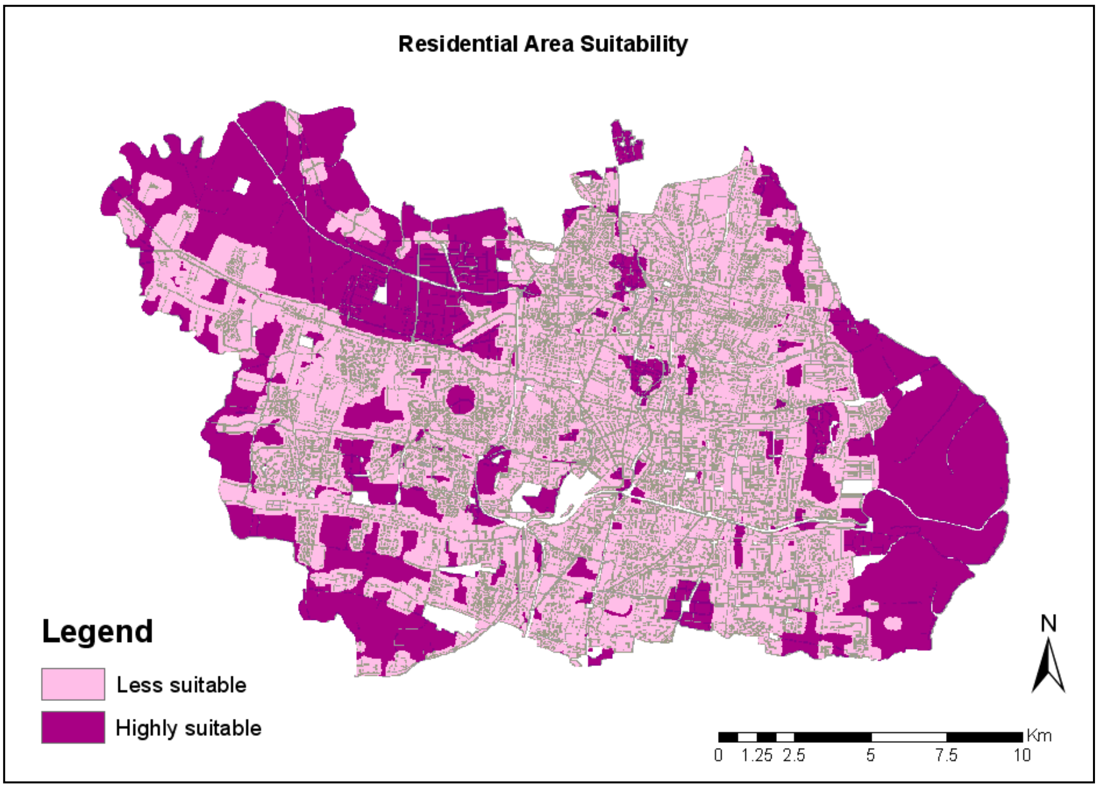


Figure 4.27 Residential Area Reclassification

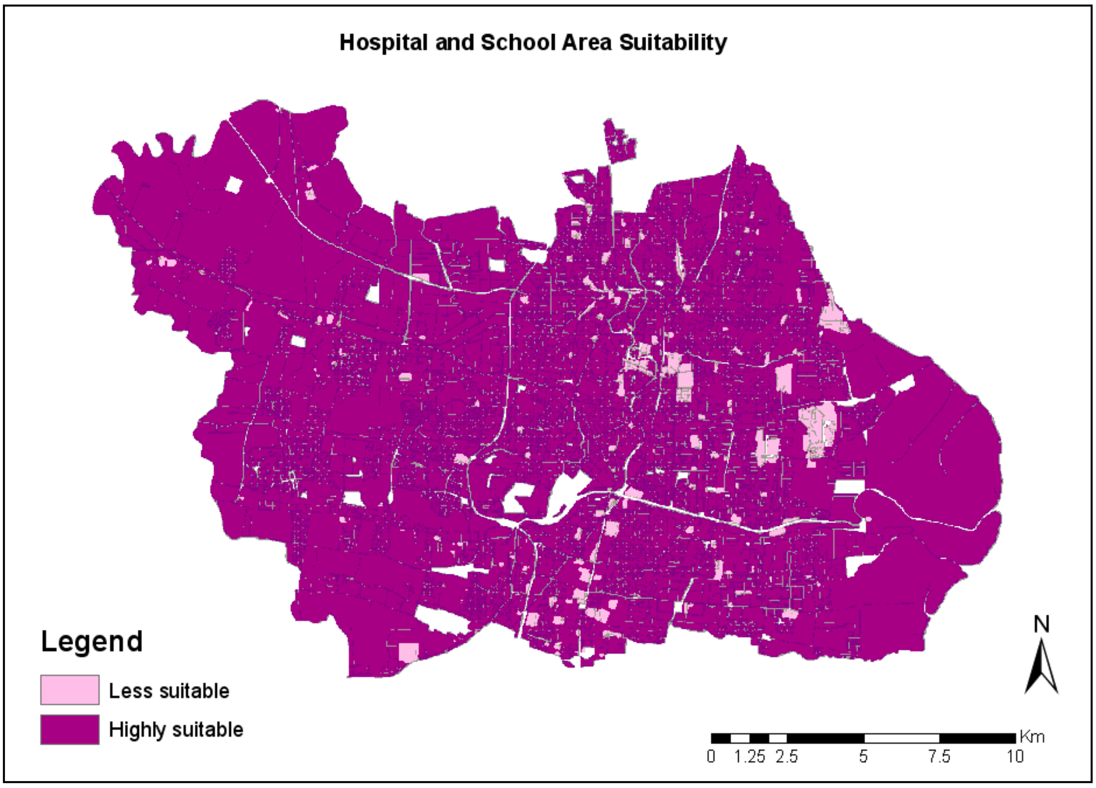


Figure 4.28 Sensitive Facility Area Reclassification

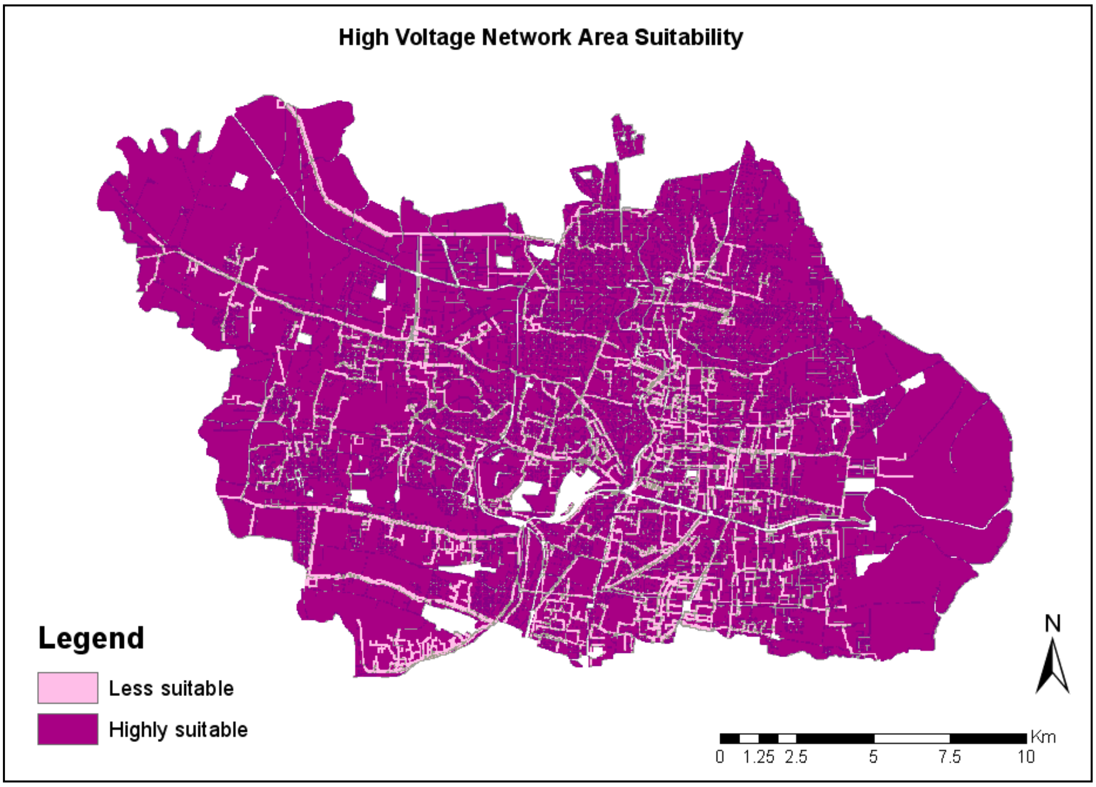


Figure 4.29 High Voltage Network Area Reclassification

c. Road safety

In the effort to prevent traffic congestions and accidents, points of intersections, road side boundaries, and grade crossing locations have to be considered when choosing PFS sites. Figure 4.30 shows classification area at point of intersections, within radius of 250 ft from intersection is considered as less suitable for determining PFS location. Meanwhile, area out of this radius is considered as highly suitable area for PFS locations.

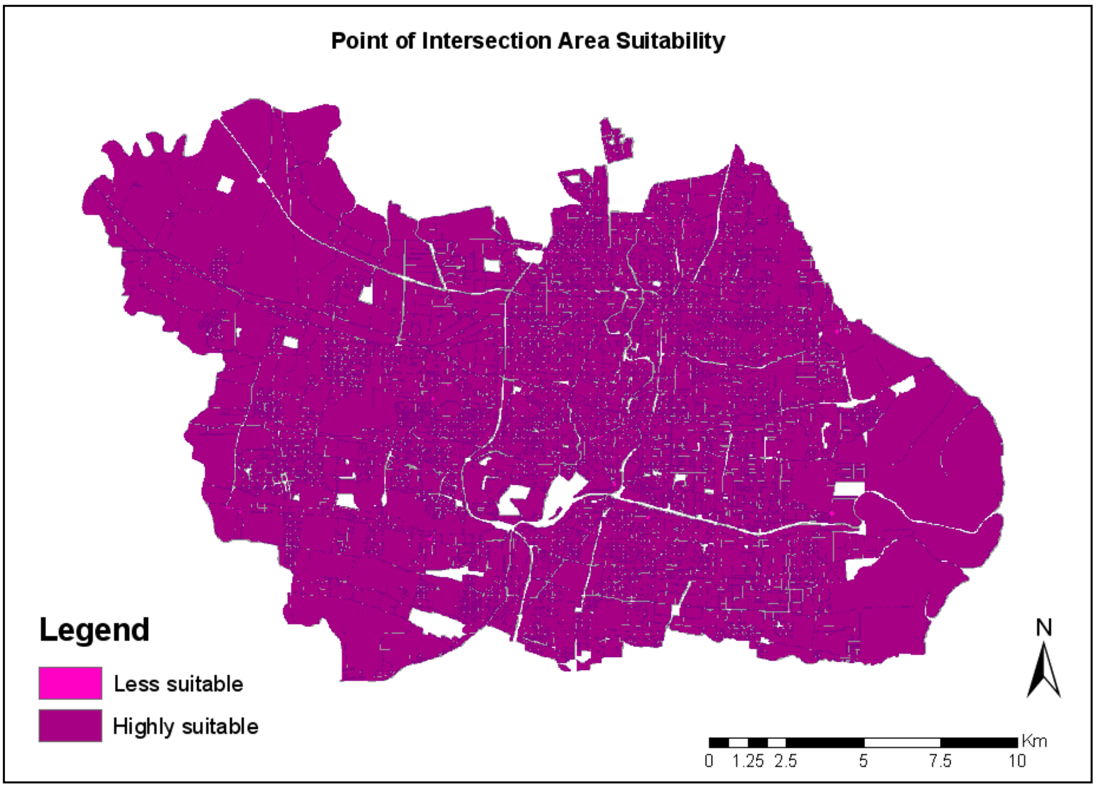


Figure 4.30 Point of Intersection Area Reclassification

Figure 4.31 shows the road side within radius 40 ft from its boundary is considered as less suitable area for PFS location site. Area out of this 40 ft radius is considered as highly suitable. For the last figure of road safety criteria, Figure 4.32 shows that area within radius 820ft from the grade crossing line is considered as less suitable area due to safe reason for vehicles that need to access PFS.

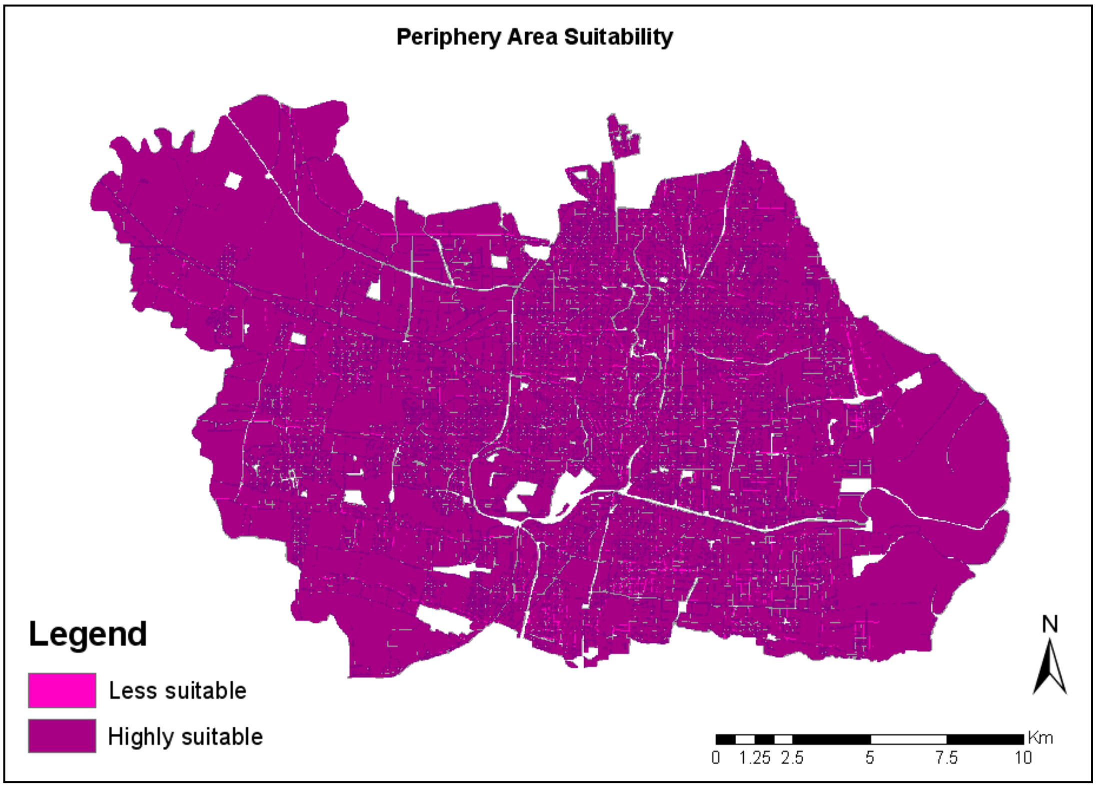


Figure 4.31 Periphery Area Reclassification

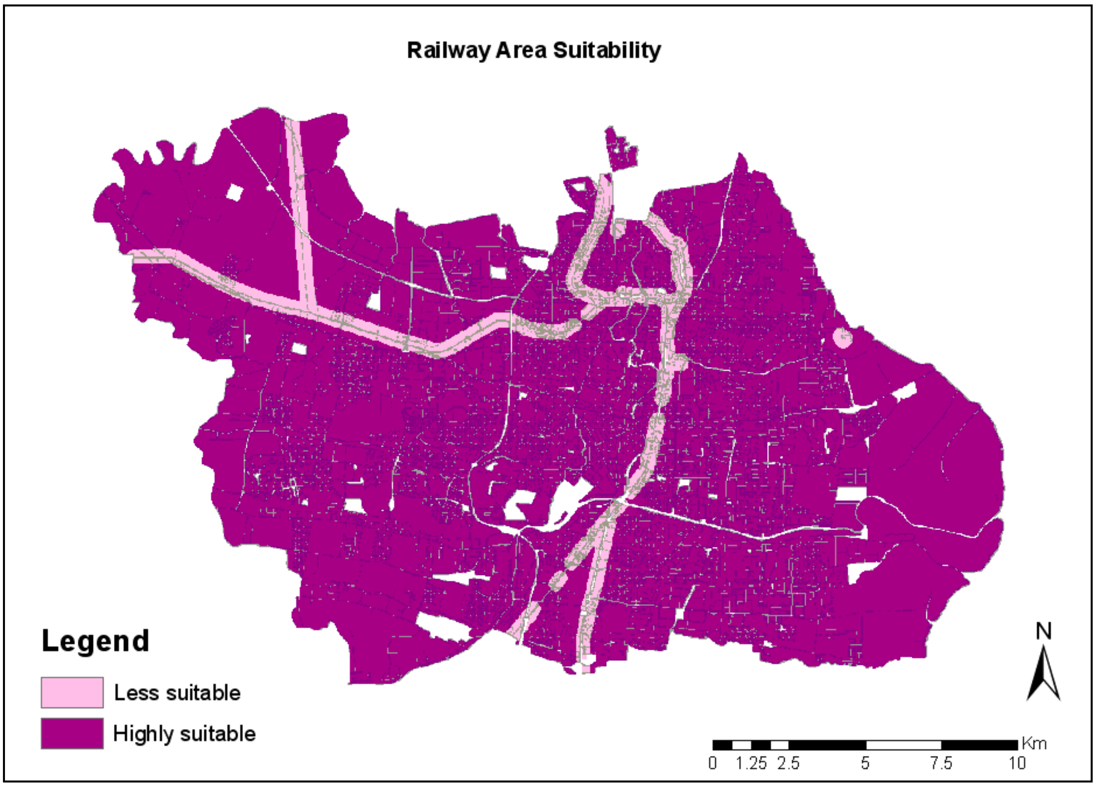


Figure 4.32 Railway Area Reclassification

d. Proper Land Selection

Highly suitable classification for selecting proper land is represented by vacant land, slope within 1-10%, and commercial and industrial zones. All of them are depicted by the dark purple colour which as shown in Figure 4.33, Figure 4.34, and Figure 4.35 respectively. Figure 3.33 shows that vacant area that most of them situated at the west part of Surabaya are considered as highly suitable area for PFS. This area represented by the dark purple colour.

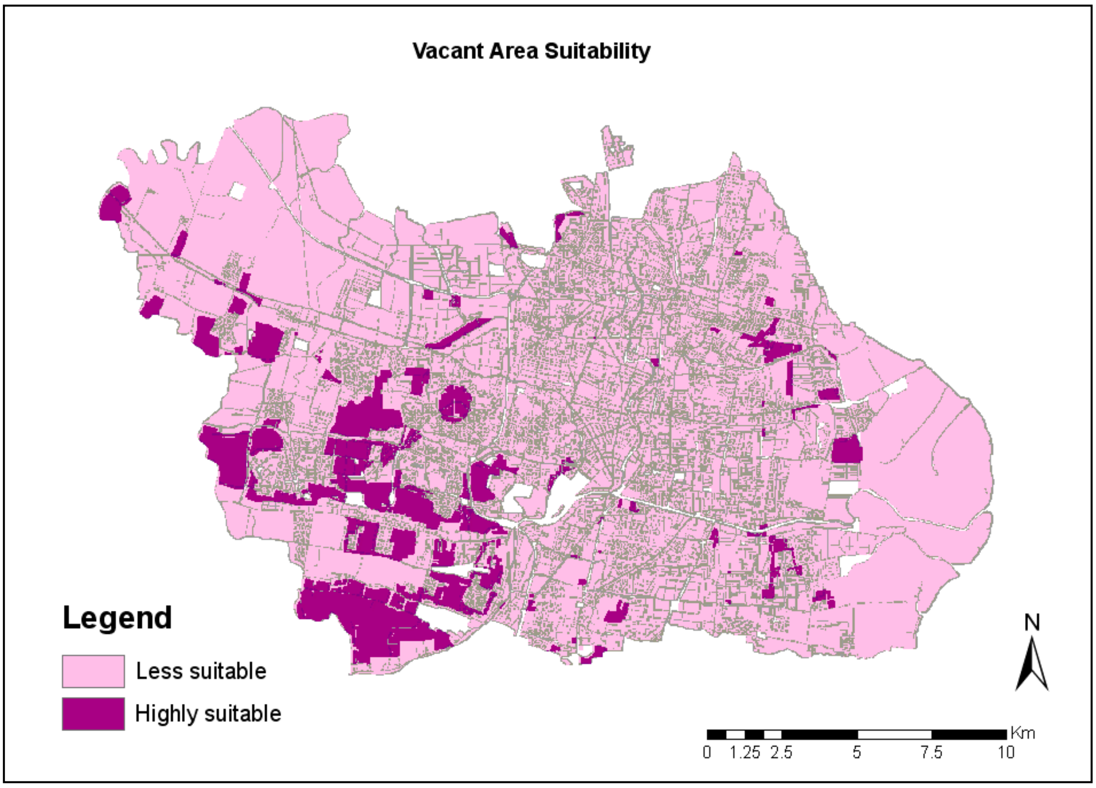


Figure 4.33 Vacant Area Reclassification

In regards of slope requirement, PFS should be built on level ground rather than on slopes to prevent rolling of discarded materials such as cans, drums, etc. Figure 4.34 shows three classification: areas with 1:40 gradient is considered as low suitable areas, areas with 1:15 gradient is considered as medium suitable areas, and areas with 1:10 gradient is considered as high suitable areas for PFS construction sites. Meanwhile, Figure 4.35 shows the classification of land use. Fish ponds and green open space zone are categorized as less suitable area. Residential and school zone are categorized as moderately suitable area. Lastly, industrial and commercial zone are categorized as highly suitable area.

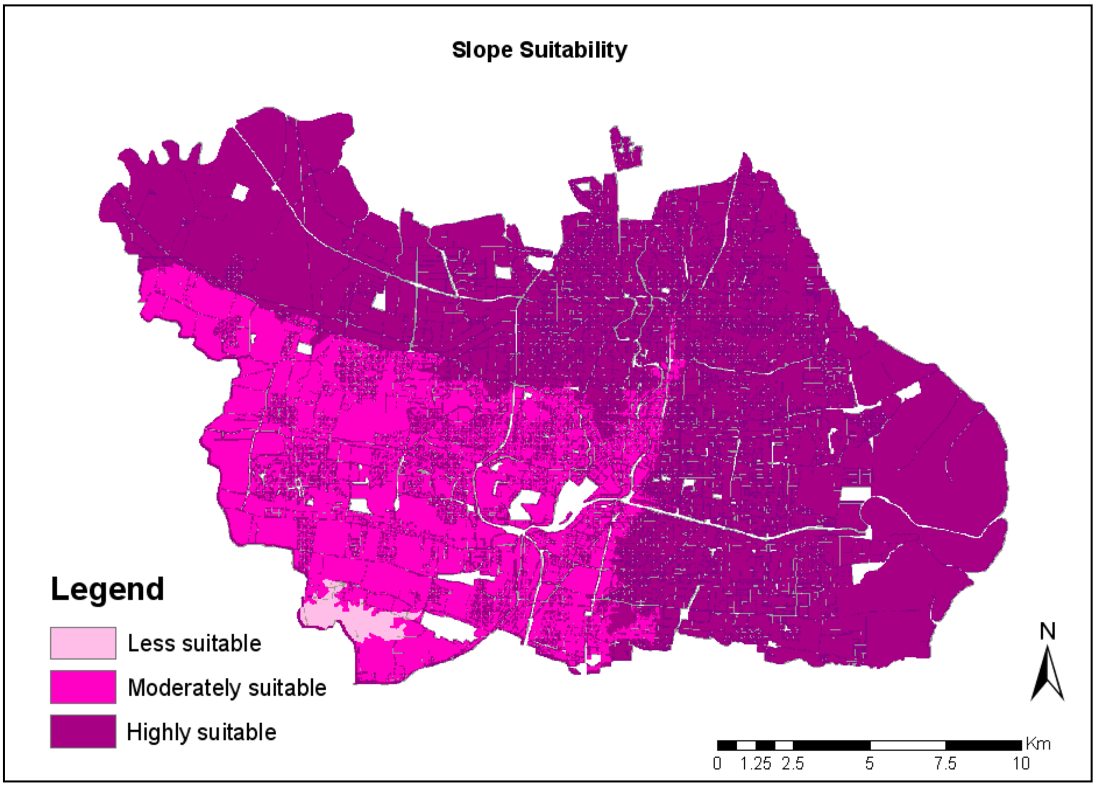


Figure 4.34 Slope Area Reclassification

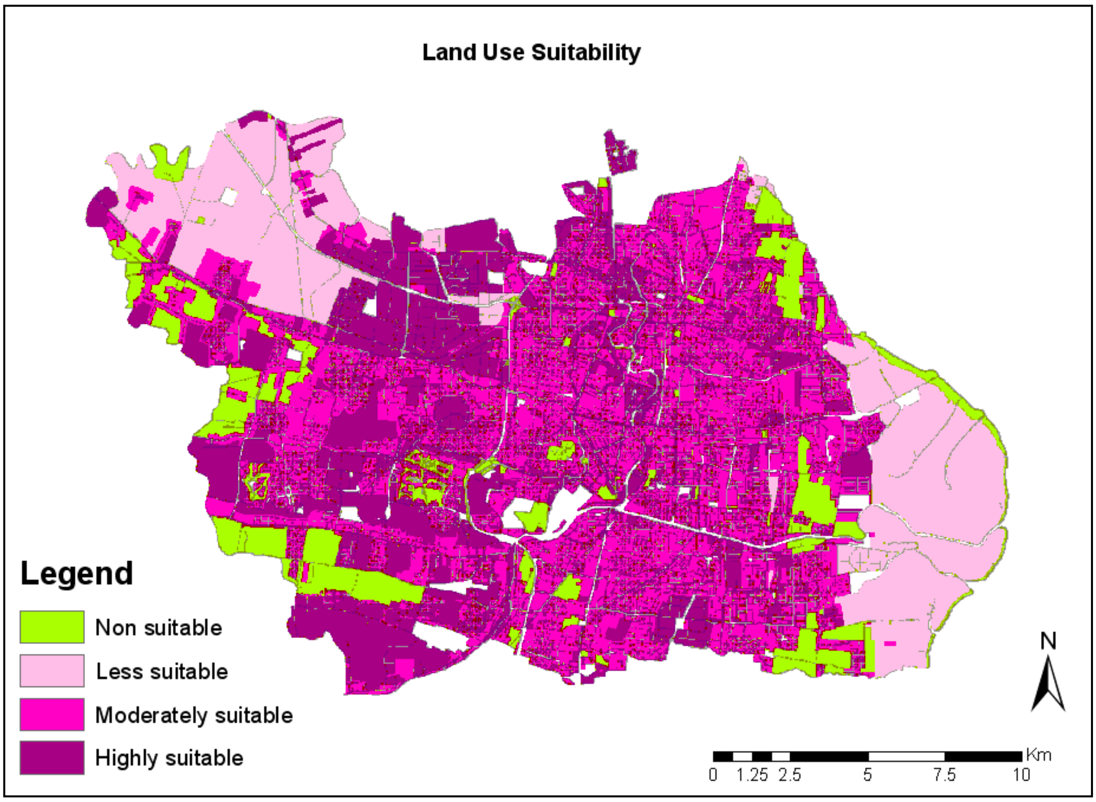


Figure 4.35 Land Use Reclassification

e. Emergency Response Services

Fire stations' and hospitals' emergency response time are classified into three suitability classes. Based on NEPA 1710 [87], area within 0 minute until 4 minutes coverage emergency response time from fire station is categorized as highly suitable zone for PFS siting. Secondly, area within 4 minutes until 6 minutes coverage emergency response time from fire station is categorized as moderately suitable zone. At last, area within 6 minutes until 8 minutes coverage emergency response time from fire station is categorized as less suitable zone. This classification is briefly shown on Figure 4.36.

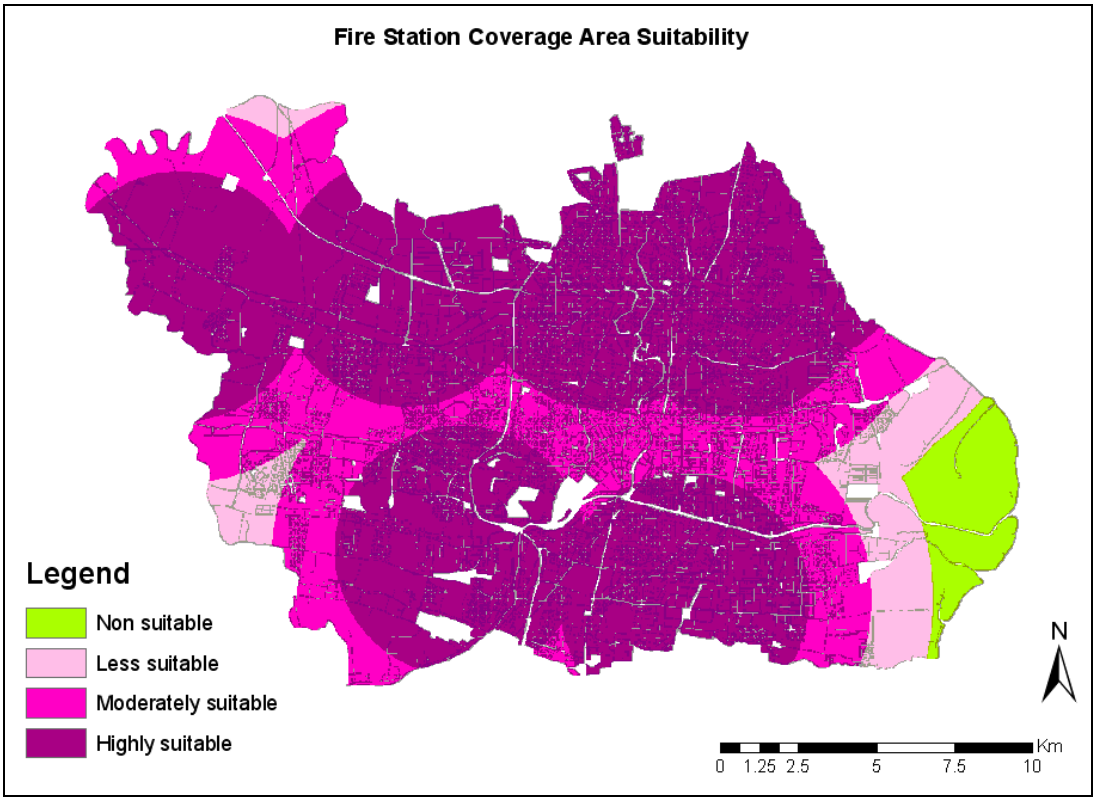


Figure 4.36 Fire Stations' Emergency Response Time Reclassification

Figure 4.37 shows reclassification for hospital's emergency response time. Mostly hospitals are located in the city centre. Based on the range of emergency response time given, some area especially on the most Western part of the city is not covered by hospital service. The most Eastern part of the city also not covered by fire station service and categorized as non suitable zone.

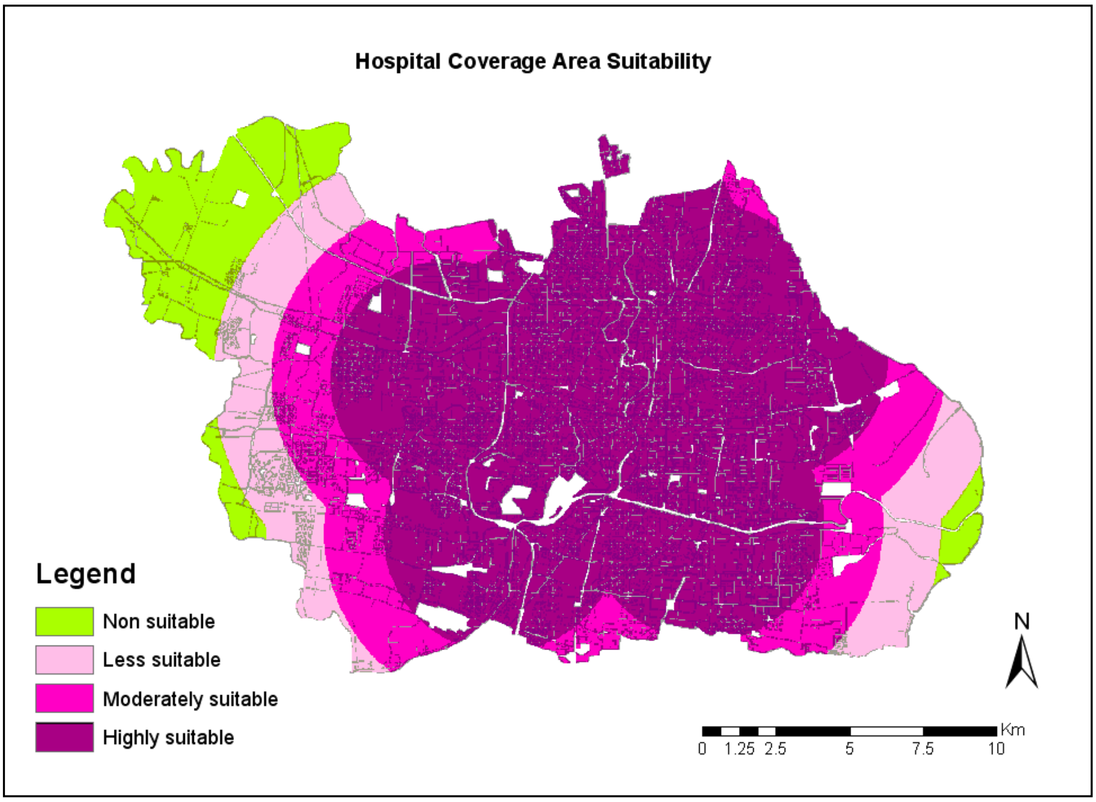


Figure 4.37 Hospitals' Emergency Response Time Reclassification

4.4.3 Implementation and Results of Exclusive Suitable Analysis

Weighted overlay sum is a method that overlays several raster multiplying each by their given weight and summing them together. One major difference between the weighted overlay tool and the weighted sum tool is the weighted sum tool allows for floating point values whereas the weighted overlay tool only accepts integer raster as inputs [74]. The main purpose of utilizing weighted sum method is to differentiate the suitability result with the result of weighted overlay method which includes stakeholders' preferences.

The final suitability map for locating petrol filling station sites is shown briefly in Figure 4.39. Thirteen raster layers are ranked for development suitability on a scale of 1 to 3. As for the weighted overlay sum result, all those raster layers with same weightage are added to the weighted sum table (see Figure 4.38). The result is one final output raster which each cell size is ranked on a scale of 20 to 39.

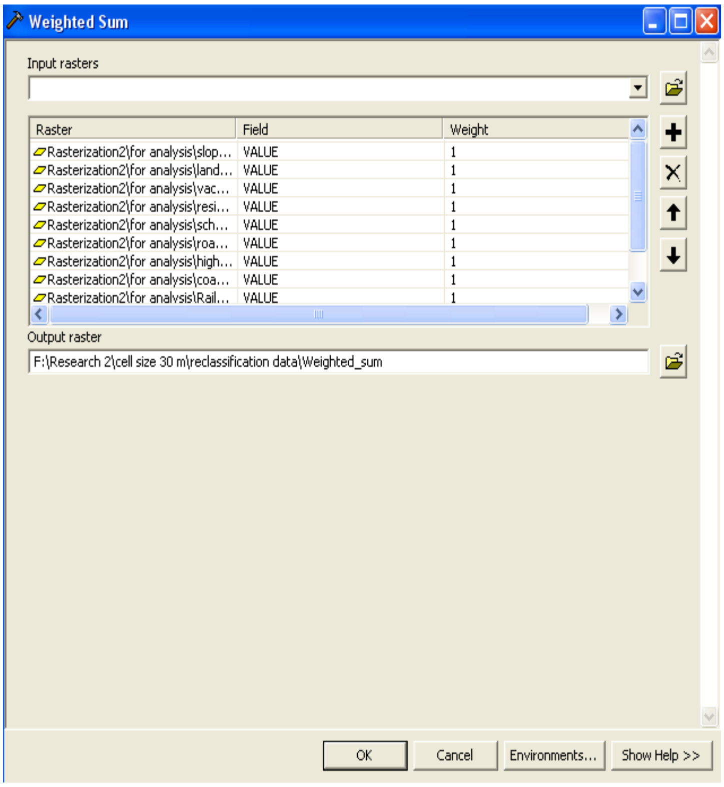


Figure 4.38 Weighted Sum Simulation using ArcGIS 9.3

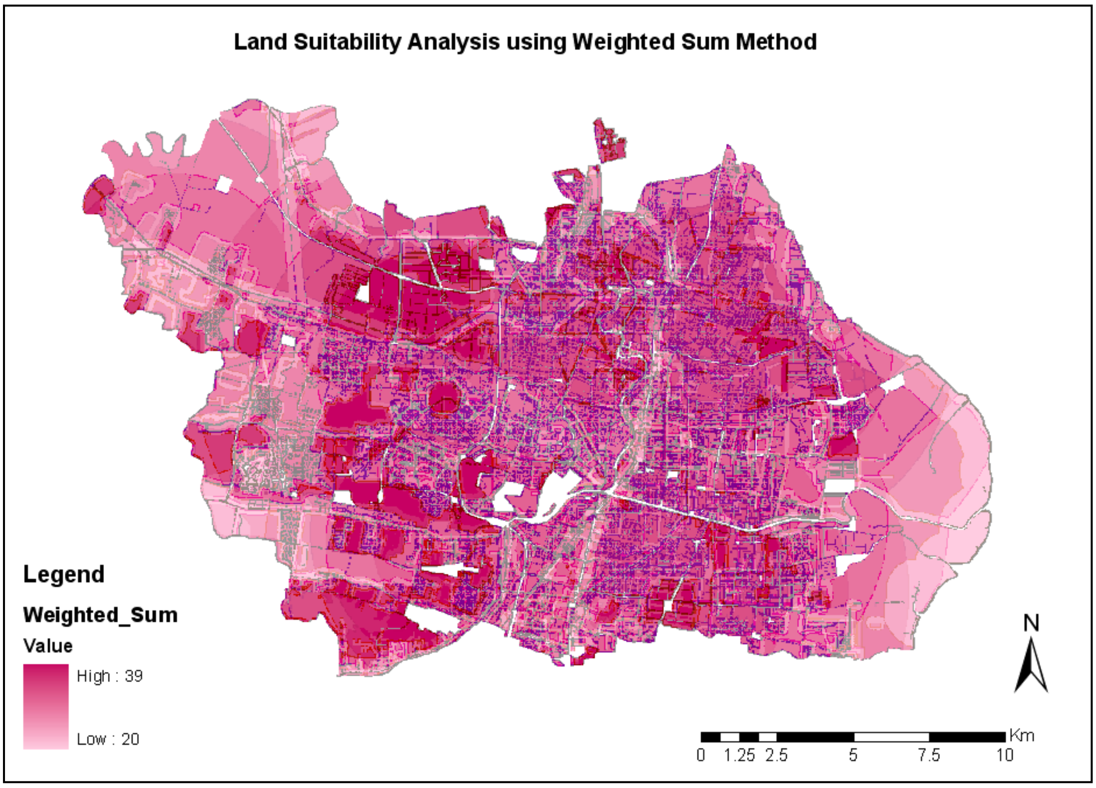


Figure 4.39 Results of Land Suitability Analysis using Weighted Sum Method

4.4.4 Implementation and Results of Preferable Suitable Analysis

Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis. Weighted overlay is needed due to the factors in analysis may not be equally important. Referring to multi criteria decision analysis that had been done before, every criterion has its own level of importance. These levels of importance are assigned into weighted overlay analysis as percentage value followed after reclassifying. The total influence for all raster must equal 100 percent. Figure 4.40 shows the criteria level of importance was assigned to influence column at weighted overlay analysis work sheet.

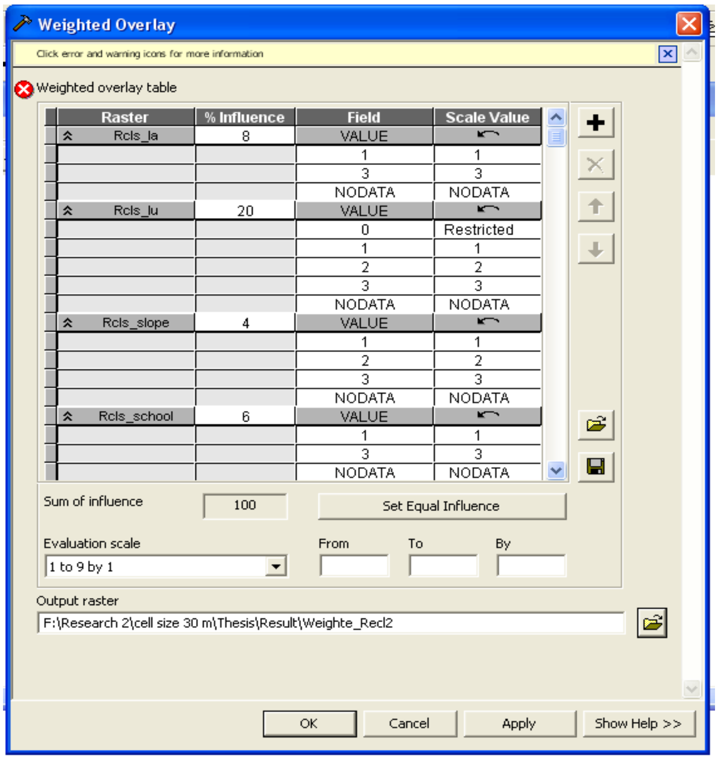


Figure 4.40 Weighted Overlay Simulation using ArcGIS 9.3

Designing spatial analysis model is required to create backbone of GIS operations for this research [74]. The process for determining the suitable parcel for petrol filling station in this study is performed by a GIS Spatial analysis using ArcGIS Model Builder. In model builder process to convert these themes to grid themes using the vector conversion process was carried out. Models are represented as sets of spatial processes, such as buffer, classification, and reclassification and overlay techniques. Each of the input themes is assigned a weight influence based on its importance, then the result successively multiplying the results by each of the constraints. This process is often used in site suitability studies where several factors affect the suitability of a site [89]. Then the GIS overlay process can be used to combine the factors and constraints in the form of a weighting overlay process. Figure 4.41 shows that the model builder for constructing weighted overlay analysis consists of three main system tools: Euclidean distance, rasterization, and weighted overlay.

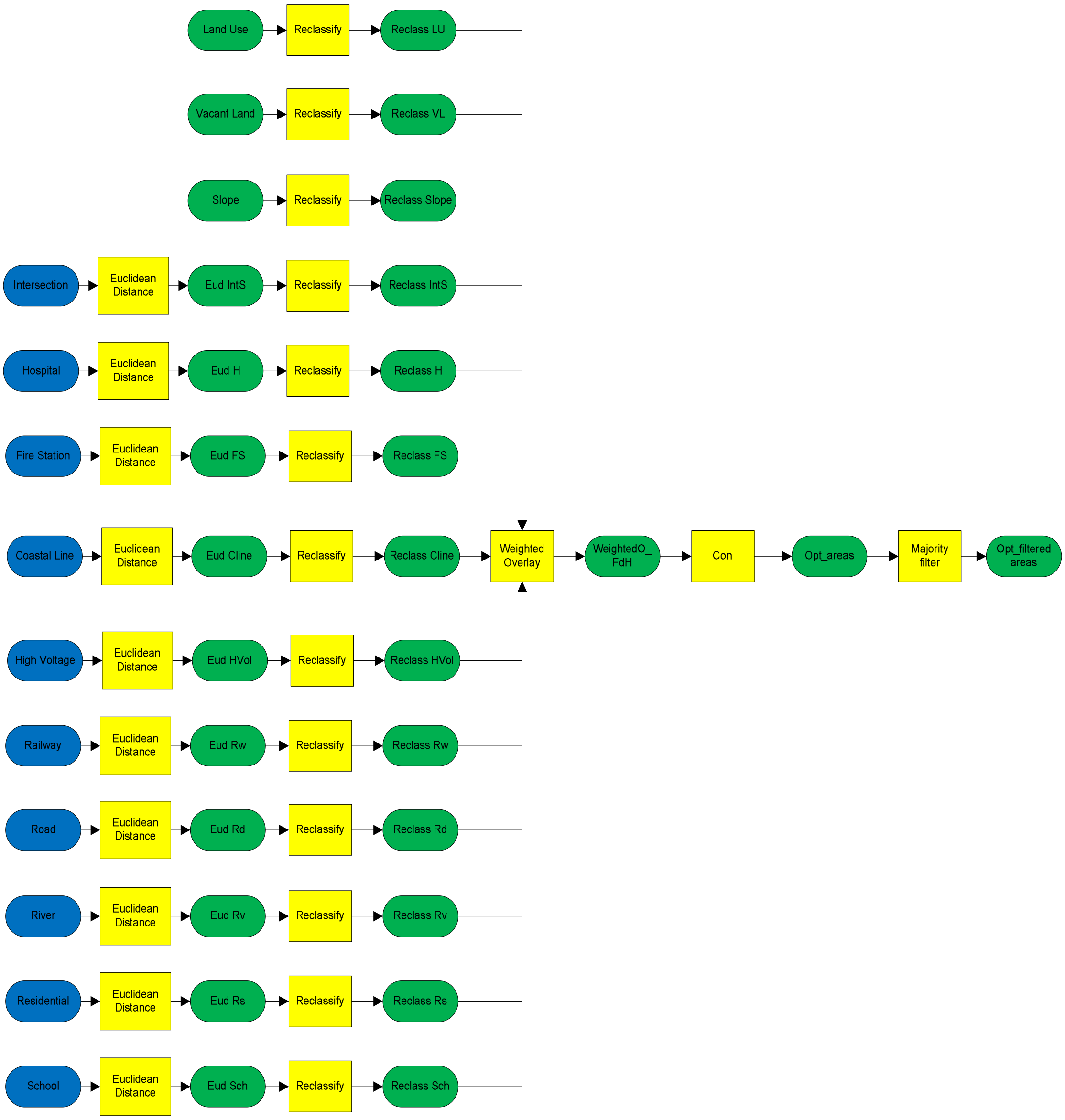


Figure 4.41 Model Builder Weighted Overlay Analysis

The result of weighted overlay analysis is shown in Figure 4.42. The figure below may explain that the area studied has been divided into two sub areas based on the suitability analysis result. Areas that are marked with light purple colour have medium suitability for PFS and finally areas in dark purple colour are highly suitable sites for PFSs. Most of the highly suitable areas for PFSs occupy the western and northern part of Surabaya. Moderately suitable areas occupy the city central and the most eastern parts of Surabaya. In addition, several zones in Surabaya are considered as confidential areas so several spot will be found without colour because have no data availability.

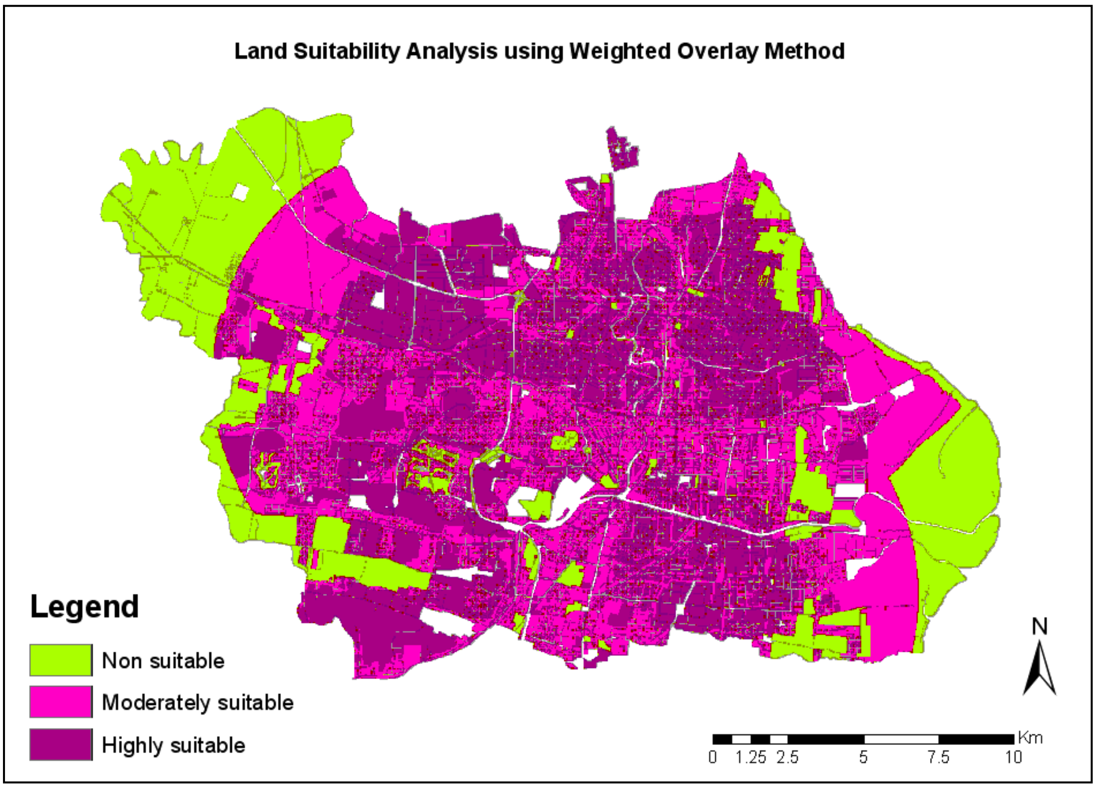


Figure 4.42 PFS Site Suitability Result based on Priority Preference

Figure 4.43 shows the detailed breakdown in terms of the distribution of the suitability index where 44% of Surabaya is classified as moderately suitable for PFS siting. Secondly, highly suitable area makes up 30% of Surabaya. Thirdly, 26% of Surabaya is found to be non suitable for PFS siting.

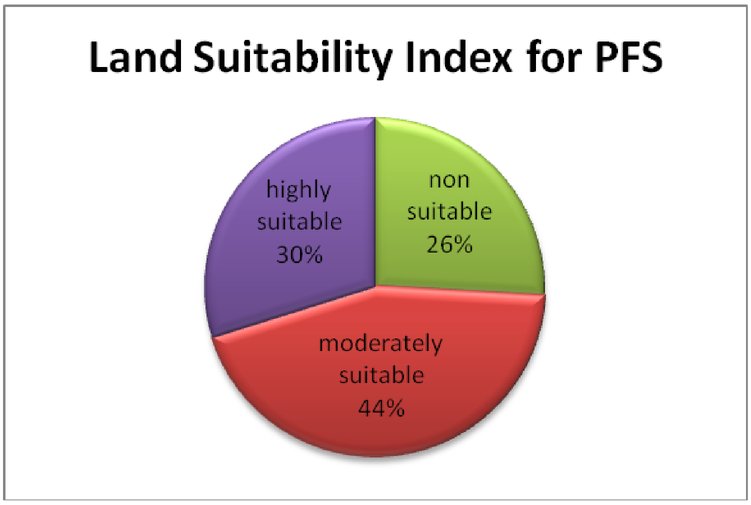


Figure 4.43 Land Suitability Analysis Index for PFS in Surabaya

4.5 Spatial Sensitivity Analysis

Sensitivity analysis is an alternative method to the indirect incorporation of uncertainties into the decision-making process. Sensitivity analysis is concerned with the way in which errors in a set of input data affect the error in the final output (criterion outcomes). Broadly speaking, multicriteria spatial error analysis aims at evaluating the effects of errors (uncertainties) associated with the criterion maps and the decision maker's preference (weights) on the decision outcomes [65].

Depending on the way in which the errors in the input data are defined, two approaches to the error analysis can be distinguished: sensitivity analysis and error propagation analysis [90-92]. Sensitivity analysis is a collection of method used for evaluating how sensitive the spatial multicriteria model output is to small changes in input values. The two most important elements to consider in sensitivity analysis are criterion weights and criterion (attribute) values. Of these, sensitivity to attribute weights is perhaps more important. A sensitivity analysis involving weights consists of investigating the sensitivity of the alternatives to small changes in the value of attribute weights. If the ranking remain unaffected as the weights are varied, errors in the estimation of attribute weights can be consider insignificant [65].

Table 4.4 shows that the initial weight for each criteria was increased or decreased by 10% to perform dynamic sensitivity analysis so that the effects of even a little weight change on priorities can be figured out.

Table 4.4 Results of Sensitivity Analysis PFS Criteria Preference

No.	Alternative		MDTAR (12.7)		PLU (31.2)		PVA (18.3)		PWS (14.2)		ER (23.6)	
			10%	-10%	10%	-10%	10%	-10%	10%	-10%	10%	-10%
		%	13.97	11.4	34.32	28.08	20.13	16.47	15.62	12.8	25.96	21.7
1	Land use pattern	**19.7 (1)**	19.4 (1)	20 (1)	21.6 (1)	**17.7 (2)**	20.8 (1)	20.1 (1)	19.4 (1)	20 (1)	**19.1 (2)**	20.2 (1)
2	Distance to river	11.7 (3)	11.5 (3)	11.9 (3)	11 (3)	12.2 (3)	10.6 (3)	11.9 (3)	12.9 (3)	10.4 (3)	11.3 (3)	12 (3)
3	Distance to residential	**6.1 (6)**	6.1 (6)	6.2 (6)	5.8 (6)	6.4 (6)	6.8 (6)	5.5 (7)	6 (6)	6.2 (6)	**6 (7)**	6.3 (6)
4	Distance to school	6.4 (5)	6.4 (5)	6.6 (5)	6.1 (5)	6.7 (5)	7.1 (5)	5.8 (5)	6.3 (5)	6.6 (5)	6.3 (5)	6.6 (5)
5	Distance to high voltage area	**5.7 (7)**	5.6 (7)	5.8 (7)	5.4 (7)	6 (7)	6.3 (7)	5.1 (8)	5.6 (8)	5.8 (7)	**5.5 (8)**	5.8 (7)
6	Land availability	7.9 (4)	7.8 (4)	8 (4)	8.7 (4)	7.1 (4)	8.3 (4)	8.1 (4)	7.8 (4)	8.1 (4)	7.7 (4)	8.1 (4)
7	Distance to railway	5 (9)	5.4 (9)	4.4 (9)	5.2 (9)	5.2 (9)	5 (9)	5.1 (9)	4.9 (9)	5.1 (9)	4.8 (9)	5.1 (9)
8	Distance to intersection	4.3 (10)	4.7 (10)	3.8 (10)	4.5 (10)	4.5 (10)	4.3 (10)	4.4 (10)	4.3 (10)	4.4 (10)	4.2 (10)	4.4 (10)
9	Distance to road boundary	3.4 (12)	3.7 (11)	3 (12)	3.5 (12)	3.5 (11)	3.4 (11)	3.4 (12)	3.3 (12)	3.4 (12)	3.3 (12)	3.5 (12)
10	Slope	**3.6 (11)**	3.6 (12)	3.7 (11)	4 (11)	**3.3 (12)**	3.8 (12)	3.7 (11)	3.6 (11)	3.7 (11)	3.5 (11)	3.7 (11)
11	Distance to coastal Line	2.5 (13)	2.5 (13)	2.6 (13)	2.4 (13)	2.6 (13)	2.3 (13)	2.6 (13)	2.8 (13)	2.3 (13)	2.5 (13)	2.6 (13)
12	Distance to fire station	18 (2)	17.8 (2)	18.3 (2)	16.9 (2)	18.8 (1)	16.3 (2)	18.4 (2)	17.7 (2)	18.3 (2)	19.7 (1)	16.6 (2)
13	Distance to hospital	**5.6 (8)**	5.5 (8)	5.7 (8)	5.3 (8)	5.9 (8)	5.1 (8)	5.7 (6)	5.5 (7)	5.7 (8)	**6.2 (6)**	5.2 (8)

By referring to Table 4.4 it could be seen that land use priority attribute drops slightly from 1 to 2 when imposing 10% less weight to proper land selection criteria. On the other hand, slope priority attribute decrease slightly from 11 to 12. Other systems marks slightly changes only within a one rating intensity of priority. This means that small changes in this dynamic sensitivity are not significant to the total priority weighting preference.

By comparing Figure 4.44 and Figure 4.45 it could be seen the slight change of land use priority attribute weighting preference when imposed 10% less weight to proper land selection criteria by dynamic sensitivity analysis. A decrease of 10% to proper land selection criteria from 31.2% becomes 28.1% creates slight change for land use priority attribute which decreases from 19.7% to 17.7%.

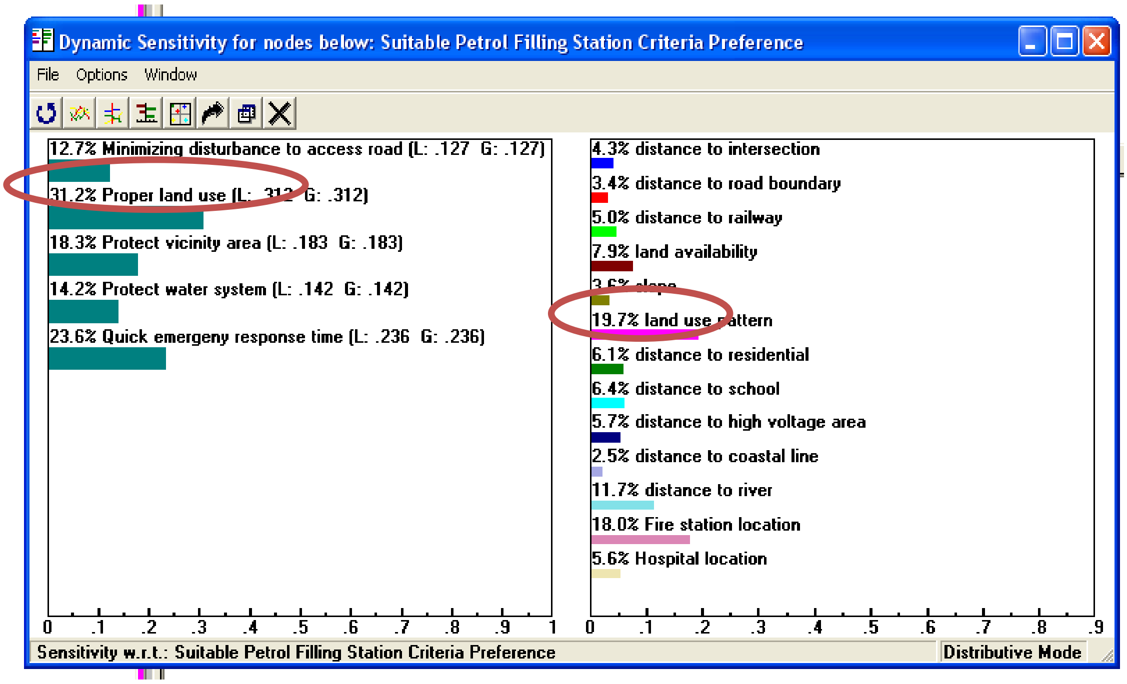


Figure 4.44 Dynamic Sensitivity Analysis

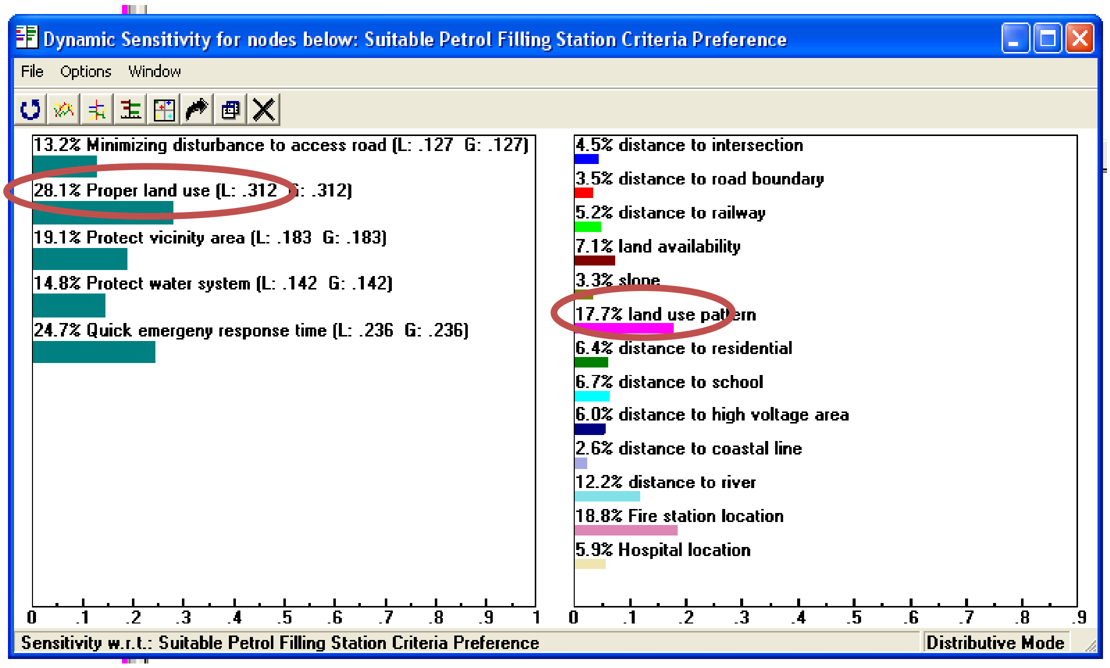


Figure 4.45 Dynamic Sensitivity Analysis with imposing 10% Less Value for Proper Land Selection Criteria

These slightly changes are also changed the distribution of suitability index which is spatially depicted in Figure 4.46. It shows where 26% of Surabaya is classified as non suitable for PFS siting. Secondly, moderately suitable area makes up 40% of Surabaya. Thirdly, 34% of Surabaya is found to be highly suitable for PFS siting.

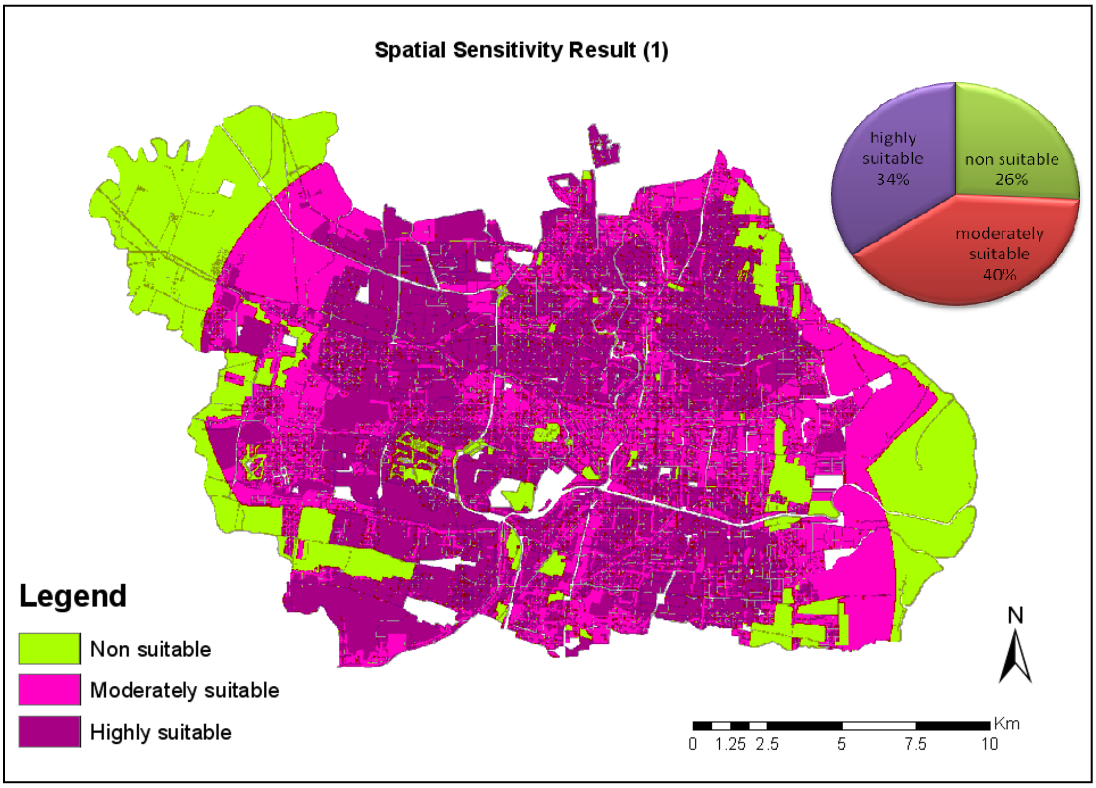


Figure 4.46 The Result of Spatial Sensitivity Analysis with imposing 10% less for Proper Land Selection Criteria

Table 4.4 may also explains that land use priority attribute drops slightly from 1 to 2 when imposing 10% more weight to emergency service criteria. On the other hand, distance to residential priority attribute increases slightly from 6 to 7 when imposed 10% more weight to vicinity area protection and emergency service facility criteria. These slightly changes priority also found for distance to high voltage attribute, slope attribute, and distance to hospital attribute.

By comparing Figure 4.44 and Figure 4.47 it could be seen the slight change of land use priority attribute weighting preference when imposed 10% more weight to emergency service criteria by dynamic sensitivity analysis. An increase of 10% to emergency facility criteria from 23.6% becomes 25.9% creates slight change for land use priority attribute which decreases from 19.7% to 19.1%.

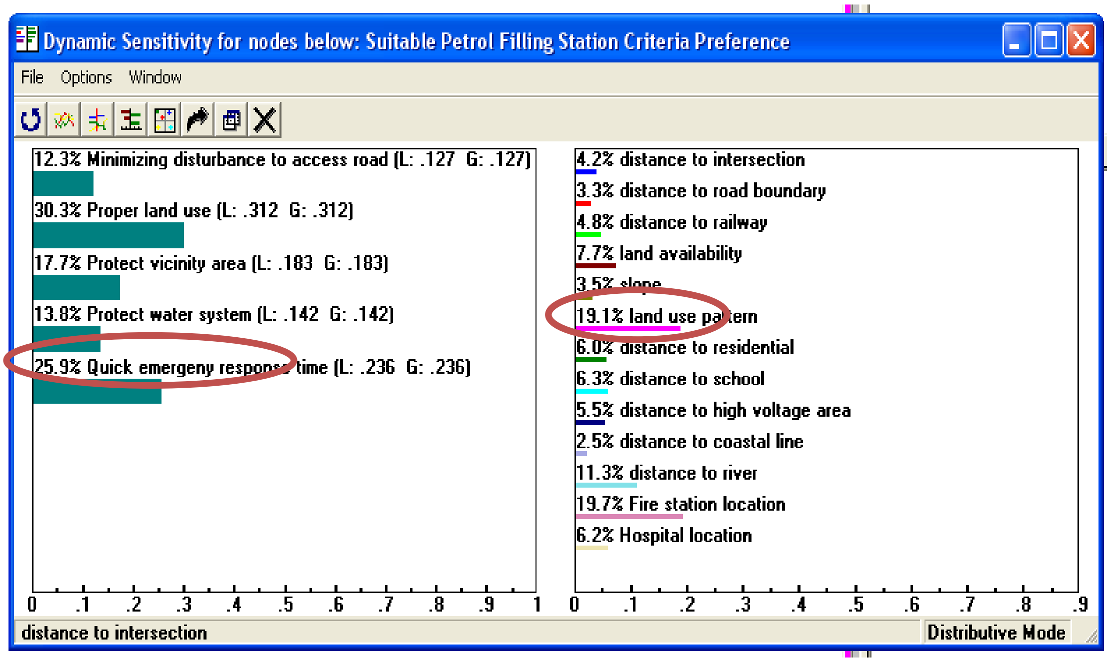


Figure 4.47 Dynamic Sensitivity Analysis with imposing 10% More Value for Emergency Service Facility Criteria

These slightly changes are also changed the distribution of suitability index which is spatially depicted in Figure 4.48. It shows where 26% of Surabaya is classified as non suitable for PFS siting. Secondly, moderately suitable area makes up 44% of Surabaya. Thirdly, 30% of Surabaya is found to be highly suitable for PFS siting.

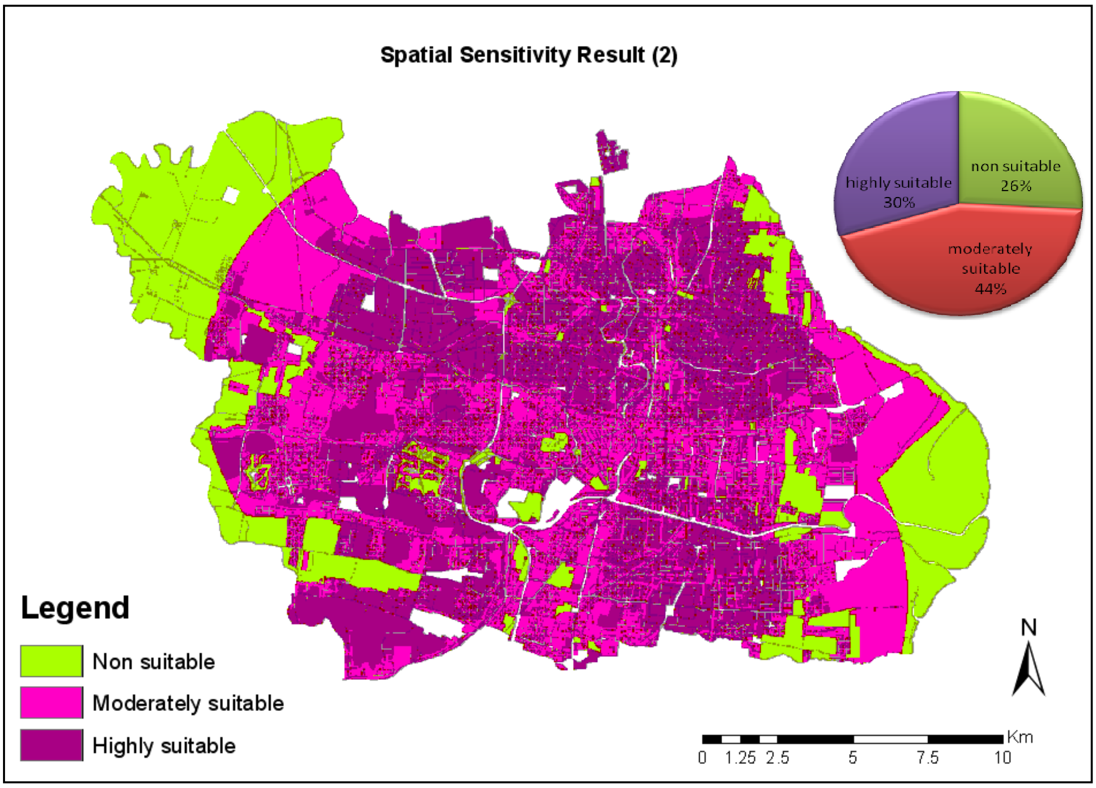


Figure 4.48 The Result of Spatial Sensitivity Analysis with imposing 10% More Value for Emergency Service Facility Criteria

From both result of spatial sensitivity analysis it could be concluded that the sensitivity of priority preference, which is land use attribute taken as example, do not give significant influence to spatial changes. The highly suitable zone remains in the range of 30%-34% of Surabaya. The medium suitable zone are in the range of 40%-44% and non suitable zone does not show any changing which is statically make up 26% of Surabaya.

4.6 Comparison with Factual Condition

Surabaya currently has 90 PFS sites. This PFS distribution can be viewed from Google earth. By converting kml file to shp file, these existing PFS location distributions can be transformed into ArcGIS data file in order to be overlaid with the result of suitability analysis so that the number of PFSs that are already sited in highly suitable zone can be known. The result is shown in Figure 4.49.

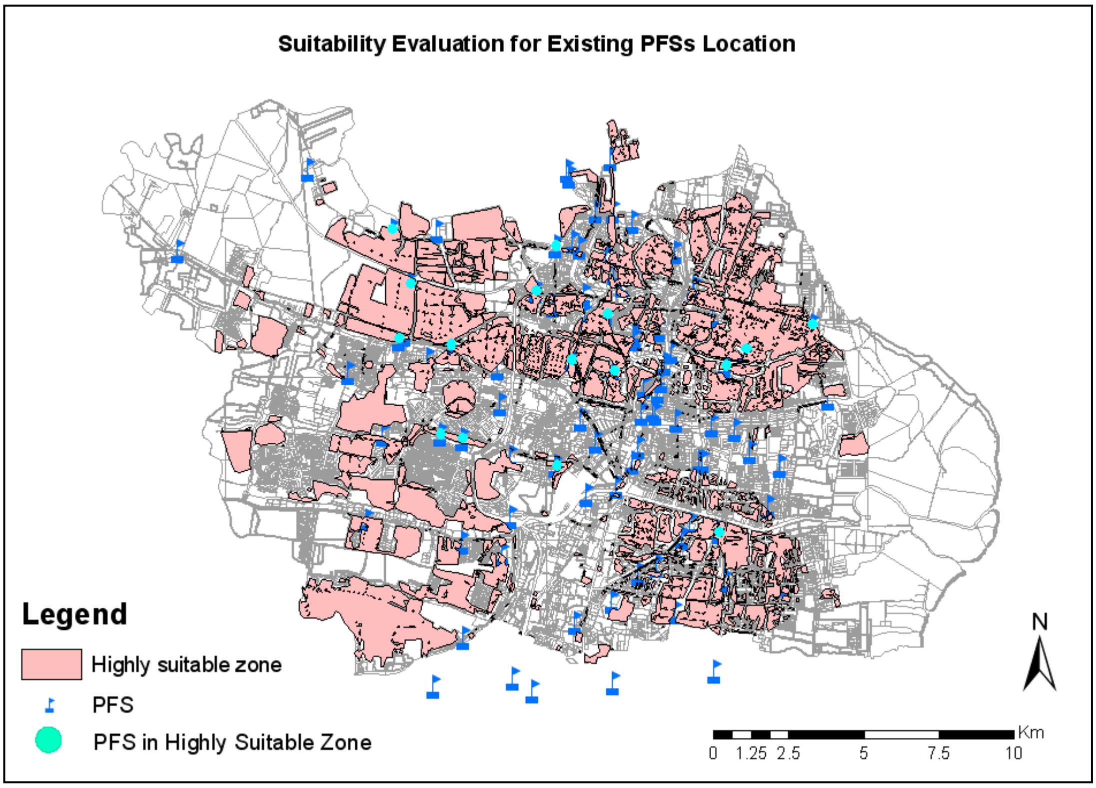


Figure 4.49 Existing PFS which are Located in High Suitable Sites.

Figure 4.49 shows over ninety PFSs already exist in Surabaya: sixteen of them are sited completely within highly suitable zone based on this suitability analysis study. In conclusion, the integration of GIS and AHP in this study has uncovered the fact that 82.22 % of the total numbers of existing PFSs in Surabaya are not located in highly suitable zone.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

The findings of this research have provided vital information about PFS siting in the metropolitan area of Surabaya. The conclusions of this research have to answer the objectives of the study. The site suitability of PFS Surabaya based on GIS-based hierarchy process approach has been identified into highly suitable, moderately suitable, and non suitable areas. The areas which are represented by dark purple colour is represented as highly suitable zone, light purple colour as moderately suitable zone, and green purple colour as non suitable for PFSs sitings.

Below are the answers for the main objectives of this research. Five criteria were considered to determine the PFS location with regards to the risks that might occur. The criteria are avoiding access road obstruction, proper land selection selection, vicinity area protection, water system protection, and quick emergency response time.

1. Based on the hierarchy process, the highest ranking or the most influential criteria for determining PFS location is proper land selection with a 0.312 weightage or 31.2% preference. This is followed by emergency service response facility with 0.236 weightage or 23.6% preference, vicinity area protection with 0.183 weightage or 18.3% preference, water system protection with 0.142 weightage or 14.2% preference, and minimized disturbance to access road with 0.127 weightage or 12.7% preference.
2. The result of suitability analysis shows detailed breakdown in terms of the distribution of the suitability index where 44% of Surabaya is classified as moderately suitable for PFS siting. Second most are areas with highly suitable

which make up 30% of Surabaya. Only 26% of Surabaya is found to be non suitable for PFS siting.

3. Dynamic sensitivity analysis was utilized to assess the validity of those criteria ranking. It shows that only small changes occur as much as 4% of the spatial output suitability index when imposing 10% influence by increasing or decreasing the initial weightage for each criterion. This means that small changes in this dynamic sensitivity are not significant to bring changes for spatial output model.
4. The comparison between actual conditions and the result of suitability analysis shows over ninety PFSs already exist in Surabaya: sixteen of them are sited completely within highly suitable zone based on this suitability analysis study. In conclusion, the integration of GIS and AHP has uncovered the fact that 82.22% of the total numbers of existing PFSs in Surabaya are not located in highly suitable zone.

5.2 Recommendations

As can be seen from the finding of this study, due to environmentally insensitive PFS siting, presently about 82.22% or 74 PFS in Surabaya are not located in highly suitable zone. It is strongly recommended the finding of this research should be used as a guideline for the siting of future PFS in Surabaya as the other localities. Several other parameters which were not included in this study such as groundwater and public well should also be included.

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PUBLICATIONS

1. A.N. Matori and B.U. Aulia, “Suitability Analysis of Petrol Filling Station Site Using GIS”, *Malaysian Construction Research Journal (MCRJ) 2010, Vol.7, No.2, Pg. 1-14.*
2. B.U. Aulia and A.N. Matori, “Suitability Analysis of Petrol Filling Station Site Using GIS”, *International Conference on Suitability Building and Infrastructure 2010,* Kuala Lumpur, Malaysia.
3. B.U. Aulia and A.N. Matori, **“**Suitability Analysis of PFS Site Using GIS-based on AHP: An Evaluation Study for Factual Condition”, *9th Annual Asian Conference & Exhibition on Geospatial Information, Technology and Applications 2010*, Kuala Lumpur, Malaysia.

APPENDIX A

QUESTIONNAIRE

Appendix A consists of a questionnaire that has been distributed to thirteen respective stakeholders. Number of questionnaires received is also thirteen, all obtained via email or direct interview.

UNIVERSITI TEKNOLOGI PETRONAS

CIVIL ENGINEERING

Research Questionnaire of Siting Suitability Analysis of Petrol Station Site Using GIS and AHP: A Case Study of Surabaya Metropolitan

UNIVERSITI TEKNOLOGI PETRONAS

INTRODUCTION

Dear respondent,

For your kind information, The Department of Civil Engineering of Universiti Teknologi PETRONAS (UTP) is conducting a study on 'Site Suitability Analysis for Petrol Filling Station: A case Study of Surabaya Metropolitan' using Geographic Information System (GIS) and Analytical Hierarchical Process (AHP) through one of its Postgraduate Research Project.

Petrol Stations are amongst those that high potential of fire hazard due to their dangerous storage, hence their placement should be carried out properly. Their improper placement could lead to disastrous consequences during fire and causing pollution to surrounding soil and underground water should leakage occur to their under storage tanks.

In Surabaya metropolitan, the growth of motor cycle is around 12% per year and the total number of car and motor cycle is up to 1.6 million, hence the need to establish new petrol stations is always there to add to the 90 stations that have already existed. Therefore this study has the objectives of assisting the proper placement of the new stations and the suitability location assessment of the existing petrol stations.

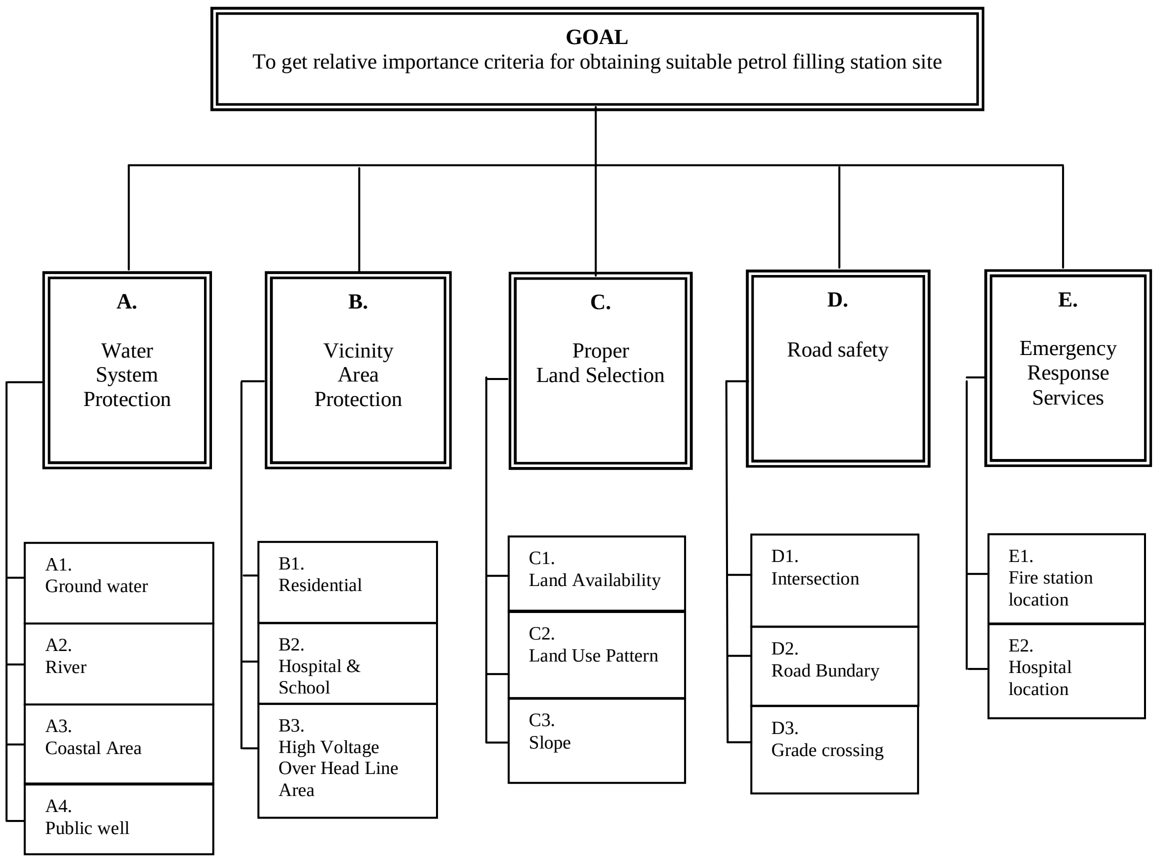
Amongst others to address the above issues, we have devised a questionnaire which we would like your good self to complete and return to us before 30th November 2009 with the enclosed self-address and prepaid-postage envelope. The survey will take no more than 15 minutes to complete, and for further clarification please contact Ms. Belinda Ulfa Aulia. Response and time is greatly appreciated. Thank you!

Yours sincerely,

Researcher:
Belinda Ulfa Aulia
MSc Student of Civil Engineering
University Technology PETRONAS
Tronoh, Perak, Malaysia
Ph: +60134830795
+628179612187
E-mail: b3ltown@gmail.com
b3l_city@yahoo.co.id

Supervisor:
Dr. Abd. Nasir B Matori
Assoc. Prof of Geomatics/Geoinformatics,
Civil Engineering Department,
University Technology PETRONAS,
Tronoh, Perak, Malaysia.

Criteria Hierarchy of Petrol Filling Station Suitability Site



INSTRUCTIONS

The purpose of this questionnaire is to rank the relative importance of evaluation factors as shown in the table below by utilizing the AHP method. The question ask you to:
(1) rank evaluation factors (criteria),
(2) compare two factors of them as a pair, and
(3) repeat such pairwise comparison for all combinations.
The question starts from level 1 for Criteria and level 2 for Sub-Criteria.

Table A1. Analytical Hierarchical Process Scale of Judgments by Saaty 1990

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the property.
2	Weak or slight	
3	Moderate importance of one over another	Experience and judgment slightly favour one element over another.
4	Moderate plus	
5	Essential or strong importance	Experience and judgment slightly strongly favour one element over another.
6	Strong plus	
7	Very strong importance	An element is strongly favourable and its dominance is demonstrated in practice.
8	Very, very strong	
9	Extreme importance	The evidence of favouring one element over another is of the highest possible order of affirmation.

Referring to the ranking that you have above, please compare two factors in each table below as a pair, select one that is more important than the other and **<u>Bold/Underline</u>** the coresponding box. If you think from two criteria, A is moderate important other than B, please leave boxes in the A row number labelled **"3".**

Example:
If "Energy Efficiency" is **moderate importance** than "Indoor EQ", then the **Intensity of Importance** is **3**, afterward number **3** had to be **<u>Bold/Underline</u>** in Energy Efficiency row number.

Energy Efficiency	9	8	7	6	5	4	**<u>3</u>**	2	1	2	3	4	5	6	7	8	9	Indoor EQ

If "Energy Efficiency" is **equal importance** than "Indoor EQ", then the **Intensity of Importance** is **1**, afterward number **1** had to be **<u>Bold/Underline</u>**.

Energy Efficiency	9	8	7	6	5	4	3	2	**<u>1</u>**	2	3	4	5	6	7	8	9	Indoor EQ

RESPONDENT PROFILE

Name : ....

Gender : Male/Female *

Age : (20-30) / (31-40) / (41-50) / (>50) years *

Degree : Bachelor/Master/Doctorate//Other.................. *

Profession : ....

Organisation/Institution/Company : ....

Experience in Green Building : <2 / 3-5 / 6-10 / 11-15 / >15 years *

Date : ....

***<u>Bold/Underline</u>**

SECTION A: LEVEL 1 - CRITERIA

Referring to the instructions on page 3, please compare two Criteria/Sub-Criteria and judge the relative importance in each pair in the table below (i.e. how much more important one of paired factors is than the other) by using the judgement scale of AHP method. **Bold/Underline** the number in one box corresponding to your judgement on the side of the more important criteria than the other. If two criteria are equally important, **bold/underline** the number of "equally=1" in the centre of the scale.

Please rank the followong six criteria's in order of importance, and indicate an appropriate number in the bracket on the left of each factor. If you think two or more factors are equally important, please assign the same number to them.

A. Protect Water System:
UST's leaking is having great hazard for water system. It can contaminate groundwater then possibly flow towards private/public well, river, and lake. In another case by intrusion of sea water, it can be corode then leaking.

B. Protect Vincinity:
Fire break out potential hazard of petrol filling station is giving threat to the vincinity specially for sensitive area such as residential, hospital, and school.

C. Proper Land Use:
Due to environmental safety, petrol filling station should be built in particular area that is considering about topography, zoning, and availability of width parcell.

D. Minimizing Disturbance to Access Road:
Petrol station has high trafic attraction so it is able to cause obstructions for access road due to entering or leaving activities from station.

E. Quick Response to Fire Accident:
Due to fire breakout hazard that is potential occured in petrol station so it is important to provide coverage and analyze response times from the station to the emergency site.

A	Protect water system	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Protect vincinity	**B**
A	Protect water system	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Proper land use	**C**
A	Protect water system	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimizing disturbance to access road	**D**
A	Protect water system	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quick Response to fire accident	**E**

B	Protect vincinity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Proper land use	**C**
B	Protect vincinity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimizing disturbance to access road	**D**
B	Protect vincinity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quick Response to fire accident	**E**

C	Proper land use	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimizing disturbance to access road	**D**
C	Proper land use	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quick Response to fire accident	**E**

D	Minimizing disturbance to access road	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quick Response to fire accident	**E**

SECTION B: LEVEL 2 – SUB CRITERIA

Please rank the following Sub Criteria in order of importance concerning Suitability Analysis of Petrol Station Site, and indicate an appropriate number in the bracket on the left of each factor. If you think two or more factors are equally important, please assign the same number to them.

A. Sub-Criteria of Protect Water System

Please repeat ranking and pair wise comparisons of the following four sub criteria's of protect water system:

A1. Ground water : protect groundwater from contamination caused by UST's leaking
A2. Sea water : protect sea water from to of UST's corrosion because the brine leads to leakage
A3. Private well : protect private well from UST's leaking
A4. River & lake : protect river and lake as one of important drinking resource from ground water contamination or direct UST's leaking

A1	Ground water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Sea water	**A2**
A1	Ground water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Private well	**A3**
A1	Ground water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	River & lake	**A4**
A2	Sea water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Private well	**A3**
A2	Sea water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	River & lake	**A4**
A3	Private well	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	River & lake	**A4**

B. Sub-Criteria of Protect Vincinity

Please repeat ranking and pair wise comparisons of the following three sub criteria's of protect vincinity:

B1. Residential : protect residential as sensitive area for dwelling facility
B2. Hospital & school : protect hospital and school as facility that accomodate public service
B3. High voltage area : protect vincinity area from electro static environment that could be occured by high voltage elctricity utility that is located near to pump island of petrol filling station

B1	Residential	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hospital & School	**B2**
B1	Residential	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Electro static environment	**B3**
B2	Hospital & School	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Electro static environment	**B3**

C. Sub-Criteria of Proper Land Use

Please repeat ranking and pair wise comparisons of the following three sub criteria's of proper land use:

C1. Land availability : area of land to be developed should be sufficient to allow maneuvering of vehicles within its cartilage but should not be less than 12,000 sq.
C2. Topography : petrol filling stations should be built on level rather than sloping site to prevent rolling or discarded materials such as cans, drums, etc.
C3. Land use pattern : petrol filling station should be located in commercial/industrial zone or be designated specifically for the purpose in a subdivision.

C1	Land availability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Topography	**C2**
C1	Land availability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Land use pattern	**C3**
C2	Topography	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Land use pattern	**C3**

D. Sub-Criteria of Minimizing Disturbance to Access Road

Please repeat ranking and pair wise comparisons of the following three sub criteria's of minimizing disturbance to access road:

D1. Traffic light junction : avoiding traffic jam becuase petrol station that's located near to traffic light junction will create obstructions.

D2. Road width : road width at least 8 m will give good access for any type vehicle to access petrol filling station.

D3. Grade crossing : vehicular access/egress/crossover should be reasonably safe with adequate approach distances especially where main roads, intersections, and grade crossing are involved.

D1	Traffic light junction	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Road width	**D2**
D1	Traffic light junction	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Grade crossing	**D3**
D2	Road width	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Grade crossing	**D3**

E. Sub-Criteria of Quick Response to Fire Accident:

Please repeat ranking and pair wise comparisons of the following three sub criteria's of quick response to fire accident:

E1. Fire station location : fire station location determine response times for emergency calls of fire accident.

E2. Hospital location : hospital location determine response times for any victim of fire accident.

E3. River & lake location : river and lake is supporting fire station to obtain water suply for emergency condition.

E1	Fire station location	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	River & lake location	**E2**
E1	Fire station location	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hospital location	**E3**
E2	River & lake location	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hospital location	**E3**

SECTION C: General Questions

[1] What is your opinion about petrol filling sation location in Surabaya now days?

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[2] How much do you think GIS will help much to propose appropriate location for petrol filling station?

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 # Thank you for your cooperation and greatly appreciates for your time and early response#