SOIL CHARACTERISTICS USING BORELOGS DATABASE FOR PENANG ISLAND

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SOIL CHARACTERISTICS USING BORELOGS DATABSE FOR PENANG ISLAND

by

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ABSTRAK

Sistem Maklumat Geografi (GIS) mampu mengintegrasikan, menganalisis, dan mengurus data dan atribut yang berkaitan dan memaparkan maklumat yang dirujuk secara geografi, yang secara spasial dirujuk ke Bumi. GIS juga berupaya untuk menggabungkan pelbagai peta dan maklumat penderiaan jauh untuk menghasilkan model yang digunakan dalam persekitaran masa nyata. Oleh itu, perisian GIS mampu mengembangkan peta tanah berdasarkan laporan penyiasatan tapak di Pulau Penang untuk penyelidikan ini. Penyelidikan ini bertujuan untuk menentukan taburan tanah di Pulau Penang yang diambil dari data sekunder. Data tanah dikategorikan kepada 13 kelas jenis tanah dan 10 kumpulan jumlah bilangan pukulan (SPT-N) untuk menghasilkan peta tanah untuk Pulau Pinang. Kaedah interpolasi Kriging dan Natural Neighbor digunakan untuk menghasilkan peta jenis tanah tanah dan peta SPT-N di Pulau Penang. Hasil dari pemetaan menunjukkan bahawa jenis tanah pada kedalaman 5m hingga 10m majoriti mengandungi pasir dan mewakili 44% hingga 40% dari keseluruhan kawasan di Pulau Penang. Ini disokong oleh data yang dikumpulkan dan melalui pemetaan di mana lebih dari 31% jenis tanah adalah pasir berlumpur pada kedalaman 5-meter dan lebih dari 30% pada kedalaman 10m. Selama 15 hingga 30m, sebahagian besar tanah di tingkat itu adalah Kerikil dan Granit yang merupakan 46% hingga 55% dari keseluruhan kawasan di Pulau Pinang. Ini disokong oleh data yang dikumpulkan dan dipetakan pada kedalaman 15m, yang menunjukkan bahawa Granit merangkumi lebih dari 45% permukaan bawah tanah, dan di 20m hingga 30m di mana Granit meliputi lebih dari separuh kawasan. Ini akan memudahkan jurutera dan pembuat dasar membuat perancangan dan pelaksanaan yang sesuai dalam pembangunan masa depan di Pulau Pinang.

ABSTRACT

Geographic Information System (GIS) is capable of integrating, analysing, and managing data and associated attributes and displaying geographically referenced information, which are spatially referenced to the Earth. GIS also allows to combine various maps and remote sensing information to generate models which are used in real time environment. Therefore, GIS software is capable to develop the soil map based on the Site Investigation reports in Penang Island for this research. This research aim is to determine the distribution of soil in Penang Island retrieved from secondary data. The soil data were categorised into 13 classes type of soil and 10 group of number of blows (SPTN) to develop the soil map for Penang Island. Kriging and Natural Neighbor interpolation method were used to develop the soil mapping of soil type and SPT-N map of Penang Island. The results of the mapping demonstrate that Sand is the most abundant type of soil at depths of 5 to 10 metres, covering for 44% to 40% of the total area of Penang Island. This is validated by the data collected and the mapping, which shows that Silty Sand makes up more than 31% of the soil type at 5-meter level and more than 30% at 10-meter level. Gravel and Granite make up the majority between 15 and 30 metres, accounting for 46% to 55% of Penang's total area. This supported by data gathered and mapping at a depth of 15 metres, which shows that Granitic rock makes up more than 45% of the subsurface, and from 20 metres to 30 metres where Granite covers more than half of the region. This will ease the engineers and policy makers make appropriate planning and implementation in the future development on Penang Island.

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CHAPTER 1

INTRODUCTION

1.1 Background

Geotechnical design plays key role in construction work responsible for evaluating subsurface, soil conditions, and materials. At the first step of the construction, the physical properties, initial condition, and types of the soil in the location are needed to be verify in the engineer's site investigation report designing the geotechnical structure based on the geotechnical conditions found. Thus, the soil characteristics such as the strength of the soil can be determined.

A population of 752,800 (Department of Statistics Malaysia,2015) and a density of 1663/km^2 (Penang Institute,2016), Penang Island is one of the most rapidly increasing and densely populated area. As a result, coastal areas are becoming increasingly congested and compact as the human population grows. The urbanisation area was saturated in the northeast corner of the island around Georgetown and spread along the north coast to the east coast of Penang Island. However, Penang Island is still undeveloped to the extent of 62.6 %. Development Penang's hilly centre is largely restricted by topography, geotechnical and environmental constraints limit development in Penang's steep central district. (Barrow, 1981, Yahaya et al., 2013)

Construction at the hill's environment requires proper management, design, construction, and maintenance (Sew and Tan 2003). A hilly or a mountainous country and slope failure are a common occurrence. Penang is one of the states in Malaysia which is corrugated with hilly topography. Due to its hilly geography and limited flat lands, land has become one of Penang's most constrained resources, which is rapidly depleting. Due to its hilly geography and limited flat lands, land has become one of Penang's most constrained resources, rapidly depleting. In facing future challenges due to rapid economic development, there are high demands for flat ground area requirements (Yahaya et al., cited in Ahmad, 2005). Therefore, new projects are move to the hilly areas as for the development. Thus, a proper engineering design based on the soil characteristic at the site is important to ensure a safe design and effective for construction.

The collected secondary data from the site investigation report at any given site location provides the required information about the soil profile of that location such as each soil type, SPT N value, and core recovery value. Thus, an inclusive soil distribution map based on each borehole depth can be developed for the whole of Penang Island by using GIS software. In addition, a study on the characteristic of the soil in Penang Island should be done as it is more comprehensive for the geotechnical experts and engineers assigned to plan and design the project properly based on the soil characteristics. This study aims at the soil characteristics in Penang Island to determine the soil parameters and their correlations to hazard susceptibility by generating sub-surface soil profile and correlating all soil data using statistical analysis. This will ease the engineers and policy makers make appropriate planning and implementation in the future development on Penang Island.

1.2 Problem Statement

Highly aware of the rapid development and resulting urbanisation of the island, the Penang state government launched several projects to spread out the population and to resolve the traffic congestion that has become a major problem in recent years. Traffic congestion is probably one of the major issues that comes with urbanisation, particularly on the island side of the state. According to Think City's chief operating officer Dr Neil Khor, the population at Central Seberang Perai is currently high but the land use is inefficient so there is a need for a detailed development plan to maximise efficient land use. Nevertheless, rapid urbanisation on the eastern coast and the extreme scarcity of flat land on the island have resulted in development creeping up hilly slopes. (Chacko, 2019).

According to a Penang Forum Steering Committee member and a former Councillor in the Penang Island City Council (MBPP), Lim Mah Hui, concurs that the pressure to develop hill land originates from the fact that hill land is much cheaper than flat land. (Chacko, 2019) This allows developers to developers to build residential units at significantly cheaper prices than if it were on flat land. However, illegal earthworks spread out over 40 acres was found on the hill measuring between 200 metres and 350 metres. (Mok, 2020) Thus, illegal hill clearing with improper planning and lack of geotechnical design at the hilly area can exposed to surface erosion, resulting in sedimentation of drainage systems that lead to flash floods. Besides, construction work on hilly areas also exposes the core rock, making them susceptible to landslides.

Penang also lacks in local plan (Hai, 2013), which regulates planning and density control. As a result, guidelines have readily tampered with the Local Planning Authority's local plan is a physical planning document that converts the structural plan's policy and strategic planning into a more precise land use map. The role of a local plan is important in preventing hazard development from happening. Thus, the state should make every effort to expedite the implementation of a local plan in Penang. Distribution of development from the land-strapped Penang Island to the wide mainland area of Penang State, which is flat and has less geotechnical obstacles to develop, must also be prioritised.

Consequently, environmental impact assessment for structure and local plans should be carried out the development plans level. This will make it easier to direct planning decisions on the ground and allow local planners or decision-makers to make informed decisions on what type of development is most appropriate for a given location, rather than only focusing on a single sort of development. plot of land. Furthermore, the site investigation process of any structure design plays a critical role. In inadequate characterization of the subsurface conditions can contribute either to a substantially over-designed, cost-effective solution or an under-designed solution that may lead to possible failures. One of the site investigation's key goals is to help solve any potential problems that might occur due to land and other local factors during the construction process. Preliminary geotechnical investigation is currently a factor in project delays, conflicts, charges, and overrun costs.

1.3 Objective

1. To determine the distribution of soil with reference to soil type and SPT-N values from secondary data in Penang Island

2. To correlate all the soil data in Penang Island based on the soil type distribution using statistical method.

3. To develop the subsurface profile of soil type of Penang Island in three-dimension.

1.4 Scope of Works

The scope of the study is to generate the Penang Island soil map using secondary data gathered from the previous site investigation report. The soil type and N-value from standard penetration test (SPT) can be determined to create soil profile layers in the site investigation report. SPT-N values of soils can be acquired during boring construction, the process starting from the driving of sampler into the soil through a borehole at the desired depth. Next, a hammer with a standard weight of 63.6 kg (140 lb) is allowed to fall freely 762 mm (30 in) onto a collar that is attached to the top of the drill string until 457 mm (18 in) of penetration has been achieved (Kumar et al., 2016). The number of blows counted until the sampler reaches the typical depth will be the SPT number.

The SPT-N value is used to determine the strength of the soil. In sandy soils, the SPT-N value reflects the friction angle, while in clay soils, it shows the stiffness of the clay stratum. The SPT has been used to correlate unit weight, relative density, angle of internal friction, and undrained compressive strength, among other soil properties. It has also been used to calculate the stress-strain modulus and the bearing capacity of foundations.

Digital Soil Mapping (DSM) has become progressively critical for enhancing existing soil information and generating soil property maps at the suitable spatial resolution for sustainable soil landscape management (Ellili-Bargaoui et al., 2020). Using the soil data attribute, the soil mapping for every 5m interval until 30m depth can be developed by using the interpolation method in ArcGIS. The software processing of geological data such as geological borehole and spatial information management, geological interpretation and three-dimension graphic visualization used to analyse geological information and create a three-dimensional geological model. Therefore, this research was carried out to produce soil type map as to predict the separation of the soil and a three-dimension soil profile based on the 34 project's site investigation report. After that the distribution of soil type were correlated using statistical analysis to determine if any significant difference between the analysis.

1.5 Importance of Study

A site survey is a process carried out by the engineer to retrieve data and produce the site investigation report as the reference for the general characteristic of the soil at that location. Soil characterization maps can be developed by integrating Geographic Information System (GIS) and Site Investigation (SI) based on soil types and SPT N values gathered for each 5m interval until 30m depth to visualize the soil data professionally. This study can assist the city councils, developers, and civil engineers to save their time and minimize the construction budget by knowing the basic distribution of the soil under the specified land use by referring to these maps. The soil mapping will characterize the existing diversity in terms of soil type and soil properties in Penang Island which will ease future development.

Different soil kinds have different behaviours and physical features. According to Green (1992), integrating Remote Sensing into a GIS database can reduce the cost, time, and amount of comprehensive information acquired for soil investigation. Furthermore, it can reduce the cost when the number of the boreholes for conduction a site investigation can be minimize. Next, this will also help guide the selection of the conversation practices for specific site and reduce the risk an overrun costly project during the planning phase based on the soil distribution map.

1.6 Dissertation Outline

This study consists of five chapters which are as follows:

Chapter 1:

This chapter consists of a problem statement, objective to be achieved, scope of works and the importance of this study.

Chapter 2:

A literature review on the explanation of the soil formation, GIS, Penang Island, statistical analysis, three-dimension analysis and method that have been used. The paper referred by previous researchers.

Chapter 3:

Methodology explaining the step taken in completing this study with the help of a flow chart and description. It provides detailed explanation, starting from the collecting of the data until the analysist part.

Chapter 4:

Result and Discussion: The data analysis was discussed in detail, including data GIS mapping, three-dimension soil profile and statistical analysis.

Chapter 5:

Summary and suggestion summarize the results of this report and some suggestions have been made to advance of future studies. At the end, references and appendices are attached.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this research, a significant studies is conducted on the geological formation of soil in Penang Island, soil properties, the method for statistical and geostatistical analysis and also three-dimensional modelling tools from previous researchers which will be further discussed in this project.

The in situ behaviour of soils is complex as it is heavily dependent on various factors necessary to analyse through associated disciplines like geology, geomorphology, hydrology, climatology and other related to sciences (Ahmad, Yahaya, Farooqi, et al., 2006). There are complex spatial changes in a field scale, even for the same soil type, particularly in geotechnical engineering. A precise soil map with mutual spatial variation across soil types and the variability within each soil type can illustrate the different soil properties in a region. (Oberthu r et al., 1999).

Users would prefer airborne and satellite methods such as remote sensing and Geographic Information System (GIS) or direct ground-based techniques such as piezometer and laboratory tests for engineering and environmental problems over geophysical methods, solve engineering and environmental problems. (Talib, 2003; Ahmad et al., 2006; Khan et al, 2010; Lateh et. al, 2011). A Geographic Information System (GIS) is an essential tool for incorporating spatial data with other data. It permits one to evaluate the incorporated information and characterize the data spatially, simplifying resource expansion, ecological safety, and logical investigation (Mehmood et. al, 2016). Thus, geostatistics plays an important role in representing soil analyses spatially and highlighting variations between different parts in a study area (Rahman et al., 2021).

2.2 Geography and Geology of Penang Island

Among 13 states in Malaysia, Penang is the second smallest state situated in the Northwest of the Peninsula of Malaysia. Penang consist of Penang Island and the coastline on the mainland. The mainland portion is called Butterworth which is the city is linked to over 738 km^2 apart from a regular ferry operation, 13.5 km long for the first Penang Bridge and 24 km long for the second Sultan Abdul Halim Muadzam Shah Bridge. The Penang Island occupies 293 km^2 and located between latitudes 5° 8' N and 5° 35' N and longitudes 100° 8' E and 100° 32' E (Fauziah Ahmad, 2014). The elevation of the terrain ranges from 0 to 820 meters above sea level and the slope gradient ranges from 0 to 87°. (Tay, Alkhashawneh et al. 2014)

The climate is tropical, with an average daily maximum and minimum temperature of 31.4°C and 23.5°C, respectively, and an average daily mean temperature of around 27°C. Individual extremes, on the other hand, are 35.7°C and 23.5°C, respectively. The average daily humidity ranges from 60.9 percent to 96.8%. The average annual rainfall is about 267 cm, although it can reach 624 cm. The southwest monsoons that last from April to October and the north-east monsoons last from October to February are the two rainy seasons. Coastal plains, hills, and mountains make to the landscape. The population is primarily concentrated on the island's eastern side of because of its proximity to the mainland.

2.3 Geographic Information System (GIS) Based Mapping

In the last decade, geographic information systems have emerged as an essential tool for urban and resource and resource planning management. Theoretically, Geographic Information System (GIS) is a set of technology, software, and methods for managing, manipulating, analysing, modelling, and displaying georeferenced data to solve difficult resource planning and management (NCGIA,1990). GIS can also capable of integrating, manipulate store data and associated attributes and display geographically referenced information, which is spatially referenced to the Earth. GIS also allows combination of various maps and remote sensing information to generate models which are used in real time environment.

Nowadays, geographic information system are widely used for land use planning and management, ecosystem modelling, landscape assessment planning, transportation and infrastructure planning and various other applications as they are simple, fast, and easy to understand. Specific thematic and spatial features in GIS can provide more information by overlaying a number of layers of maps that are georeferenced for the same coordinates as in Figure 2.1.

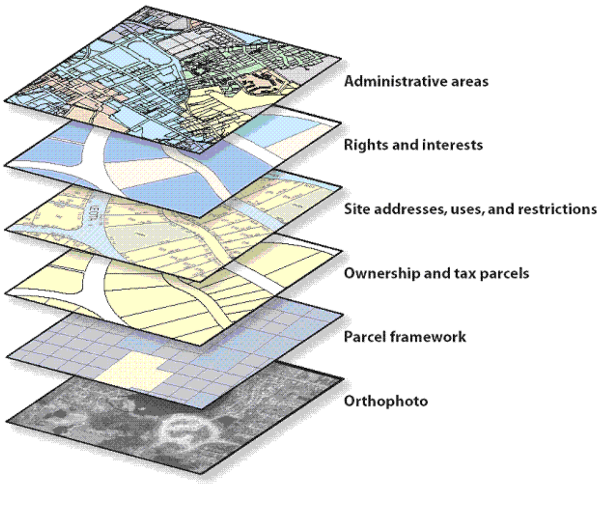

Figure 2.1: Example Layers in GIS (ESRI, 2009)

2.3.1 Component in GIS

The five key components in GIS are hardware, software, data, people, and methods. The computer system on which the GIS programme will run is included in the hardware components. Computer hardware is used to obtain inputs, processing, outputs, and storage data. GIS software components have several functional elements to perform different operations. The key idea to grasp about the GIS software component is the geographic database management system. A database management system (DBMS) can handle, organise, and integrate of spatial data and attribute data. A DBMS must be structured and provided multiple databases to allow efficient updating, minimize redundant information and data integrity.

People are also the key components as without people, GIS technology would not work, or the GIS will be useless. GIS users can be classified into two classes. Technicians or GIS operator are people behind the system's plan, implementation, and operation based on the output and work on vectorising the map objects. A GIS engineer or user is responsible for using this vectorised data to execute queries, analyses, and other tasks. People may operate individually or within a group or team. The GIS users should have the skill and basic knowledge about how the software can work with the geographic data and tool and function.

The procedures and software requirements will help define a list of skills required to operate on the GIS functions, procedures, and judgement. In summary, data quality assurance methods and procedures ensure that all data are correct, consistent, and validated for analysis. The key components of GIS in Figure 2.2 (Chang, 2012)

A geographic database is used to organise geographic data. This database is a collection of spatially related data that serves as a representation of reality. In GIS, spatial data is represented by two types of data models (Chang,2012)

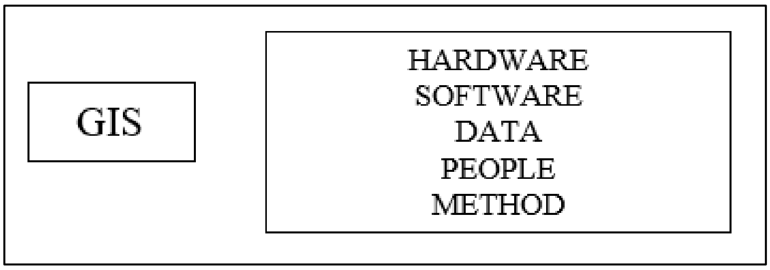

Figure 2.2: Key Components of GIS (Chang,2012)

Geographic data are organised in a geographic database. This database is considered a collection of spatially referenced data that acts as a model of reality. Spatial data in GIS are represented into two forms of the data model (Chang,2012)

I. Vector data model.

To define discrete objects, a vector data model uses sets of coordinates and related attribute data. Groups of coordinates define the location and limits of discrete objects, and these coordinate data, together with related properties, are used to generate vector objects representing actual entities. Points, lines (arcs), and polygons are the basic spatial information units of vector data. The flexibility to change the scale of observation and analysis is also improved with vector data.

II. Raster data model

When spatial data is expressed as a matrix of cells or pixels, it is a raster data model. Cell values represent the type or quality of mapped variables. Each cell in a raster contains a single value representing a spatial phenomenon's characteristic at a position defined by its row and column. Integer or floating-point data types are available for that cell value.

Many phenomena can be described using either the vector or raster conceptual approach, hence data models are sometimes interchangeable. The most common operations determine the ideal data model for a certain corporation or application, GIS users' experiences and perspectives, the type of data accessible, and the data model's impact on data quality. In terms of GIS applications and geographical analysis, both data models have advantages and disadvantages.

2.3.2 Input Data

The input data also is taken from the site investigation (S.I.) reports collected from the Public Works Department. The soil explorations of the sites were for the development of projects such as residential housing schemes, retaining wall, and higher buildings. These reports contain important information extracted such as the purpose of the project, water level, date drilled, depth of borehole, description of different layers and types of soils and rock, the thickness of different layers and types of soils and rock, standard penetration test (SPT) of different layers and types of soils.(Ahmad et al., 2014)

Identifiying and mapping of a suitable set of instability factors related to slopes failures requires prior knowledge of the main causes of landslides. The slope’s instability factors include surface and bedrock lithology, seismicity, slope steepness and morphology, stream evolution, groundwater conditions, climate, vegetation cover, land use, and human activity. Thematic data availability varies greatly depending on the type, scale, and method of data acquisition. However, assembling an ideal landslide-related database on a suitable scale is frequently appealing. To apply the probabilistic model, a spatial database that considers landslide-related factors was designed and developed. In Malaysia, these data are available as paper or digital maps.(Pradhan and Lee, 2009)

Table 2.1 : Spatial thematic layers used in the mapping analysis. (Bisjaweet Pradhan and Saro Lee, 2009)

Classification		GIS data type		Scale or Resolution	
Spatial database	Data Layers	Spatial database	Data Layers	Spatial database	Data Layers
Landslide	Landslide	ARC / INFO polygon coverage	ARC / INFO GRID	1:25,000	10m x 10m
Topographic map	Slope	ARC / INFO		1:25,000	
	Aspect	Line and Point			
	Curvature	Coverage			
Drainage map	Distance from drainage	ARC / INFO			
		Line Coverage			
Soil map	Types	ARC / INFO		1:25,000	
		Polygon Coverage			
Geology map	Litho types	ARC / INFO		1:63,000	
	Distance from lineaments	Polygon, Line Coverage			
Land cover	Land cover	ARC / INFO		30m x 30m	
		GRID			
NDVI	NDVI	ARC / INFO		10m x 10m	
		GRID			
Precipitation	Precipitation	GRID		10m x 10m	

2.3.3 ArcGIS Software

ArcGIS software is developed by a company called Environmental Systems Research Institute (ESRI). ESRI focused its efforts on creating and implementing a core set of application tools that could be used to establish a geographic information system in a computer environment. Geovisualization, geoprocessing, and geodata management are the three core categories of ArcGIS.

2.4 Soil Formation

Originally, the soil is formed by the physical and chemical weathering of rock in its natural state. Rocks can be classified into igneous, sedimentary, and metamorphic based on the several processes resulting in them. Physical weathering is the reduction of size without any change in the parent rock's original composition. Exfoliation, unloading, erosion, freezing, and thawing are the key elements responsible for this process. Chemical weathering results in both size reductions and chemical reactions to the original parent rock. Hydration, carbonation and oxidation are the primary agents responsible for chemical weathering.(M. Budhu, 2011)

Soils are chemically composed of various crystalline and amorphous mineral phases, as well as organic matter. The organic matter in the soil ranges from newly formed, mostly intact plant litter and its increasingly transformed decomposition products to the amorphous organic, variably organised stuff known as humus (van Breemen and Buurman, 2002). Furthermore, minerals are crystalline materials that make up the soil's solid constituents. Minerals are classified according to chemical composition and structure.(M. Budhu, 2011)

2.4.1 Geological Condition in Penang Island

From previous research, Penang Island is composed of igneous rocks, granite where it located geologically on its major portion. The granites in Penang Island can be classified based on proportions of alkali feldspar to total feldspars.(Ahmad et al., 2006). On this basis, granites on Penang Island are divided into two main groups: North Penang Pluton, which is further subdivided into Ferringhi Granite, Tanjung Bungah Granite, and Muka Head micro granite, and South Penang Pluton, which is subdivided into Batu Maung Granite and Sungai Ara Granite. (Ahmad et al., 2006). In the northern half of the island, the alkali feldspars that do not have distinct cross-hatched twining are orthoclase to intermediate microcline in composition, whereas. In contrast, in the southern section, they have well-developed cross-hatched twining and are assumed to be microcline (Ong, 1993).

The main geological formations in Penang are divided into three groups (Ahmad et al., 2006). From their research, data from various sites are grouped so that each site in one group is located over a single formation. Wherever possible, the data gathered from each group of sites is subdivided into three subgroups, each representing a different type of soil which are sandy, silty, or clayey are found over that formation. Tanjung Bungah is located on the northern coast of Penang Island. A medium to coarse-grained biotite granite stratum with significant orthoclase and subordinate microcline underpins this location. Its topography is relatively flat. Paya Terubong, on the other hand, is located on the southeastern side of Penang Island. The South Penang Pluton (SPP) comprises of Prophyritic Muscovite-Biotite granite with coarse grains and Prophyritic Muscovite-Biotite granite with medium grains. The orientation of Paya Terubong valley is along the north-south direction. The valley marks the position of the Central Penang Fault Zone. Batu Feringgi is located at the northwestern coast where geologically, this area is underlained by a medium to coarse-grained biotite granite layer with predominant orthoclase and subordinate microcline.(Ahmad et al., 2006) According to the amount of biotite present, the colour of rock varies from light grey to dark grey. Alkali feldspar may occasionally exhibit a pinkish tinge at crystal boundaries and along feldspar cleavages due to weathering, especially in sheared rocks. Figure shows the geological formation of Penang Island (Ong, 1993)

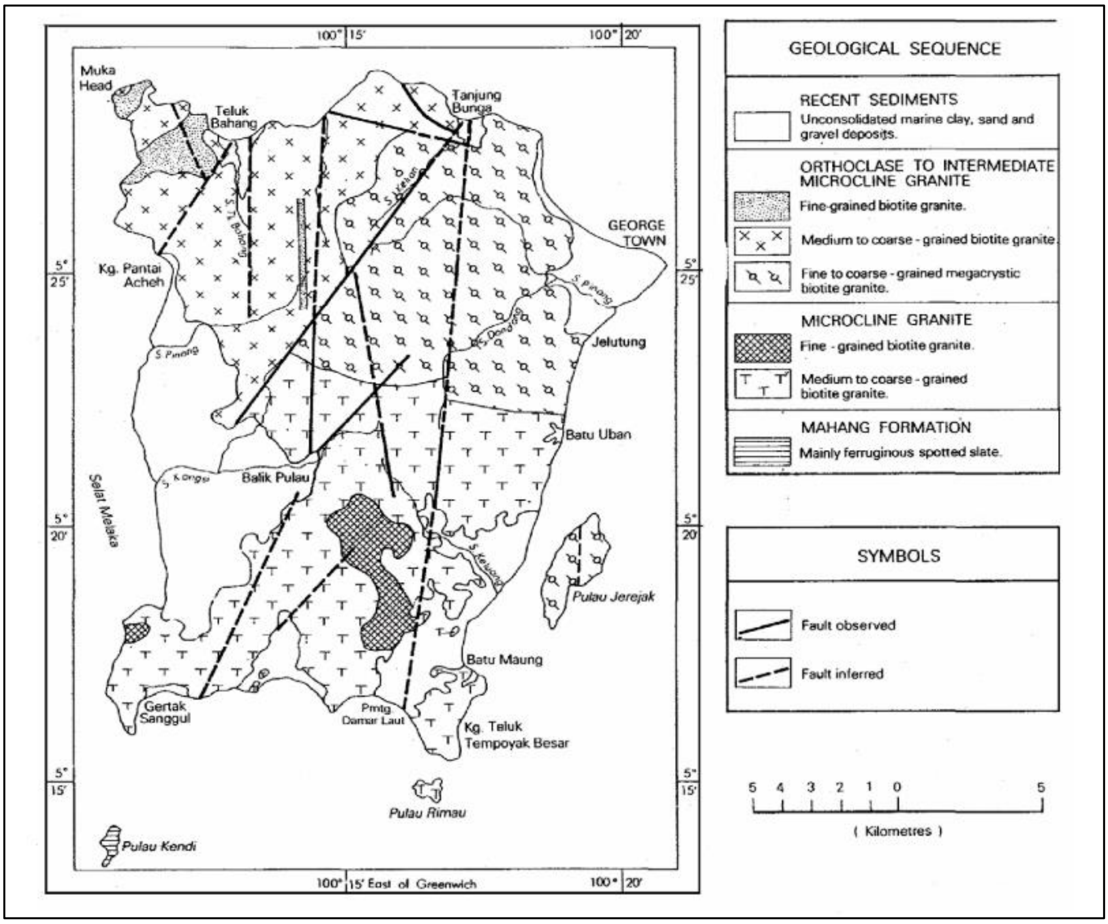

Figure 2.3: Geological Formation of Penang Island (Ong, 1993)

Furthermore, according to (Pradhan and Lee, 2009), the soil formation of Penang Island is primarily composed of eight types as shown in Table 2.2 and Figure2.4. The Kuala-Kedah permatang association mainly consists of clay material. The steep land soil series covers mostly the central part of the Island and is composed of weathered granitic rocks. The Rengam series is composed of fine to medium coarse sandy clay and is developed on igneous and high-grade metamorphic rocks whereas Selangor Kangkong association is mainly composed of medium-grained clay and is generated from acid sulphate soils. Local alluvium and colluvium series consist of fine to medium grained loamy material. More than 70% of the landslides have been reported in the steep land soil types.

Table 2.2: Major soil series of Penang Island (Pradhan and Lee, 2009).

Soil types	Texture	Grain size	Origin
Serong	Clay	Medium to coarse	Acid sulphate soils
Selangor kangkong association	Clay	Medium	Acid sulphate soils
Rengam	Coarse sandy clay	Fine to medium	Soil developed on igneous and high-grade metamorphic rocks
Kuala-Kedah permatang association	Clay	Medium to coarse	Developed on relatively flat areas and mostly used for agricultural purposes
Steep land	Weathered materials, clay	Fine to medium	Weathering of granitic rocks
Rengam bukit temiang association	Sandy clay	Medium to coarse	Soil developed on igneous and high-grade metamorphic rocks
Local alluvium-colluvium association	Loam	Fine-grained	Very fine-grained particles developed on the river delta
Urban Land	Sand and gravel	Fine to medium	Weathering phenomena, mainly composed of marine clay, sand, and gravel, and abundant in the shoreline area

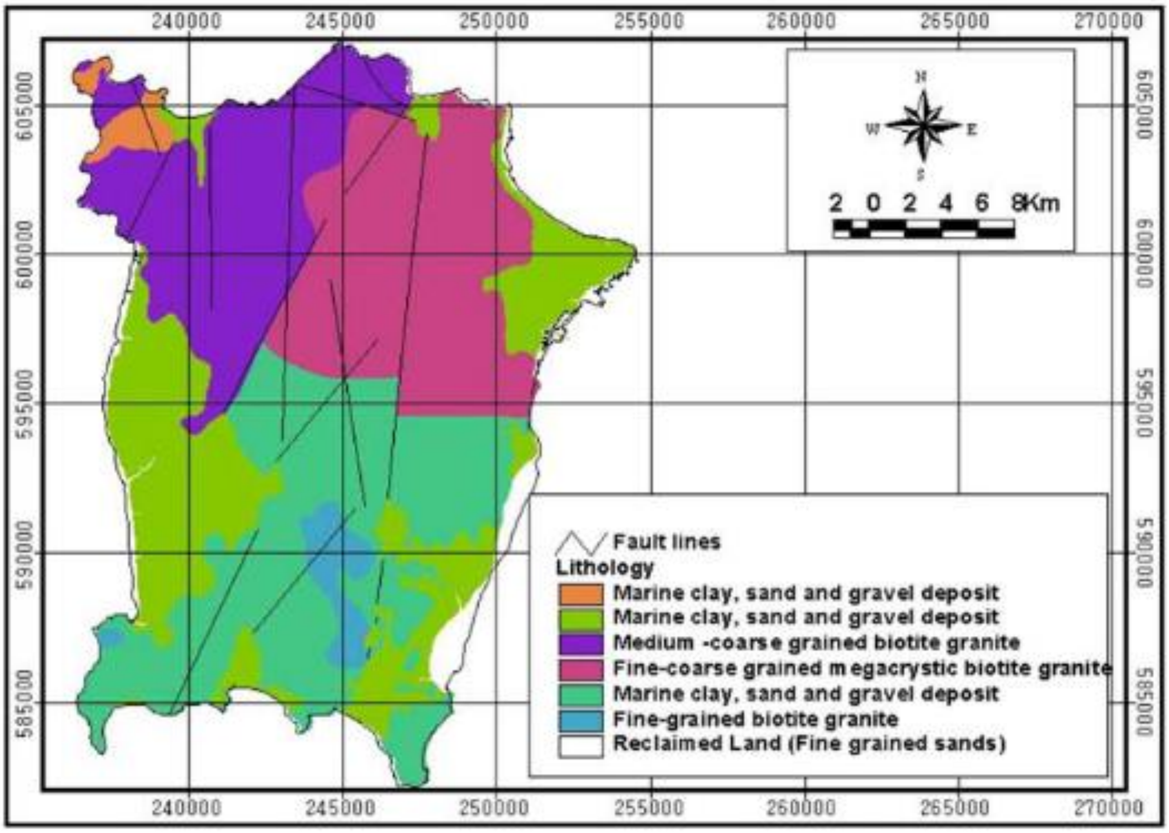

Figure 2.4 : Regional geological map of Penang Island.(Pradhan and Lee, 2009)

2.4.2 Soil Mechanics Properties of Penang Island

Soil mechanics properties studied include: specific gravity, water content, Atterberg limits and grain size distribution. A research project has been conducted (Tan, 1990), dealt with three aspects of studies, namely: engineering properties of the granitic soils, engineering properties of the granites, and slope stability. The result from the study proved that the specific gravity values range from 2.50-2.65, with 2.55-2.65 being the predominant values. This is in agreement with the specific gravity value for mineral quartz (Gs = 2.65) which form the major mineral in granitic soils, in particular the sandy soils.

According to the result in Figure 2.5 the natural moisture content, liquid limit, plastic limit and plasticity index are plotted along the depth. Paya Terubong area shows high natural moisture content and high liquid limit. The trend of natural moisture content is increasing with depth which combined with deep clay layer makes it most susceptible area to landslides. The soil at the Paya Terubong area shows suchcharacteristics that it is highly susceptible to deep landslides. The soils at Tanjung Bungah area, despite showing high liquid limit values, are only susceptible to shallow landslides. The soil in the area of Paya Terubong exhibits low values of specific garavity which may be attributed to higher clay content. The plasticity charts shows that soil at Batu Feringghi area is silty type while at Paya Terubong and Tanjung Bungah are clayey type.

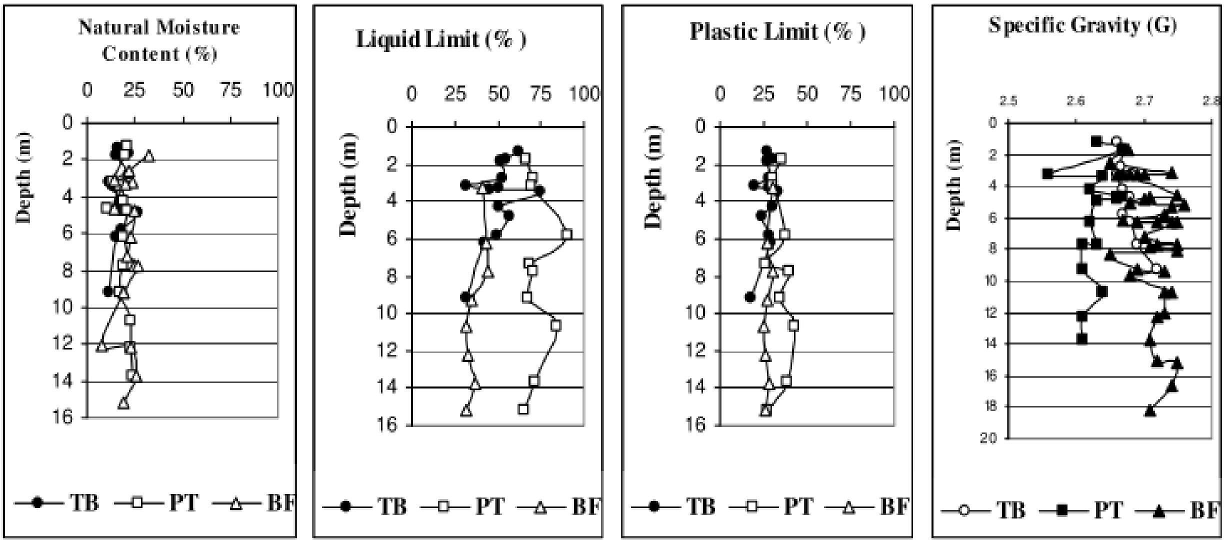

Figure 2.5: Variation of liquid limit, plastic limit, natural moisture content and specific gravity with depth (Ahmad et al, 2006)

Next, the strength characterization was conducted using Standard Peneteration Test (SPT) to give better information about the behavior of residual soils. According to the Figure 2.6, the SPT-N values were plotted against depth for Tanjung Bungah, Paya Terubong and Batu Ferringhi. The result has validated that Batu Ferringhi has high values in all three soil types while the silts of both Paya Terubong and Tanjung Bungah area shows quite low values. TB clay also shows low N-values while the clays of both PT and BF show quite high N-values which may be attributed to the high gravel content. (Ahmad et al, 2006)

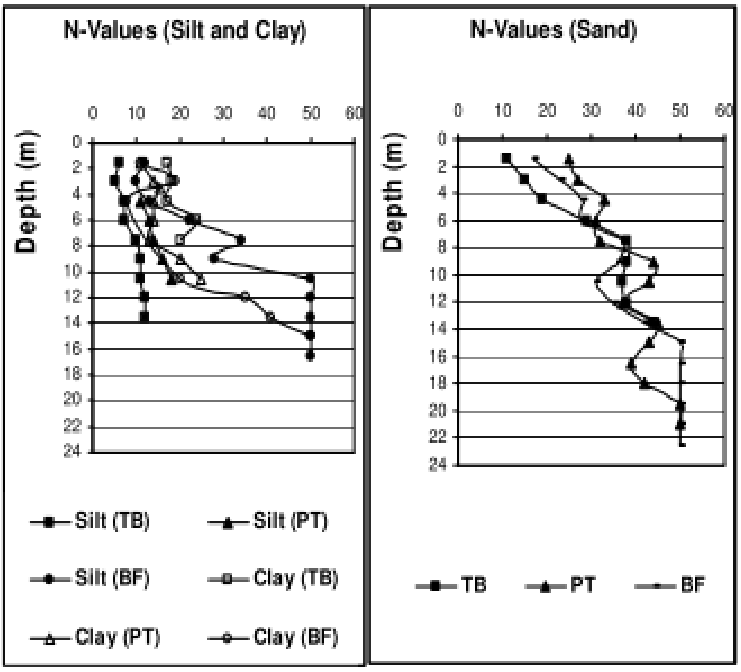

Figure 2.6: Variation of SPT-N values with depth. (Ahmad et al, 2006)

2.5 Methodologies Based on Legacy Data

As shown in Figure 2.7, the flow chart illustrates the methodology for global soil mapping based on legacy soil dat. All scorpan or environmental covariates, and existing soil data, are gathered for a specific area of interest. The next step is to analyze how the soil data covers the covariate space and find possible training areas.(B,Minasry and A.B. Mcbratney, 2010)

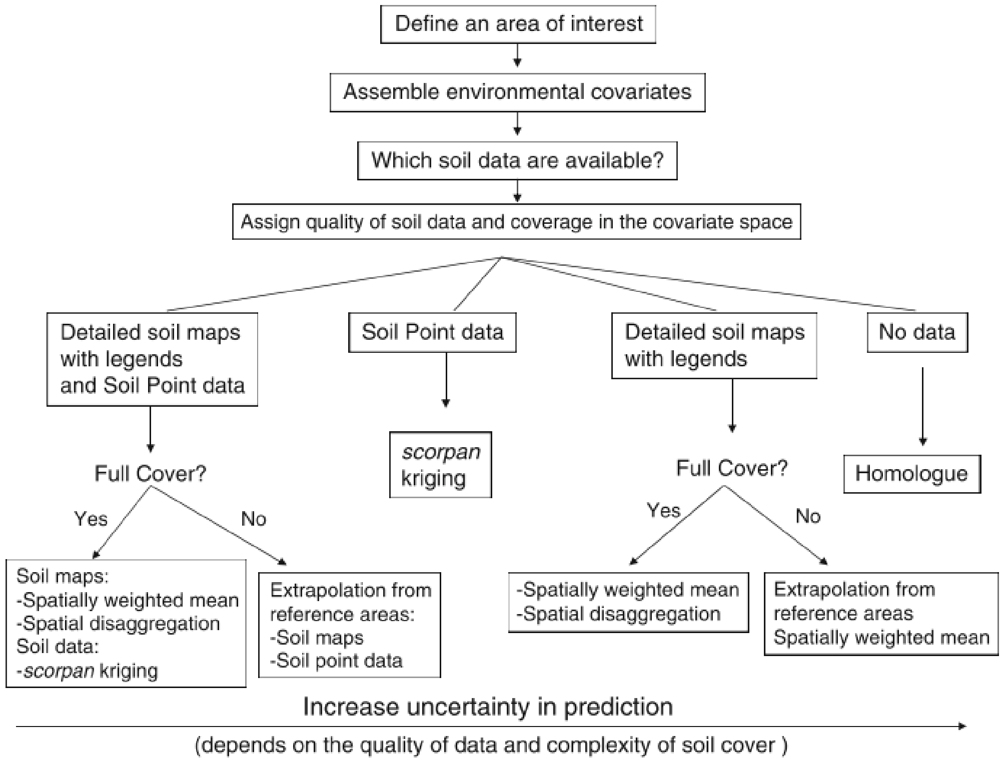

Figure 2.7 : A decision tree for digital soil mapping based on legacy soil data (B.Minasny and A.B. Mcbratney, 2010)

2.5.1 Amount of Soil Data Used in the Specific Method

- Soil maps include legends and information on soil points.

Soil mapping is the most comprehensive information available for predicting soil properties. Soil maps provide inventories, or lists, of soils that occur in mapped regions, and illustrations of the dominant spatial patterns displayed by these listed soils and information to characterise the main properties of these soils. Soil properties can be extracted from a soil map using a weighted spatial measurement. Various techniques can be used for spatial analysis such as soil map spatial disaggregation, Scorpan Kriging, IDW, Natural Neighbor, TIN and their combination. (Henderson et al., 2001, 2005).

- Soil point data

Information of the spatial location of soil profile data enables the analysis of correlations between known data values at a location and other covariates (predictor) data sets. A predictive model can be developed if a statistically significant relationship can be established between the value of a soil property at multiple locations and the corresponding values of environmental variables at the same locations. (Hengl, T., MacMillan, R.A., 2019). Scorpan kriging approach is a method where soil properties can be interpolated and extrapolated to the entire area when soil point data is available, using a combination of empirical deterministic modelling and a stochastic spatial component (Minasny and A.B. Mcbratney, 2010)

- No information or data are available.

When no data or soil maps are available in a given location, the Homosoil technique is used to determine the likely soil properties based on observed soil-forming variables or scorpan factors to extrapolate soil mapping rules. Jones et al. (2005) revisited the homoclime approach and defined the homologue approach to determine which crops could be grown at a particular location worldwide. The underlying principle is that crops will behave similarly in similar environments wherever they occur in space and time. (Minasny and A.B. Mcbratney, 2010). The factor for this approach is based on the hierarchical nature of soil-forming factors which are climate, lithology, and topography.

2.5.1(a) The details of the methods are:

- Extracting information from soil maps

Soil attributes must be obtained from a soil map when only information available for a given region. The map's quality is determined by the scale, sampling effect, and variance in soil cover. The most suitable map for global mapping is a comprehensive map with a scale of 1:100,000 or better with a legend. The definition of its soil map units, which collectively create the map legend, and the spatial arrangement of the map units include the information contained in soil maps (Bui, 2004). The central concept of the soil mapping unit is the fundamental basis of soil prediction. A soil property is assumed to be the sum of the mean, median, or mode mapping unit and a spatially independent noise term at a given location. The noise term accounts for the within-map heterogeneity. Bregt et al. (1987) proved that attributes produced from soil survey maps are of comparable quality to maps obtained by spatial interpolation (kriging). However, investigations have found that standard soil maps are only 60–65 percent accurate (Marsman and de Gruijter, 1986).

- Extrapolation based on reference areas.

Lagacherie et al. (2001) proposed the computation of a taxonomic distance between the local soilscapes and those in a reference area. Classification trees, and many other classification algorithms, lack mechanisms for incorporating spatial relationships into the model (B. Minasny and A.B. McBratney, cited in Moran and Bui 2002). However, environmental attributes at neighbouring locations can effectively analyse soil pattern (McBratney et al., 2003). Another method involved using the rule induction process to detect a relevant physiographic region by characterising entire reference areas as separate target classes (Bui and Moran, 2003)

- Kriging

When estimating values in unknown locations, kriging is a geostatistical interpolation approach that considers both the distance and the degree of variation between known data points. It is a weighted linear combination of known sample values in the region of the estimated site. Kriging is a multistep process that includes exploratory statistical analysis of