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GIS APPLICATION FOR URBAN SOLID WASTE MANAGEMENT – A CASE STUDY OF PHU LY CITY IN VIETNAM

Bachelor's thesis

Environmental Engineering

2020

South-Eastern Finland
University of Applied Sciences

Author (authors)	Degree title	Time
Hoang Vu	Bachelor of Environmental Engineering	December 2020

Thesis title	
GIS Application for Urban Solid Waste Management – A Case Study of Phu Ly City in Vietnam	43 pages

Commissioned by

GeoViet Consulting Co.Ltd

Supervisor

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Abstract

The objective of this thesis was to provide an overview of waste management and to show how Geographic Information System (GIS) could be used as a decision support tool in the urban solid waste management. Specifically, ArcMap, an GIS software, was used to suggest new waste collection points in the Phu Ly city of Vietnam.

In this thesis, the field method and data analysis method were used. The field method was carried out by taking a field trip to Phu Ly to record the locations of the current waste collection points in 6 downtown wards of the city. Besides, data analysis was conducted by using ArcMap to analyze and process the available dataset of Phu Ly provided by GeoViet Consulting company.

After obtaining and displaying the locations of the current collection points on a map, it can be seen that there were some limitations of these points which affected the waste collection efficiency of the city. On the other hand, the optimization of new collection points done in ArcMap was fairly successful. The result of this analysis created suitable areas which meet all the necessary criteria for setting up a new collection point. Then, new collection points were placed on these suitable areas and a map depicting those points was generated as a suggestion.

The study showed that the application of GIS to the management of waste collection points in 6 downtown wards of Phu Ly city was complete feasible. In the future, the application of GIS technology in waste management deserves to receive more attention and proper investment from the government in Vietnam.

Keywords

geographic information system, gis, gis application, urban solid waste management, waste management, thesis, case study, Phu Ly city.

CONTENTS

1 INTRODUCTION

During the last few decades, a rapid economic development and urbanization have significantly improved the well-being and income of a large proportion of the world population. However, along with this improvement, it is observed that the consumption of resources has skyrocketed, especially in cities, and the amount of waste released to the environment has increased dramatically. According to the American National Academy of Sciences (2014), 94% of the substances that are extracted from the Earth enter the waste stream within months. Solid waste, in the recent years, appears to be one of the most unresolvable problems in urban cities and large towns around the world. This nuisance is not only heaped in enormous quantities in landfills but also thrown on the streets and in illegal dumps which are created on any unused land (Igbinomwanhia 2011). Solid waste causes harmful effects on both human health and environment. Theenvironmental impacts are land and water pollution, whereas human effects can range from mild signs of stress due to the unfavorable smell of biodegradable waste to some serious diseases, such as cancer, for those who are exposed to different types of hazardous waste. In comparison to developed nations, citizens in developing countries are more severely impacted by unsustainably managed waste. In low-income nations, over 90 percent of waste is often disposed in unregulated dumps or openly burned (Kaza et al. 2018). These practices create serious health impacts, and more importantly contribute to global climate change through methane generation. Proper solid waste management, therefore, is critical for building livable and sustainable cities.

The world generated 2.01 billion tonnes of municipal solid waste in 2016, with at least 33 percent of that is not managed in an environmentally safe manner. With rapid population growth and urbanization, annual waste generation is expected to increase by 70% from 2016 levels to 3.40 billion tonnes in 2050. Globally, waste generated per person per day averages 0.74 kilogram but ranges widely, from 0.11 to 4.54 kilograms. Despite accounting for only 16 percent of the world’s population, high-income countries generate approximate 34 percent, or 683 million tonnes, of the world’s waste. (Kaza et al. 2018.). In the last few decades, waste management has been developing operationally and technologically in response to resolve contemporary environmental, technical and economic challenges. However, current global waste management practices focus on reducing the impacts rather than preventing them and suggest, so called, ‘end of pipe’ solutions to waste problems rather than long term sustainable measures (Kaza et al. 2018). Waste collection is among the preventive measures to reduce the burden of waste disposal but has not received enough public attention, especially in developing countries. Low-income countries collect about 48 percent of waste in cities, but this proportion drops drastically to 26 percent outside urban areas. In contrast, Europe, Central Asia and North America collect at least 90 percent of waste. (Kaza et al. 2018.)

In Vietnam, waste collection in cities is still facing many difficulties, such as a lack of technology and human resources, insufficient funding, overpopulation and a poor awareness of people. Even in the capital of Hanoi, only 70 percent of household waste is collected and processed (Embassy of Denmark in Vietnam 2013). Therefore, it is extremely urgent to find solutions to increase the efficiency of waste collection and transportation in cities.

The objective of this thesis is to assess the current collection points of municipal solid waste in Phu Ly city, the capital city of Ha Nam Province of Vietnam, located 60 km south of Hanoi and utilize GIS applications to suggest new waste collection points in the city.

2 OVERVIEW OF WASTE MANAGEMENT

This chapter provides an overview of waste management on the aspect of waste classification, waste hierarchy, waste handling and waste management components.

2.1 Waste classification

Waste is generated in various forms and can be classified based on its characteristics (Ebikapade Amasuomo & Jim Baird 2016). However, there are two main types of waste, which are liquid waste and solid waste. Liquid waste, also known as wet waste, refers to any waste in the liquid form, such as wastewater, used oils, sludge, household liquids and cleaning fluids (eWaste Disposal Inc no date). Most of these liquids are harmful to human and environmental health. On the other hand, solid waste, also known as dry waste, refers to the useless and unwanted products in the solid form which are usually derived from human production and discarded in our daily activities (Ifeoluwa 2019). Solid waste can be divided into several major types, including plastic waste, papers, metals and tins, cardboard and glasses. While most of these solids are recyclable materials, some of them, such as plastic, are not and still go to the landfill or be incinerated.

2.2 Waste hierarchy

The waste hierarchy is a set of priorities for an efficient use of resources and it underpins the objectives of Waste Avoidance and Resource Recovery Act 2001. This Act promotes waste avoidance and resource recovery to achieve a continual reduction in waste generation. The Act provides for the development of a state-wide Waste Strategy and introduces a scheme to promote extended producer responsibility for the life-cycle of a product. (NSW Environment Protection Authority 2017.)

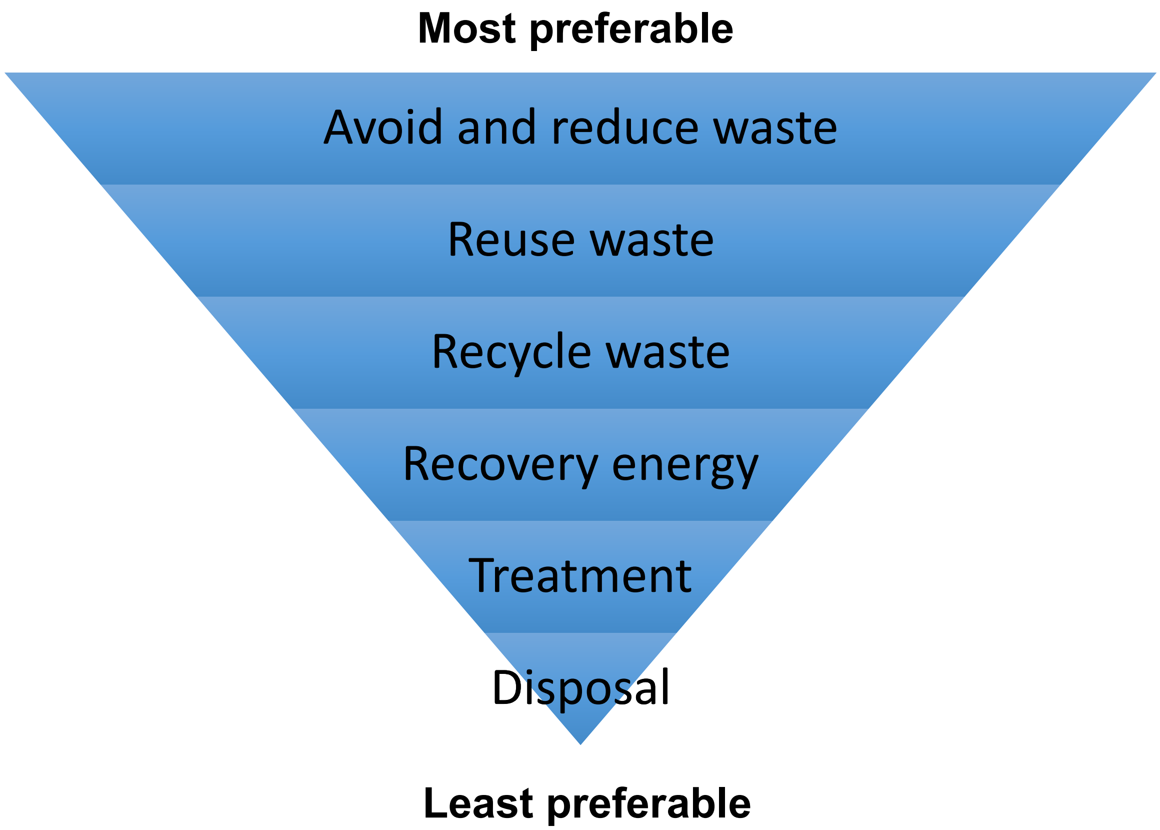

Figure 1. Waste Hierarchy (NSW Environment Protection Authority 2017)

The waste hierarchy includes avoidance, resource recovery and disposal (Figure 1). Avoidance refers to the actions to reduce the amount of waste generated by households, industry and all levels of government. Resource recovery consists of re-use, recycling, reprocessing and energy recovery. Disposal refers to management of all disposal options in the most environmentally responsible manner. (NSW Environment Protection Authority 2017.)

2.3 Waste handling

Waste handling practices is extremely important to every organization. ISO 14001 is an international standard that helps companies improve their environmental performance by setting out requirements for an environmental management system (ISO 2015). ISO 14001 does not prescribe the steps in waste handling, but there are some common steps in the process that every organization can follow (Stojanovic 2016). First of all, the waste need to be classified to be handled properly in accordance with legislation. Secondly, the waste should be carefully stored in appropriate storage facilities based on its characteristics. Hazardous waste, in particular, must be stored in a sturdy, leak-proof container and this container must be placed on an impermeable surface with enough aisle space to allow for weekly inspections (Stojanovic 2016).

In addition, the organization is responsible for labelling its waste according to the law. For each type of waste, there will be different label styles for waste containers, but every container in general must be clearly labelled with some crucial information, including the waste type and its characteristics, the date that the waste was ad to the container and the name and contact of organization or individual who own the waste. In terms of waste transportation and disposal, it is recognized that organizations have permanent responsibility to the environmental impacts of the waste (ISO 14001 2004). Moreover, according to ISO 14001 (2004), every organization should establish, implement and maintain a procedure to identify and respond to potential emergency situations that can affect the environment. In accidental situations, the better preparedness of the procedure is, the less harmful impact the environment suffers. In addition, to achieve the most effective handling practices, an organization need to ensure to provide sufficient training for any individuals working on waste management. Each person of the company should be aware of the type of waste that he or she is handling, especially hazardous waste, the related actual and potential impacts of the waste and their responsibility when unfortunate situations happen. Finally, the organization should keep monitoring and recording all waste management activities to ensure that the waste is handled properly according to the procedures.

2.4 Solid waste management components

Solid waste management can be divided into 5 key components, which is generation, storage, collection, transportation and disposal.

Generation of solid waste is the stage at which materials become valueless to the owner and since they have no use for them and no longer require them, they wish to get rid of them. However, items which are valueless to one individual may not necessarily be valueless to others. For example, old clothes can be donated to the poor people instead of being thrown away and generated as solid waste.

Storage is a system for keeping materials after they have been discarded, but before they are collected and transported to final disposal site. Where on-site disposal systems are implemented, such as where people discard their items directly into family pits, storage may not be necessary (Baghri et al. 2002). However, in emergency situations, especially in the early stages, it is likely that the affected population will discard domestic waste in poorly defined heaps close to dwelling areas (Baghri et al. 2002). In this case, storage facilities should be provided. Improved storage facilities can include small containers (household containers, dustbins, etc.), large containers (communal bins, oil drums, etc.), shallow pits and communal depots. The size, quantity and distribution of storage facilities should be determined based on the number of users, type of waste and walking distance in the area. The frequency of emptying the storage should be determined as well.

Collection is a crucial stage of waste management. It refers to how waste is collected for transportation to the final disposal site. The collection system should be thoroughly designed and the waste volume should be calculated and predicted correctly in order to ensure that storage system do not become overloaded.

Transportation is the stage when solid waste is transported to the final disposal site. There are many types of waste transportation which depend on local availability and the volume of waste to be transported. Waste transportation can be divided into three categories, which is human-powered (open hand-cart, hand-cart with bins, wheelbarrow, tricycle), animal-powered (donkey-drawn cart) and motorized (tractor and trailer, standard truck, tipper-truck) (Baghri et al. 2002).

Disposal is the final stage of solid waste management is safe disposal where associated risks are minimized. There are four main methods for the disposal of solid waste, including land application (burial and landfilling), composting, burning or incineration, and recycling (resource recovery). The most common of these is undoubtedly land application, although all four methods are commonly applied in different situations.

3 OVERVIEW OF GIS APPLICATIONS FOR URBAN SOLID WASTE MANAGEMENT

This chapter introduces Geographic Information System (GIS) and provides an overview of GIS applications for urban solid waste management around the world and in Vietnam.

3.1 Introduction of Geographic Information System (GIS)

The story of GIS began in the early 20^{th} century when a printing technique called photozincography was introduced. This technique has similar functionality with GIS in which it can separate layers from a map (Tate 2018). It means that, for instance, different layers in a city map, such as roads, buildings and rivers, could be printed out separately and completely do not relate to the other ones. However, this technique did not represent a full GIS since there was no opportunity to analyze mapped data (Tate 2018). It was not until 1960s, when geographic information systems were first formally introduced with the development of Canada Geographic Information System (CGIS) by Roger Tomlinson. Between 1970s and 1990s, it was software development and commercial period of GIS. (Waters 2018.).

Throughout history, a variety of GIS definitions have been introduced. To summarize, a GIS is a system, which integrates hardware, software, data and people for capturing, managing, analyzing, modelling and visualizing geographical information in order to solve real-world problems.

3.1.1 Components of GIS

GIS integrates five key components, including hardware, software, data, people and method (ESRI 1998).

The first component is hardware. Hardware is a computer system on which the GIS software runs. This computer forms the backbone of the GIS hardware, which gets the input through a scanner or a digitizer board. Scanner and digitizer convert a picture (the input) into a digital image (the output) for further processing. The output can be stored in many formats, such as TIFF, BMP and JPG, and can be printed. Printers and plotters are the most common output devices for a GIS hardware setup. (Azad 2009.)

Software is the second component. GIS software provides the functions and tools needed to store, analyze, and display geographic information (ESRI 1998). Common GIS software are MapInfo, ArcMap, QGIS, ArcView, AutoCAD Map, etc. Depending on specific projects, the appropriate GIS software will be used. When the low cost GIS project is carried out, desktop MapInfo is a proper option. It is easy to use and supports many GIS features. On the other hand, if user intends to conduct extensive spatial analysis on GIS, ArcMap is a preferable option. (Azad 2009.)

Data is considered the most important component. There are two data types in GIS, which is spatial and non-spatial data. Spatial data, also known as geospatial data, is used to describe any data that identifies geographic location of features on the Earth (Vangie Beal no date). Non-spatial or tabular data is data that is structured into rows. Each row contains the same number of cells which provides values of properties of the thing described in the row (World Wide Web Consortium 2015). The extraordinary thing is that GIS can integrate spatial data with tabular data and even use a Database Management System (DBMS) to manage all data (ESRI 1998).

People are an indispensable part in any GIS system. Hardware and software are obviously essential in GIS, however, at the end of the day, they are just the tools used to carry out the tasks. All decisions are made by humans. Therefore, people play a key role in solving problems using GIS. People could be professionals and experts developing GIS software, or end users using GIS tools to carry out simple research and analysis.

Last but not least, methods are techniques used for map creation, spatial analysis and other usage for GIS projects. To have a successful GIS project, a well-prepared plan with a right method is completely crucial. The methods or models used in a GIS project is unique to each type of analysis. For example, suitability analysis will be used to solve a specific problem in this thesis.

Figure 2. Components of GIS (Pedro Ney Stroski 2019)

3.1.2 GIS common tasks

In GIS, there are some common tasks that both beginner and professional users carry out every day. These tasks are data import, map making, data management, query and analysis and visualization (ESRI 1998).

The very first task in every GIS project is importing data. The data need to be converted into a proper digital format before being utilized in GIS (ESRI 1998). In GIS, the process by which coordinates from a map, image, or other sources of data are converted into a digital format is called digitizing. This process becomes extremely necessary when available data is gathered in formats that is not GIS-compatible formats and cannot be immediately integrated with other GIS data.

Map making is also one the most common processes in GIS. With GIS, map making is much more flexible than the conventional manual method (Azad 2009). Paper maps can be digitized to illustrate any location on the Earth's surface at any scale. In addition, GIS offers various ways of symbolizing and highlighting features, which make it easier to read and understand the maps.

In addition, data is managed effectively and flexibly in GIS. For example, with a small project, it might be sufficient to store spatial data as Shapefiles, a simple format file in GIS. However, when data volumes and the number of users become very large, it is optimal to use a database management system (DBMS) to store, organize, and manage data. There are many different designs of DBMS's, but the relational design has been the most useful in GIS. In this design, data are stored conceptually as a collection of tables and the common fields in those tables are used to link them together. (ESRI 1998.) Moreover, GIS provides many tools to manipulate data depending on the projects that user is working on. The manipulation can be applied on both spatial data and tabular data.

A query and an analysis are where 'magic' happens in GIS. The capabilities of query and analysis in GIS ranges between a very simple click to choose an object on the computer screen and a complex analysis which requires numerous data layers and processing steps. Query and analysis tools in GIS arc specifically useful when combining with tabular data (attributes) to examine and predict patterns and trends, such as which the city areas attract the most visitors. (ESRI 1998.)

As mentioned before, GIS offers a better experience for users while visualizing geographical information through maps with exceptional symbology tool. Furthermore, statistics information, reports, images and 3D models can be generated and visualized in GIS as well (ESRI 1998).

3.1.3 Fundamental data format in GIS

GIS data represents real-world objects, such as roads, rivers, houses and elevation. Real world objects can be divided into two types: discrete objects (buildings) and continuous fields (rain fall amount or temperature) (Ontario College of Technology 2008). GIS stores these two object types as vector and raster data.

Vector data can be divided into three different types: points, polylines and polygons. A point is composed of one coordinate pair representing a specific location in a coordinate system. Points are the most basic geometry type in GIS with no length or area. On a map, points are represented using symbols that have different shapes and colors, such as circle or square. A polyline is composed of a sequence of two or more coordinate pairs called vertices. A vertex is defined by a coordinate pair, same as a point, but a vertex has some relationships with neighboring vertices while a point do not. A vertex is connected to at least one other vertex. Lines on map are symbolized using shapes that have a color, width and style such as solid, dashed or dotted. A polygon is composed of three or more line segments whose starting and ending coordinate pairs are the same. Polygons are used for geographical features that cover a particular area of the Earth's surface and can measure both length (the perimeter of the area), and area.

Raster data model consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information, such as temperature, elevation or precipitation. Rasters are digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps (Esri no date).

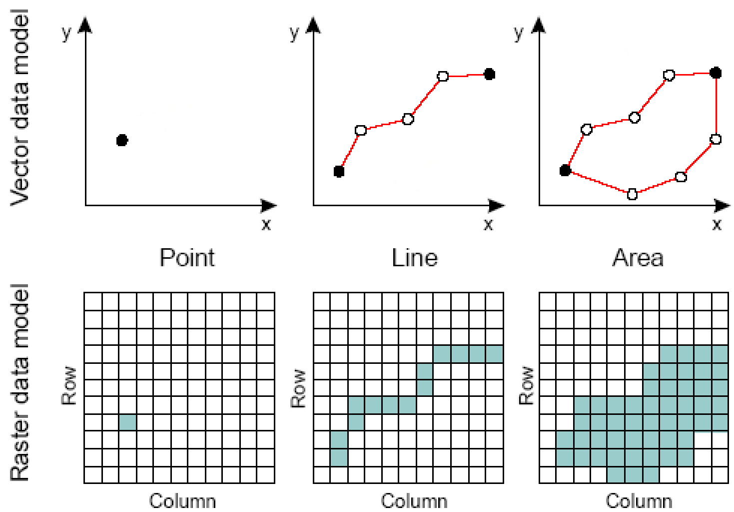

Figure 3. Vector data vs Raster data in GIS

3.1.4 Data Collection

The most crucial work in every GIS project is collecting relevant data. The data lies at the heart of geographical information system. Without data, it is impossible to conduct any experiment with GIS software. The data used in GIS represents something about the real world at some point in time. In fact, the result of any analysis relies heavily on the quality of the data.

The most important aspects of data quality are accuracy, precision, time, currency, and completeness. Accuracy refers to the predictability of the correctness of the data. Precision indicates the fineness of the scale with which the data was demonstrated. Time describes the interval at which the data was taken or the point when the data was taken. Time can easily affect the quality of data, for example the CO_2 concentration is definitely higher in rush hours than at midnight. Currency illustrates how recently the data was collected. Finally, completeness refers to portion of the area of interest for which data is available (Aronof 1995). Data quality is always costly to accomplish. Therefore, in reality, not every GIS project obtains the data that achieves all of the aspects mentioned perfectly. Sometimes, depending on the size and the urgency of the project, people can diminish the importance of some aspects.

3.2 International experiences of GIS applications in Urban Solid Waste Management

Nowadays, GIS is used in various fields, such as urban planning, natural resources and species protection, natural phenomena prediction, environmental modelling, transportation and health sciences (Chalkias & Lasaridi 2011). In urban waste management, GIS has been mostly applied in defining areas of landfills, waste collection and optimizing waste transportation. Such applications offer great advantages to the waste management field.

3.2.1 Landfill sitting with GIS

The selection of a landfill is a complex task as it requires the integration of various environmental and socioeconomic factors (Chalkias & Lasaridi 2011). These factors are evaluated based on different criteria before the allocation is carried out. For example, to locate a proper dump site in urban area, the following questions should be taken into account: How far is the site from residential area? Is there any rivers near the site? Is it accessible to reach the site from main roads? GIS can represent all these factors as spatial data layers and use special analysis tools to generate a standard scale to define the most promising areas to build a landfill.

The main steps of typical GIS approach for landfill selection are illustrated in Figure 2.

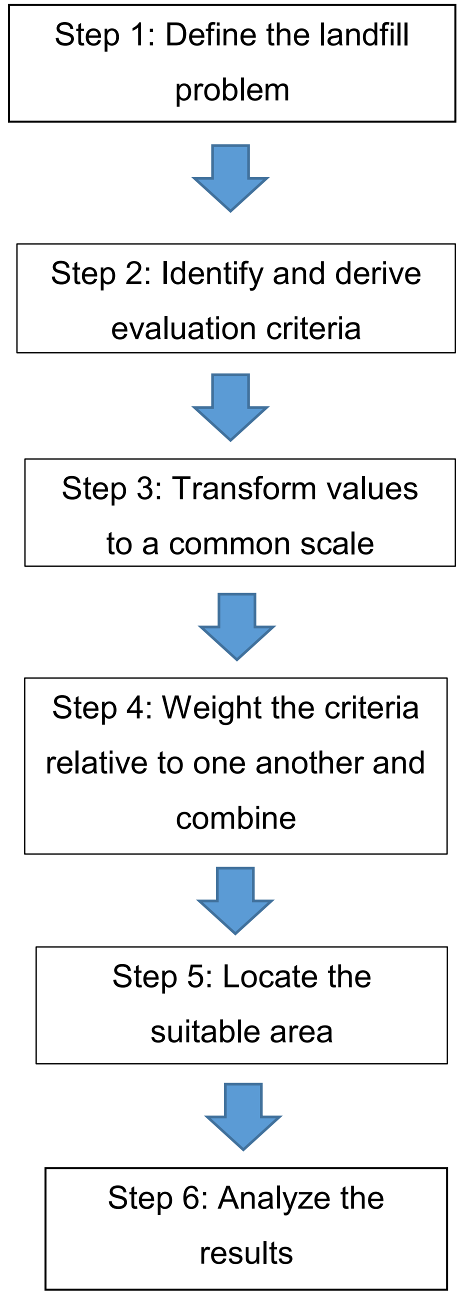

Figure 4. Landfill selection – GIS approach

3.2.2 Waste collection and transport (WC&T) with GIS

Collection and transport of solid waste are important steps in every waste management system. Moreover, the optimization of the routing system for collection and transport of municipal solid waste is a crucial factor of an environmentally friendly and cost effective solid waste management system (Chalkias & Lasaridi 2011). One of the most well-known vehicle routing problems is finding the best route in a network for a vehicle to travel in the study area, visit all the waste bins and minimizes the total travel costs, which is mostly defined on the basis of distance or time but also fuel consumption, CO2 emissions etc (Dantzig et al. 1954). GIS has a specific analysis extension to deal with routing problems, which is Network Analyst. Optimization of WC&T using the tools offered by spatial modelling techniques and GIS may provide significant economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutant emissions (Johansson 2006; Kim et al. 2006; Sahoo et al. 2005; Tavares et al. 2008). Indeed, many examples show that this statement is absolutely correct.

A comprehensive route-management system named WasteRoute was presented in the USA (Sahoo et al., 2005). The system optimized to manage nearly 26000 collection and transfer vehicles that collect over 80 million tons of garbage per year in more than 48 states of the USA. The operations of WasteRoute in the USA from March 2003 to the end of the year cut down 984 collection routes and saved 18 million dollars for the government.

A GIS-based method for the optimization of waste collection routes was developed in Eastern Finland (Nuortio et al. 2006). The method estimated an average route improvement in comparison with the existing routes of approximately 12%. Furthermore, researchers also proposed a combination of routing and rescheduling waste collection times to optimize the savings. This combination showed extremely significant fuel savings by 40% in some Eastern areas of Finland.

In the island of Santo Antao, Republic of Cape Verde, people achieved up to 52% fuel savings in waste transportation by applying GIS 3D modelling in practice, even travelling a 34% longer distance compared to the previous shortest route (Tavares et al. 2008).

3.3 GIS application in Urban Solid Waste Management in Vietnam

In Vietnam, GIS applications in urban solid waste management do not get much public attention. Some solid waste management projects using GIS application in Vietnam are monitoring and managing segregate waste collection (Nguyen & Matsui 2009) and estimation of the municipal solid waste collection and transport (Thanh et al. 2011). However, such projects are not really effective because of some reasons. First of all, Vietnam is a developing country and there are fields, such as economy and education, where the government focuses more on developing and investing budget rather than improving the waste management system. The shortage of investments leads to the shortage of modern technology, which is also a barrier for the improvement. Moreover, collection methods could not be consistent. Segregate bins are placed all around cities as an indication for citizens to dispose of their trash correctly. However, every day, workers still have to use trash in a wrong place. Since the collection system is inconsistent, it takes a handcarts to collect garbage on the streets and residential areas due to the lack of awareness of people who litter a huge amount of time and effort to collect the waste in the city. Such a problem also makes it more challenging to apply GIS solution because it is relatively difficult to calculate and determine the time when all workers finish their shifts and gather the handcarts at the transfer points. It leads to the situation that the garbage trucks have to travel several times a day between the transfer points and the landfill or the treatment plant in the same area in the city.

3.4 Introduction of ArcGIS and Spatial Analyst module

The description in this chapter about ArcGIS and Spatial Analyst module bases on the information on the official website of the Environmental Systems Research Institute (ESRI) (no date).

3.4.1 ArcGIS

ArcGIS is a geographic information system (GIS) for working with maps and geographic information maintained by the Environmental Systems Research Institute (ESRI). It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database (Northwestern University 2019). ArcGIS consists of the Windows desktop software, including ArcReader, ArcGIS Desktop and ArcGIS Pro.

ArcReader only allows user to view, identify and measure features on a map and print maps.

ArcGIS Desktop (often referred to as "ArcMap" to distinguish it from ArcGIS Pro), made up of four fundamental applications, which is ArcMap, ArcScene, ArcGlobe and ArcCatalog.

- ArcMap is the central application of ArcGIS. In ArcMap, user can carry out every task with GIS datasets in both two and three dimensions from creating, visualizing to querying, analyzing and making maps for publication.
- ArcScene is a 3D visualization application for viewing and editing three-dimensional spatial data by 3D analysis tools at local scale (GIS Geography 2020).
- ArcGlobe is also a 3D visualization application, but in contrast to ArcScene, ArcGlobe is used for viewing data at global scale and do not offer 3D analysis tools (GIS Geography 2020).
- ArcCatalog is a GIS application specifically used to manage and organize GIS contents, GIS servers and metadata.

ArcGIS Pro is a new integrated GIS application, which inherit all functionalities of ArcGIS Desktop and is planned to eventually replace ArcGIS Desktop applications. ArcGIS Pro works in both 2D and 3D for cartography and visualization, and includes Artificial Intelligence (AI).

3.4.2 Spatial Analyst module

The Spatial Analyst is one of the most popular extensions in ArcGIS, which provides a broad range of powerful spatial modeling and analysis capabilities. With Spatial Analyst, user can create, query information across multiple data layers, map, analyze cell-based raster data, perform integrated raster and vector analysis as well as derive new information from existing data.

The most common way to access Spatial Analyst functionality is with the geoprocessing tools. Geoprocessing is a GIS operation used to manipulate GIS data. A typical geoprocessing operation takes an input dataset, performs an operation on that dataset, and returns the result of the operation as an output dataset. Common geoprocessing operations include geographic feature overlay, feature selection and analysis, topology processing, raster processing, and data conversion. (Tulane University 2020.)

In the geoprocessing framework, user can perform Spatial Analyst operations by three ways, which is running individual tool dialogs from ArcToolbox, combining different tools into ModelBuilder (ESRI calls it as a visual programming language) to automate workflows and create spatial models and automating workflows and create new tools with Python programming language.

4 STUDY AREA

This chapter introduces the study area of this thesis, which is Phu Ly city, and describes the situation of solid waste management in the city.

4.1 General introduction of Phu Ly city

Phu Ly city is the capital city of Ha Nam province of Vietnam. It is located on National Highway 1A, on the bank of Day River, 60 km south of Hanoi. The area of the city is 87,87 km^2. (Pham Huu Giap 2015.) The city has undergone strong development and achieved many important goals in all fields. Phu Ly fully converged the conditions of a grade II city in Vietnam in 2018 (Investing synchronously and sustainably developing Phu Ly city 2018).

Figure 5. Satellite image of Phu Ly city

Phu Ly city has 21 subordinate administrative units, which are divided into 11 wards and 10 communes (Phu Ly City People's Committee 2020). For the scope of this thesis, only waste collection points in 6 wards in the city center will be used for analysis and evaluation. These target wards are Tran Hung Dao, Hai Ba Trung, Minh Khai, Luong Khanh Thien, Quang Trung and Le Hong Phong. Table 1 shows population, area and population density of the 6 target wards.

Table 1. Demography information of 6 target wards in Phu Ly city (Pham Huu Giap 2015)

Ward	Population	Area (ha)	Density (ppl/km^2)
Tran Hung Dao	5129	18.53	27679.4
Hai Ba Trung	6183	57.65	10725.1

Minh Khai	6489	36.07	17990.0
Luong Khanh Thien	7219	29.92	24127.7
Quang Trung	6351	256.74	2473.7
Le Hong Phong	6168	287.86	2149.0

The inner city road network is in the form of a chess board with a distance of 150-200 meters, mostly paved. The eastern road network is old and degraded, the western road network has been newly built with good quality. (Pham Huu Giap 2015.)

4.2 Situation of solid waste management in Phu Ly City

The total waste volume of Phu Ly city is approximately 100 tons per day. At the present, the solid waste collection in Phu Ly city achieves 85%. (Pham Huu Giap 2015.) Table 2 shows the waste sources in the city.

Table 2. Waste sources in Phu Ly city (Pham Huu Giap 2015)

Waste sources	Proportion (%)
Organic	55
Metal	3.4
Paper	2
Glass	9.2
Cardboard	13
Plastic	9.4
Other impurities	8

Solid waste in households is collected by 2 ways. People bring their waste to the nearest collection point or the waste is collected by garbage workers using handcarts and then transported to the collection points. From the collection points, the waste is transported to transfer locations which are located far from residential areas. After that, the waste is continued to be transported to the landfill or the treatment plant by the garbage truck from transfer locations. Besides, handcarts and small trucks are also used to collect waste on the streets, in markets and other public places. Figure 6, 7 and 8 which were taken on a field trip to Phu Ly city show the vehicles used to collect and transport waste in the city.

Figure 6. Small truck used to transport the waste to the transfer points

Figure 7. Handcart used to collect waste in the city

Figure 8. Garbage truck used to transport waste to the landfill or treatment plant

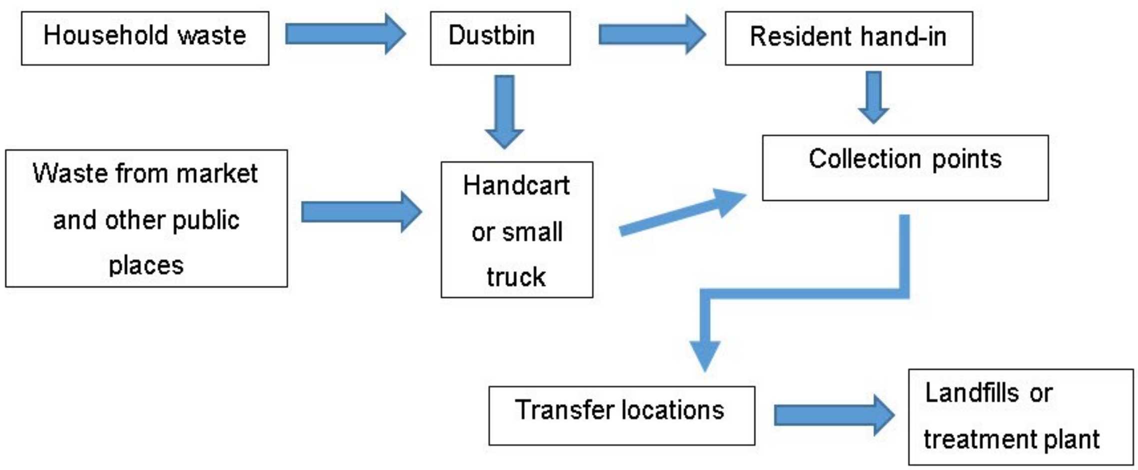

Figure 9. Method of organizing the collection, transportation and solid waste treatment in Phu Ly city

Overall, compared to the waste volume of big cities in Vietnam, such as Hanoi and Ho Chi Minh City (8000 tons/day) (Chen Liu & Trung Thang Nguyen 2020; Verma et al. 2016, 127-139), Phu Ly consumes much smaller amount of waste (100 tons/day) due to its lower population and smaller area. However, the city is facing uncomfortable waste-related problems. For example, the waste is not sorted at source, air pollution and rotten odors are caused by uncovered handcarts and the location and the number of collection points in the city are inappropriate. In addition, despite the regulations enacted by the city authorities, the people's awareness is still poor. Residents are lazy to bring garbage to collection points. (Waste collection points in Phu Ly cause environmental pollution and urban beauty loss 2018.)

5 MATERIALS AND METHODS

This thesis aims to solve the problem of the collection points by conducting suitability analysis in ArcMap, a GIS software, to suggest new collection points in 6 target wards of the city.

5.1 Data collection

The data used in this thesis comes from 2 sources. The first source is the complete dataset of Phu Ly city providing by GeoViet Consulting company. The second one is collected from the field trip to Phu Ly city taken on 11 August, 2020. The purpose of the trip was to take pictures of the current collection points and geocode those points on a map in ArcMap. Besides, the additional pictures of vehicles (handcart, small truck and garbage truck) used to collect and transport the waste in the city were taken as well. By navigating the current collection points in 6 target wards, it is more practical and easier to compare them with the new points which will be generated from the analysis in this thesis.

Figure 10. One of the waste collection points taken on the field trip

All of the pictures on the field trip were taken by a dedicated camera, which records coordinates of the location where the picture was taken. By doing this, the coordinates of collection points were recorded with the pictures. After that, these coordinates were extracted and geocoded on a map using ‘Creating feature class from XY table’ in ArcMap.

5.2 Finding optimal waste collection points in Phu Ly with Spatial Analyst

To conduct the analysis in ArcMap to find the new optimal waste collection points in 6 target wards in Phu Ly city, a complete dataset from GeoViet Consulting company is provided. The complete dataset consists of 4 feature sub-datasets, including urban land use, city background, population and public place. Most of layers in urban land use dataset are polygons, except the transportation, which is lines. Urban land use dataset shows how the land was occupied for different purposes. City background dataset contains the terrain of the city in raster and the administrative units (11 wards and 10 communes) in polygon. Population is the only tabular dataset, which contains the information of population and population density of administrative units. Finally, public place dataset describes public places of the city with their names and addresses in point format.

Table 3. Phu Ly city dataset from GeoViet Consulting company

Feature dataset (multi-layer)	Feature class (layer)
Urban land use	- Industrial area (polygon) - Tourism (polygon) - Transportation/roads (line) - Rice field (polygon) - Water (polygon) - Military area (polygon) - Residential area (polygon) - Trees (polygon) - Park (polygon)
Background	- Terrain/DEM (raster) - Administrative units (polygon)
Population	Population (tabular)
Public place	- Market (point) - Hospital (point) - Temple/Cathedral (point) - School/University (point) - Bus station (point) - Gas station (point)

5.2.1 Derive criteria for the analysis

To find the best collection points, it is not necessary to use all layers from the complete dataset. The chosen layers depend on the evaluation criteria in the analysis. In this problem, 4 criteria are set and from that ArcMap will rate the ideal locations for the new waste collection points. These 4 criteria include the followings:

- Firstly, the new collection points should be set up near the residential areas so it is easy for people to walk to the points and discard their waste. The distance of 100 – 400 meters would be sufficient for the residents.

- Secondly, the new collection points should be placed not far from main roads so it is easy for garbage workers driving small trucks around cities to collect the waste from the points. The distance of 50 – 200 meters from a point to main road would be good enough.

- Thirdly, the new collection points should not be very close to water surfaces, such as rivers and lakes. There might be a small chance for a waste collection point to contaminate the water, but in some unfortunate situation, wastewater can be leaked into the water surfaces. The areas which are less than 200 meters away from the water surfaces are not recommended to be set up as a collection point.

- Finally, the new collection points should be located in an area that its slope is not steep, or in plain and flat terrains. It will be more challenging for workers to drive the truck on the unfavorable terrain to collect the waste in the collection points. The areas which have the slope less than 5^{o} are suitable.

Table 4. Criteria and associated layers will be used in the analysis

Criteria	Layer will be used
1.Near residential areas (100 – 400m)	Residential areas (polygon)
2.Near main roads (50 – 200m)	Roads/Transportation (line)
3.Not very close to water surfaces (> 200m)	Water (polygon)
4.Plain/flat terrain (slope < 5^{o})	Terrain/DEM (raster)

Table 4 summarizes 4 criteria and layers which will be used in the analysis in the next chapter.

5.2.2 Geoprocessing

Once the criteria are derived, the suitability analysis can be conducted by the following steps:

Select by attributes tool extracts 6 target wards from the ‘Administrative units’ layer.

Select by attributes tool extracts the ‘residential areas’, ‘water’ and ‘roads’ layers from the ‘Urban land use’ feature dataset for further geoprocessing.

The ‘Select by attributes’ tool is used 3 times in this step to extract each layer mentioned above. The land use code for residential areas, roads and water is 111, 131 and 145 respectively in the dataset.

Clip tool is used to clip the residential areas within the target wards.

Slope tool in Spatial Analyst toolbox generates slope layer which is a raster from DEM raster layer.

Clip Raster tool is used to clip the slope area within the target wards.

Euclidean distance tool in Spatial Analyst toolbox creates raster layer which indicates the existing distances from a figure (can be raster or vector data) to the rest of the field or to the predefined maximum distance. In this problem, the Euclidean distance are created for residential areas, roads and water layers within the target wards. The output cell size of the 3 raster layers is the same as the cell size of the DEM raster model, which is 7.5 pixels. The reason why the cell size is similar between raster layers is to have the consistency during the analysis.

Reclassify tool in Spatial Analyst toolbox changes the values in the residential areas, roads and slope layers to a scale from 1 to 5 to weight each criteria in the next step. In this scale, 1 indicates the least suitable area and 5 indicates the most suitable ones. For water layer, only areas which have a distance greater than 200 meters are accepted to set up a collection point. Therefore, these areas are set to be value of 1 while other unsuitable areas are set to Null value, meaning they are not showed up on the map.

Weighted overlay tool in Spatial Analyst toolbox overlays 4 classified raster layers using a common measurement scale from 1 to 5 and weights each layer according to its importance. In 4 criteria mentioned above, criteria 1 (near residential areas) and criteria 2 (near main roads) are more important than the other 2 criteria. Therefore, criteria 1 and 2 have an influence of 40% each, whereas criteria 3 and 4 occupy 10% each.

Raster to Polygon tool converts suitable areas in raster format to polygons. This tool is used because ‘Erase’ tool, which is a tool used in the next step, requires vector data as an input.

Erase tool is used to erase overlapped residential areas and roads in the suitable areas. After erasing these features, the final suitable areas are created.

After erasing the coincident houses and roads, the final suitable areas for establishing new collection points are created.

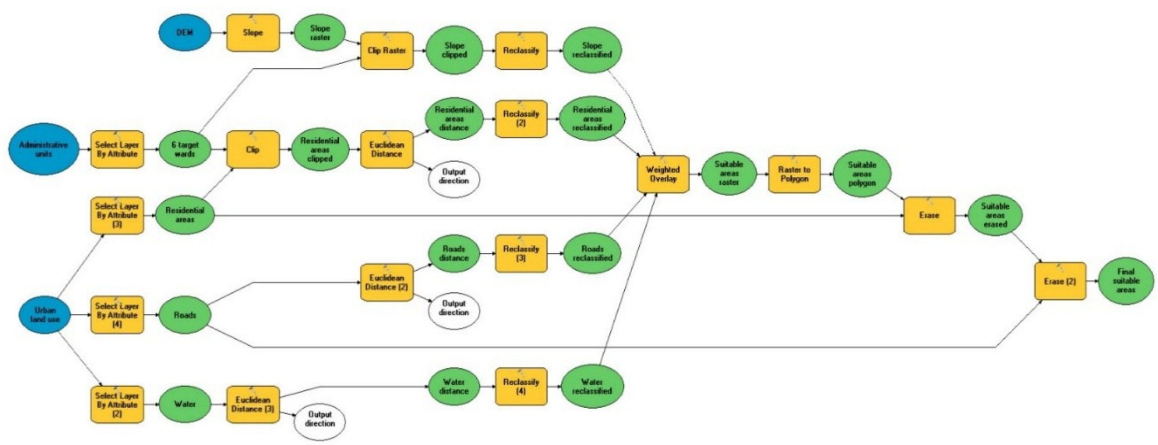

Figure 11. Geoprocessing workflow model

6 RESULT AND DISCUSSION

This chapter shows and discusses the results of the field trip to Phu Ly city and the optimization of waste collection points in ArcMap.

6.1 Field trip to Phu Ly city

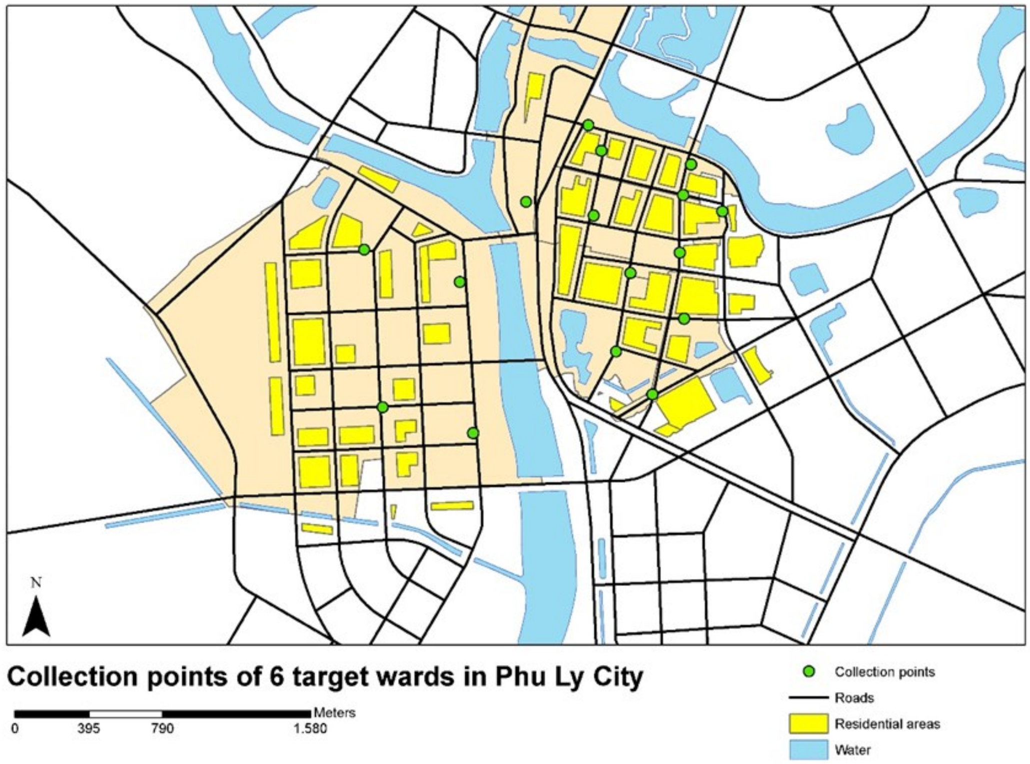

Figure 12. Current collection points of 6 target wards in Phu Ly City

As can be seen from the figure 12, there are limitations of these collection points. Firstly, the collection points are not evenly distributed between residential areas. The residential areas on the west side of Day river have only 4 collection points while there are 12 collection points on the east side. Even with 12 points, the number of collection points on the east side is still not sufficient compared to the residential areas. This leads to a second problem. It is that some current points are relatively far from residential areas. It might take much more time for citizens to walk from their houses to collection points. In the worst situation, some people are so lazy that they do not take their waste to collection points and just throw their trash wherever they find it ‘convenient’. Therefore, planning to set up new waste collection points in the city is totally necessary.

6.2 Optimization of waste collection points in ArcMap

This chapter presents the results and discussion of the implementation of the geoprocessing above.

Figure 13. Residential areas clipped within target wards

As might be seen from figure 13, residential areas are concentrated along the Day river bank. Besides, all residential areas are located near the main roads as well. This is because the road network of the city is well-planned. The fact that houses are close to the roads brings both advantages and disadvantages in establish new waste collection points. The benefit is that it is less challenging to find an area to set up a collection point near houses and roads since they are already close to each other. On the other hand, more collection points are needed to ensure that every residential area has at least 1 collection point. In this case, it will take more time for small trucks to move between collection points to transport the waste.

One of the most important results in the geoprocessing is the Euclidean distance of residential areas, roads and water.

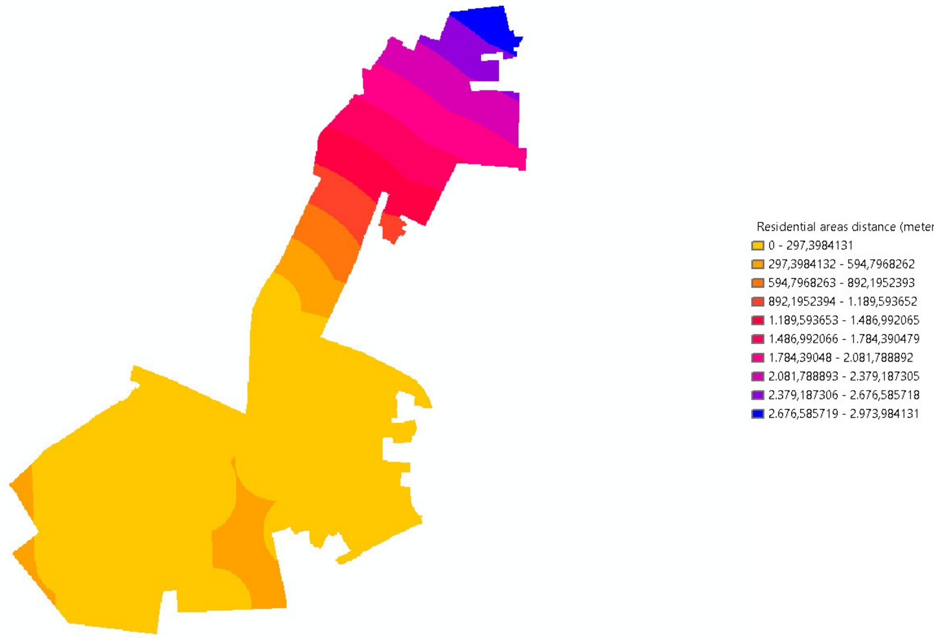

Figure 14. Euclidean distance of residential areas

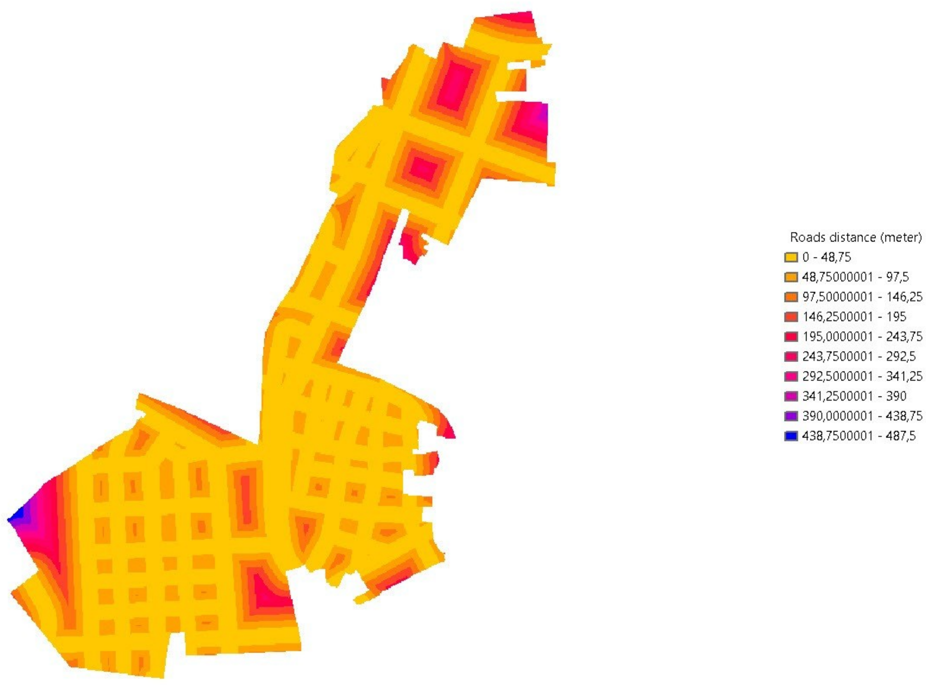

Figure 15. Euclidean distance of roads

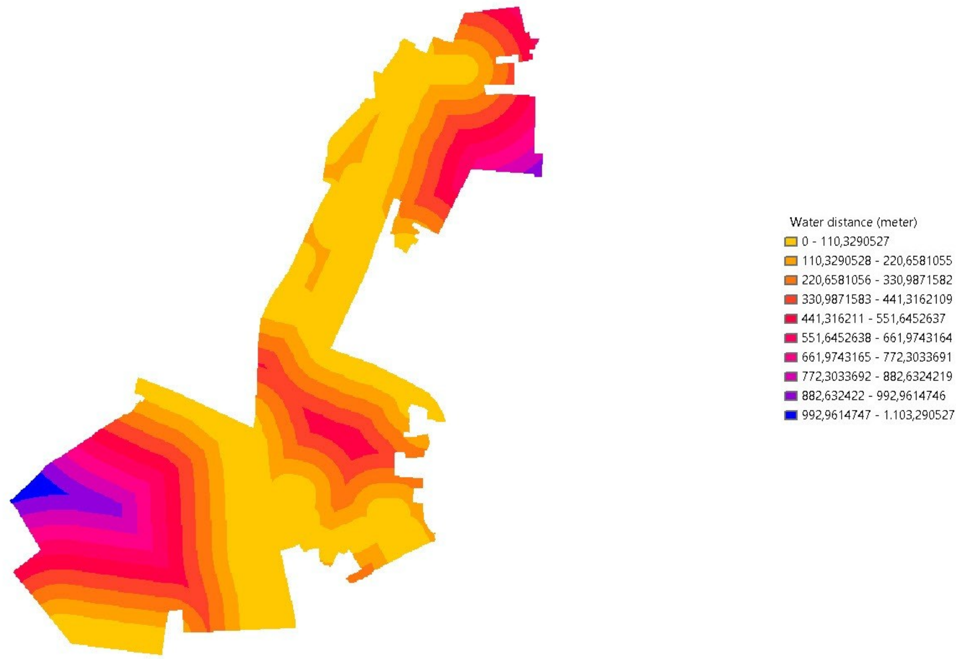

Figure 16. Euclidean distance of water

From the three Euclidean distance raster, it is possible to predict some sites to establish new waste collection points for the city. Suitable areas could be spread evenly across the 6 target wards according to the Euclidean distance figures of water and roads. However, according to Euclidean distance figure of residential areas, the north (Quang Trung ward) is not populated so it is predicted that the collection points will be concentrated in the southern wards (almost in Le Hong Phong, Hai Ba Trung and Minh Khai wards)

After Euclidean distance of the 3 layers were created, the values of these layers were reclassified so that they are similar with the defined criteria. After that, overlaying method was used to generate suitable areas.

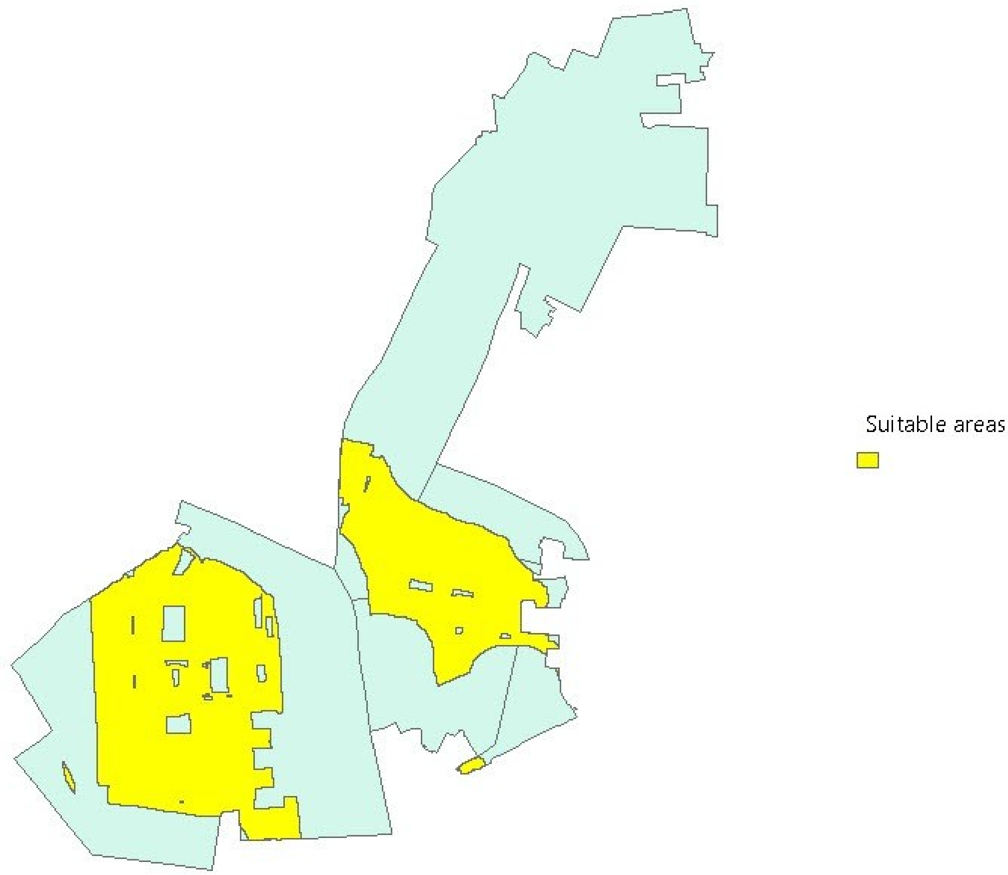

Figure 17. Suitable areas derived from overlaying layers

The suitable areas derived from the overlaying step are not really ideal. If these areas are compared to the residential areas and roads extracted from the urban land use dataset at the beginning of the analysis, it can be easily seen that some parts of the suitable areas are coincident with houses and roads. The problem might lie in the reclassification step when the distance from residential areas and roads to a collection point is set to start at 0. In fact, it is impossible to establish a collection point in a house or on a road. Therefore, Erase tool is used to remove the coincident parts and the remaining areas are suitable to set up new collection points.

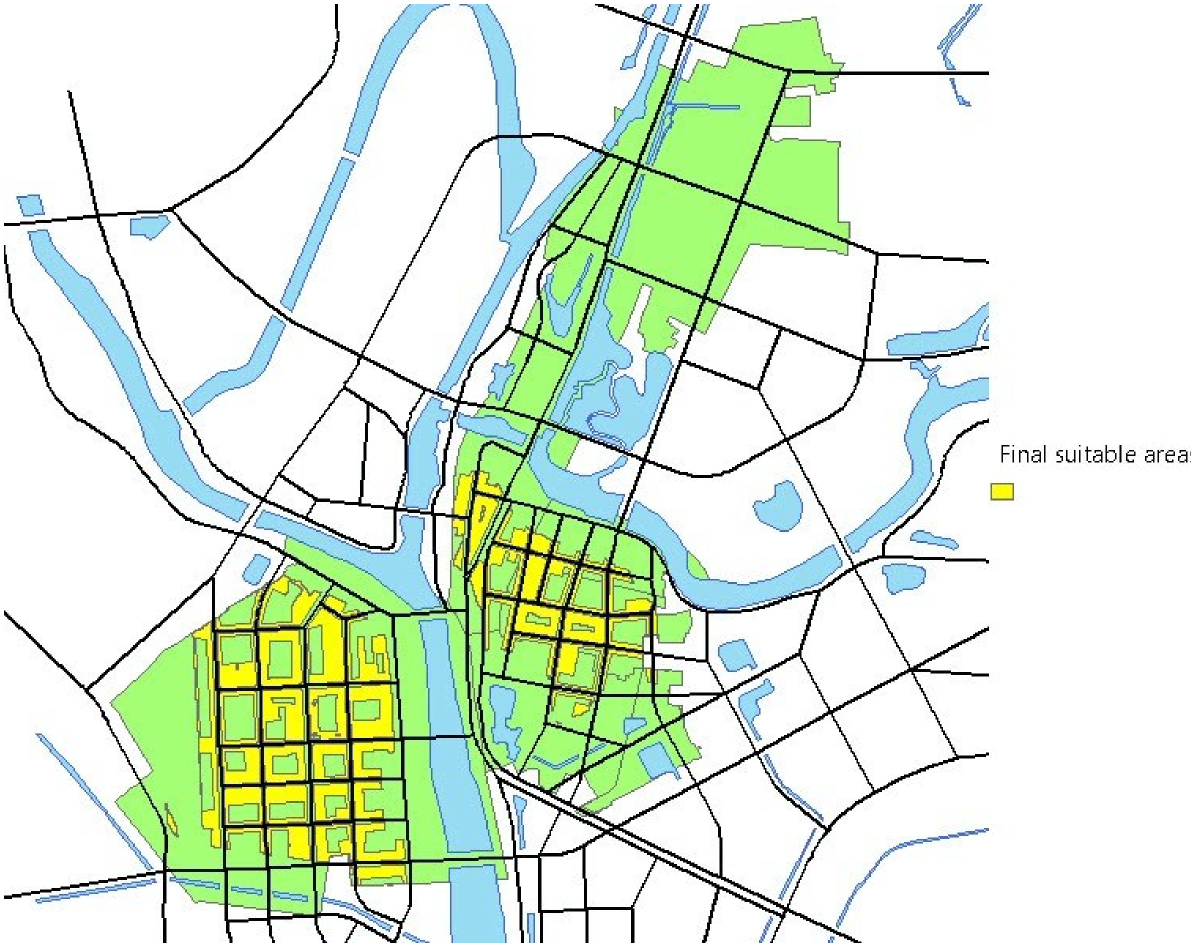

Figure 18. Final suitable areas to set up collection points

Once all criteria have been met and the most suitable areas have been determined (Figure 18), it is easy to put new collection points within these ideal locations. The following figure depicts an example of new possible collection points which can be set up in the target wards of Phu Ly.

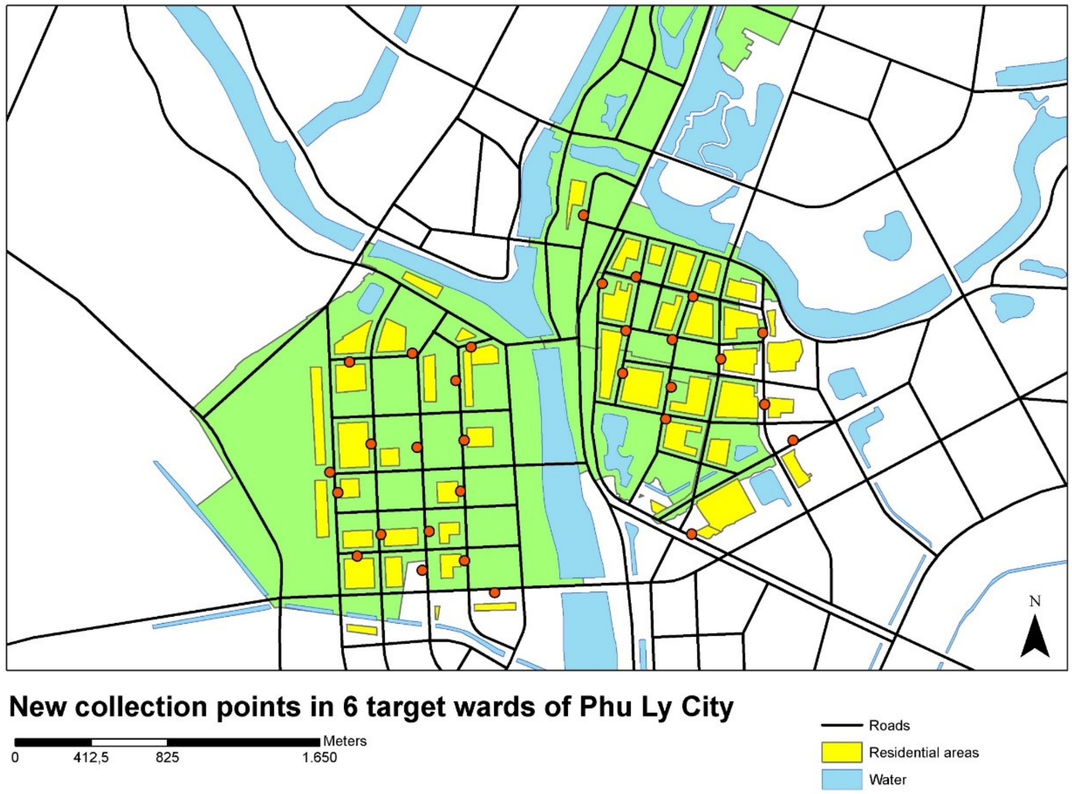

Figure 19. New collection points in target wards of Phu Ly city

As can be seen in the figure 19, the location of the new collection points has been improved in comparison with the old ones. The number of collection points has been evenly distributed between the residential areas on the east and to the west of the Day river. In addition, it is absolutely more convenient for people to dispose their waste and garbage workers to collection waste since all collection points are located very close to houses and main roads. Moreover, in terms of environmental protection, no collection points are placed near water areas to prevent possible contamination.

7 CONCLUSION

In this thesis, an overview of waste management and GIS applications in urban solid waste management were provided. Waste management is an urgent issue that is concerned by all countries around the world since the amount of waste discharged into the environment is increasing rapidly every day. The most effective, least impact on the environment and least costly waste management method is still a big question mark for every nation. Along with the development of science and technology, GIS contributes to making waste management easier, especially in terms of waste transportation, and navigating landfill sites and treatment plants.

Phu Ly city is a developing city in the Ha Nam province of Vietnam and has been facing some environmental problems, including waste collection in recent years. Applying GIS to establish new waste collection points in the target wards of the city will largely solve the problems that old collection points are facing at the moment. If this project is implemented successfully in 6 target wards, then the suitability analysis in GIS to locate collection points can be applied for the whole city and will bring great benefits. For that to come true, it is necessary to have the attention and proper investment from the authorities and the government. However, more importantly, every citizen needs to be more aware of the environmental protection and dispose the waste at the right place.

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