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GIS Modeling for Selection of a Transfer Station Site for Residential Solid Waste Separation and Recycling

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ABSTRACT

In this study a GIS model was developed and spatial analytical techniques performed to identify and select a suitable location for a waste transfer station in the sprawling suburban town of Petaling Jaya. The lack of a transfer station in urban centres of Malaysia has caused many problems and affects the efficiency of waste collection and disposal. With diminishing space for landfills and the increasing cost of solid waste management, the need for urban solid-waste recycling has become very important. However, finding a place for waste to be efficiently sorted before unwanted waste can be carried to disposal landfills has social and physical constraints. This study applies GIS techniques and analysis for site selection and identifies an acceptable area. In the model, environmental, physical and social constraints were taken into account, resulting in the selection of a potential area that is acceptable to the residents of the area because it is out of range of causing public nuisance and within minimum travelling distance for collection vehicles. The results show that the potential location for the transfer station should be in proximity of the industrial area of Petaling Jaya, allowing for the possible sale of recyclable materials to local industries. The location is also sited near a major highway to allow quick transportation of the rest of the unwanted waste to the landfill.

Keywords: GIS, solid waste, recycling, transfer station, Petaling Jaya, Malaysia

INTRODUCTION

In recent years, municipal waste recycling has been encouraged as a sustainable method for waste management due to environmental concerns and diminishing land for landfills. Extensive studies of waste composition in Petaling Jaya and most urban centres of

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Malaysia have shown that there is a high percentage of organic (71.2%) and of non-organic (28.8%) material in the waste produced (Meulen, 1996; UNCHS, 1994; Arshad, 1992). Waste composition in Malaysia shows that significant reduction of the amount disposed of at landfills can be achieved if an efficient system of waste separation is in place to separate waste for idea compost or recyclable materials (Triantafyllou & cherrett, 2009; Lopez *et al*., 2008). Attempts, however, to encourage people to separate their waste at home have not been successful. Suggestions have been made by different interest groups for the waste-management authorities and agencies to conduct waste separation by themselves. Till now, waste management companies have not been able to site and efficiently operate a transfer station in Malaysia due to social and operational constraints.

Geographic Information System (GIS) application and modelling in solid waste management

Geographical information systems have traditionally focussed on environmental mapping and monitoring of the changes within the local and regional environments. As computer technology improves more software is being developed to increase the range of research in the application of GIS in areas such as solid waste management (Ghose *et al*., 2008; Lopez *et al*., 2008; Goodchild, 2003; Li *et al*., 2001). Some of these GIS planning applications include the location and selection of sites, visualisation, interpretation and the forecasting and modelling of various spatial phenomena. They are best performed using a prescriptive model. A prescriptive model in its purest form is designed to impose a best solution for problems in which a description of existing conditions is insufficient as a decision aid (Chalkias & Lasaridi, 2010; Karadimas & Loumos, 2008; Tomlin 1991). According to DeMers (2002), the prescriptive model is more closely associated with answering the "what should be" type of question. GIS modelling scenarios may be applied to answer such questions as: What is the best location in which to site a factory?; and What is the most likely place to reintroduce falcons in the southwestern United States?

Geographic Information System (GIS) application in solid waste management

There is specific solid waste management software such as the Solid Waste Integrated Management Model (SWIM) (Wang *et al.*, 1996). Although these packages have strong tools for waste statistical analysis, they lack the spatial analysis, modelling and visualisation tools that general GIS have. They are thus limited in spatial data processing that are sometimes required in site evaluation and the selection of suitable land for a transfer station or landfill. General GIS application in waste management involves the routing of waste collection and shortest path analysis. But perhaps the widest areas of GIS applications in waste management are in the selection, management and monitoring of waste disposal sites (Banerjee, *et al*., 2004). This involves the overlay factors that are processed into GIS thematic maps such as the slope of the land, the soil type, the depth of the bedrock, the depth of the ground water and the distances to historic sites, main roads and towns. Various spatial processing and geospatial analytical processes are performed to identify possible sites/locations best suited for the development of a waste disposal site (Oliveira & Borenstein, 2007; Wolfgang & Gang, 1997; Massie, 1997).

Where the identification of a transfer station is a problem to be resolved, the factors that may be processed will include social-cultural considerations such as smell and proximity to residential areas (Chalkias and Lasaridi, 2010; Triantafyllou and Charrett, 2009; Vijay *et al*., 2008).

In a general GIS modelling, Gruenert *et al*. (2010) identified three stages i.e. data, process and parameter models to be executed in a hierarchical process. The first stage, "data model", is concerned with the observational process which specifies the distribution of the data given the fundamental process of interest and parameters that describe the data model. The second stage then describes the process, conditional upon other process parameters. The last stage models the uncertainty in the parameters from both the data and process stages. This hierarchical process is not new in disciplines such as statistics; however, the basic formulation for modelling spatial and spatio-temporal processes in the environment is a new development (Longley *et al*., 2005). This method allows problems to be simplified by breaking them down into sub-problems.

MATERIALS AND METHODS

The study area is located in the fast growing urban municipality of Petaling Jaya in Malaysia (Fig.1). About 200tons of municipal waste is collected from the housing and residential areas of Petaling Jaya daily. This waste is disposed of at a sanitary landfill that is 26.6km away, a distance that has increased the cost of waste collection. The rising cost is a major concern for the local municipal council (MPPJ), and efforts are being made to minimise waste collected through waste recovery for reasons of environmental protection, cost of transportation and landfill and the diminishing space for landfill. There is a nationwide recycling programme, "Project Bumiku" the objectives of which are reflected in the waste recycling practices in

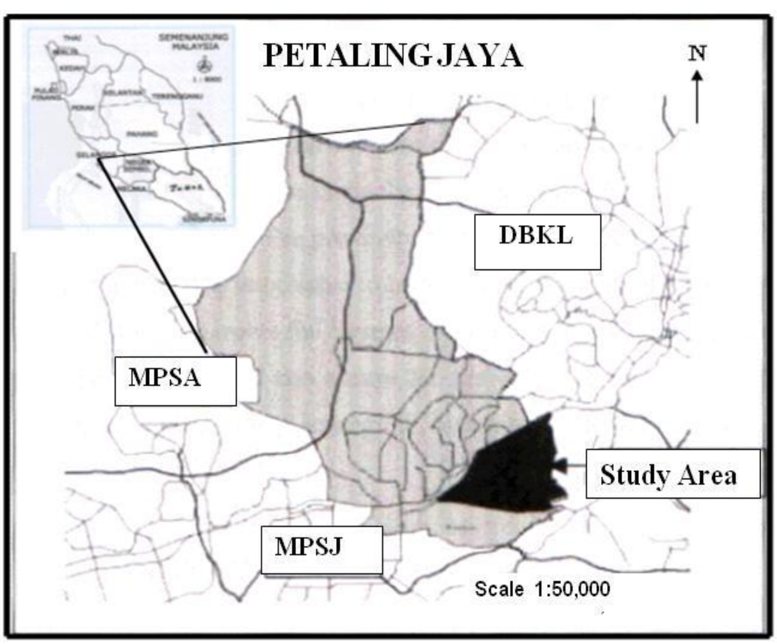

Fig.1: Study area (Petaling Jaya)

Petaling Jaya. The programme is ongoing, and aims to get citizen participation in community development, mobilise various interest groups, promote community development through a comprehensive community education programme and promote a clean and beautiful urban environment through a better community . According to Vijay *et al*. (2008), for recycling programmes to be successful especially in commercial and some housing areas, there is the need for transfer stations. At the transfer station waste can be effectively sorted out to remove recyclable items.

Waste collection for zone 8 and 9 study areas (MPPJ municipality)

Waste collection and the layout of the situation is better explained by the thematic map generated from GIS (Fig.2). The map displays the two zones considered in this study and the type and quantity of waste for each collection sector. This study revealed that the average population density in zone 9 is 93/ha and the average waste generation rate for the zone is calculated at 0.50kg/capita. The total daily waste production is 9,525.4kg and after effective recovery the expected waste for daily disposal in the zone is 4420.1kg. On average, waste collected from medium income households account for over 85% of the waste expected for collection. Details of the waste generation rate by sector in zone 9 are presented in Table 1.

Zone 8 collection sector has an average population density of 62/ha and the average waste generation rate is 0.55kg/cp/d. With the number of housing units at 3273, the population of the zone is calculated to be 16,365. The total waste generated is 8,875.2 kg/day. The low population

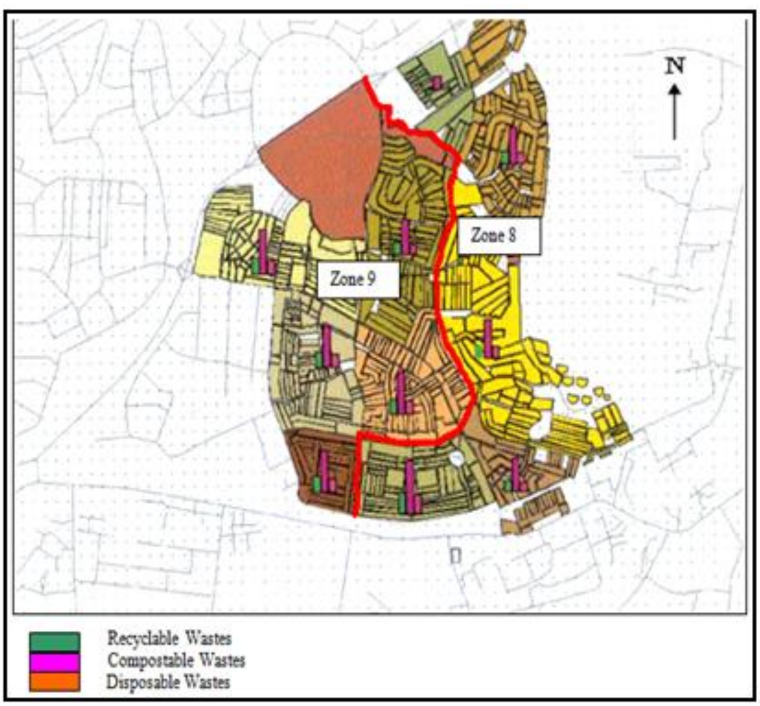

Fig.2: The type and quantity of waste for each sector

density of the sector is believed to sometimes cause lapses in the waste collection process of the area. The statistics for waste collection in zone 8 are presented in Table 3 . According to Tchobanglous *et al*. (1993), in operational waste management, such low density areas are required to have a transfer station so as to minimise waste collection costs. The transfer station is used for effective material recovery. In zone 8, the expected waste for collection after recovery is calculated to be 4,118.14kg (Table 2).

TABLE 1
Waste from zone 9

Col. Sect.	No. Hse.	Gen Rate	Qty/day in kg	Qty 3/week Col. kg	Qty after Rec k g
S 6	978	0.38	2082.40	4164.00	966.16
S 4	695	0.56	1974.00	3948.00	916.22
S 20	668	0.51	1713.60	3427.20	795.18
S 3	695	0.52	1812.20	3624.40	840.90
S 18	694	0.56	1943.20	3886.40	901.64
Tot.	3730	0.50	9525.4	19050	4420.1

Col.: Collection, Gen: Generation, Qty: Quantity, Rec: Recovery, Sect: Sector, Tot: Total, Hse: House

TABLE 2
Waste from zone 8

Col. Sect.	No. Hse.	Gen Rate	Qty/ Day, kg.	Qty 3/wk Col. kg	Qty after Rec. kg
S 2	556	0.88	2446.40	4892.80	1135.24
S 13	606	0.56	1677.20	3354.40	778.10
S S	858	0.47	2004.55	4009.10	929.98
S 5	838	0.43	1863.50	3727.00	864.84
S 7	415	0.41	883.55	1767.10	409.98
Total	3273	0.55	8875.20	17750.40	4118.14

Col. Sect.: collection sector, No. Hse.: number of houses, Gen Rate: Generation rate, Qty/Day,kg.: quantity per day in kilograms, Qty 3/wk Col.kg: quantity of 3-weeks collection in kilogram, Qty after Rec. kg: quantity after recycling in kilogram

Data and modelling process

The data used in developing the waste collection GIS include residential housing, land use and road network. The GIS layers were prepared with detailed attributes of the different housing types, land use types and road network types. The modelling process was developed based on the prescriptive (DeMers, 2002) and hierarchical (Gruenert *et al*., 2010) modelling techniques to identify the suitable location for a transfer station. Data models were established based on standards and environment considerations for establishing and operating a transfer station as suggested by Tchobanoglous *et.al.* (1993). The spatial and non-spatial data used includes land use, housing, street blocks, road network, build-block types and attributes of other features. The process model was established based on the concerns of local residents, and developed into a set of criteria to evaluate the suitability of alternatives. The following set of initial criteria was established:

- Land reserved for industrial development or open unused land
- At least 200m away from residential, commercial and other public land use
- Within 100m of a main primary distributor road
- In acceptable travel distance (not more than 10km) away and from the waste management depot and all the waste collection sectors/routes in Petaling Jaya

The spatial modelling processes involved spatial and proximity analysis as illustrated in Fig.3. Techniques such as buffering, union and overlays were performed using Arc/Info and ArcView GIS platforms. The study was limited to identifying the best area within the study area and taking into consideration the highly residential nature of the area.

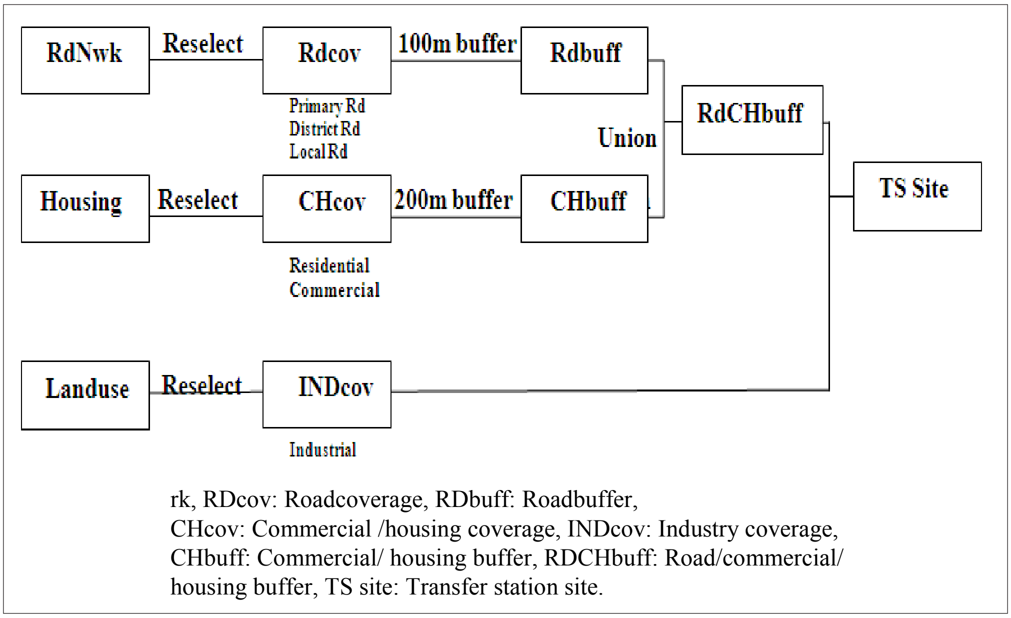

Fig.3: GIS modelling process for transfer station selection

RESULTS AND DISCUSSION

The need for transfer operations arises in consideration of economic and effective waste separation and recovery reasons (Tchobanglous, *et al.*, 1993; Tchobanglous, *et al.*, 1977). Some factors that make the operation of a transfer station attractive for Petaling Jaya include (1) the presence of illegal dumps and large amounts of garbage, (2) the location of disposal sites relatively far from collection routes, typically more than 25km away, (3) the use of small 2- to 3-ton capacity collection trucks to collect and convey waste along the narrow residential streets of Petaling Jaya (4) complex residential street network and the existence of low-density residential areas and (5) the high cost of waste collection and disposal.

Spatial modelling to identify a transfer station involved a series of geospatial processes of GIS layers. Attributes of these layers were selected, classified, buffered, merged and intersected to delineate suitable sites. In the road network data, the primary, district and local distributor roads were selected to create an ArcInfo coverage file "RDcov" on which a buffer of 100m was developed. Thus, the potential site should fall in a 100-m proximity of these main distributor roads (RDbuff). This ensured that waste brought to the station for separation was kept at the station no longer than expected. After separation unwanted waste could be transported through the modelled proximity to major highways (RDbuff) rapidly and directly to the landfill site. The attributes of commercial and housing areas in the housing data were selected and a buffer of 200m created (CHbuff). This is to ensure that the potential transfer site will be outside the exclusion zone of commercial and housing activities. The suitable area will thus be out of range and will not cause public nuisance by emitting foul smells. Fig.4 shows the buffered primary roads and the buffered housing areas.

The buffered thematic layers RDbuff and CHbuff were merged to create a combined layer of processed road and commercial and housing attributes (RCHbuff). This layer was then overlaid with the reselected industry attributes from the land use data file to generate the potentially suitable location for the transfer station (TS) site. The thematic map (Fig.5) displays the results of the potential area, where after further evaluation the location of the transfer station site is made in the study area. The map shows the industrial area and the buffered predominantly housing and commercial area. The potential transfer (Fig.6) shows the spatial modelling process

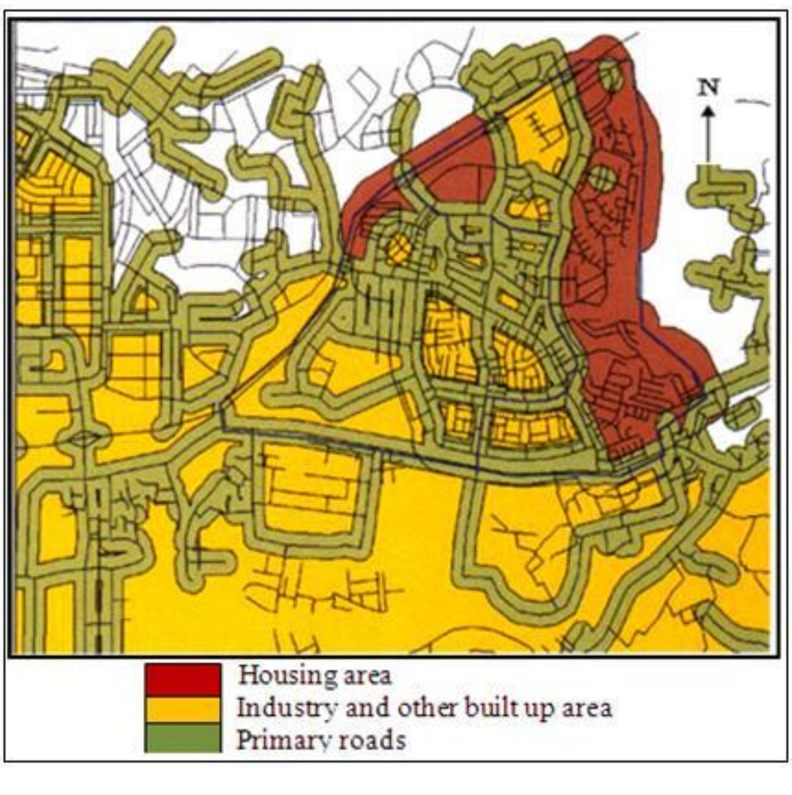

Fig.4: Buffer of primary roads and housing area

where factors under consideration were transformed into thematic layers. Using these thematic layers, the search for a potential location was narrowed to the area depicted in light colour covering about 76.3ha within the industrial zone. This site was further evaluated using on a ten-point weightage score based on (a) adjacent land uses, (b) off-site visibility, (c) closeness to collection areas, (d) closeness to a highway/primary road and (e) cost of land.

Fig.7 shows the area that has been identified for the development of the transfer station. All environment factors and the concerns of the residents were evaluated in the model. The site is located only 100m away from a major primary road; this was to allow quick and easy access for big waste collection trucks to move in and out of the area with undue obstruction. The immediate land use is a paint factory some distance away; moreover, being in an industrial zone also has it benefits as the sale of recycled materials such as paper, glass, metals etc. to other industries in the vicinity can be made. Residential houses were not located within the area and the transfer site was not visible from the housing area. People living nearby will thus not be able to see the activities at the transfer station.

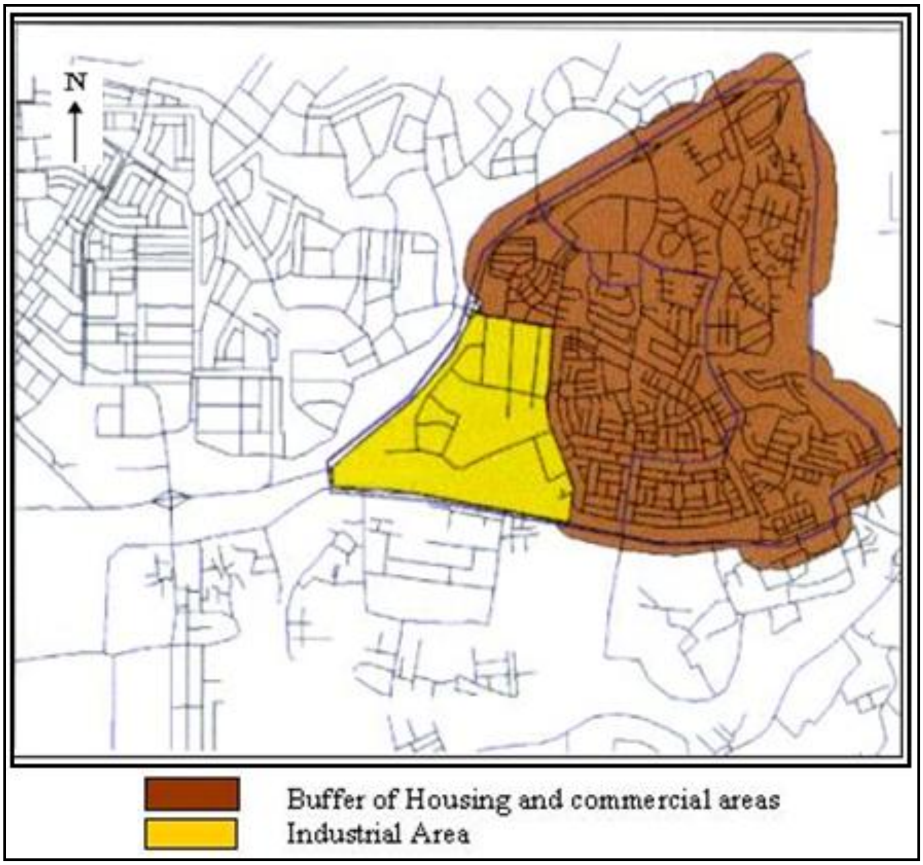

Fig.5: Map of 100 m buffer of housing/commerce overlaid by industry

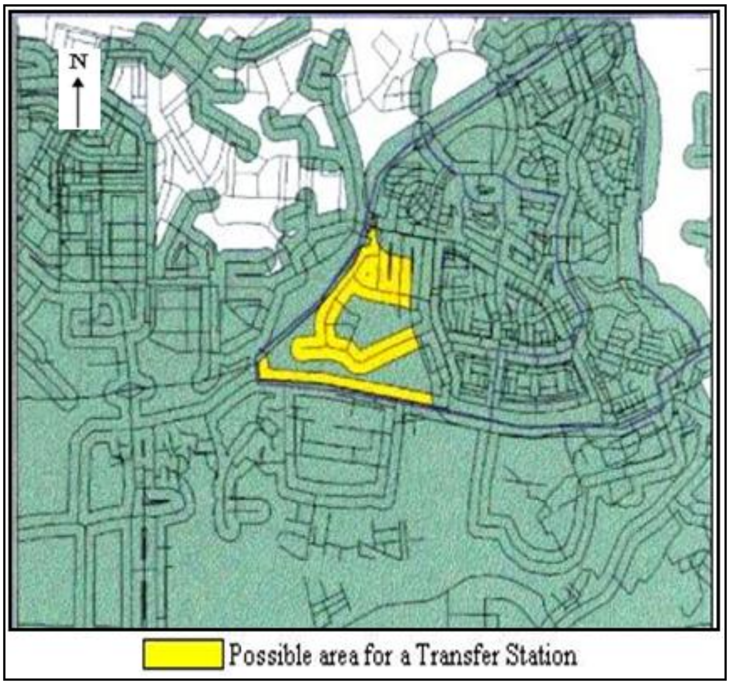

Fig.6: Modelling potential areas for placement of the transfer station

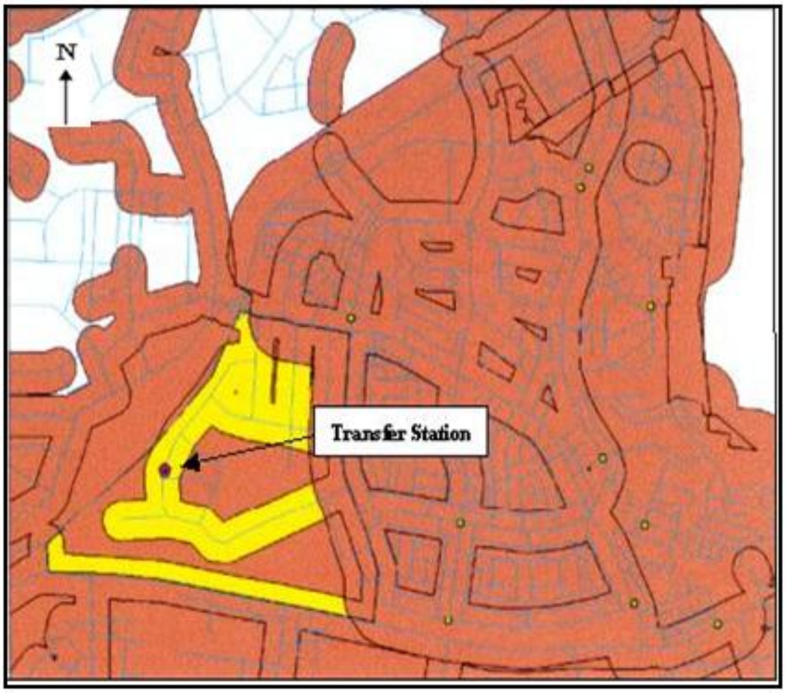

Fig.7: Identification of transfer station location

CONCLUSION

Studies show urban solid waste composition in Malaysia to be 71.2% organic and 28.8% non-organic with significant potential for reducing waste through waste separation. This has, however, not been possible due to the difficulties of identifying a suitable place for a transfer station for efficient waste separation. The increasing potential of GIS in spatial analysis and modelling has made it possible to develop scenarios of site selection taking into account socio-cultural, environmental, physical and waste management operational concerns. Currently, a lot of waste management software incorporates GIS functionalities but do not provide the full potential of GIS capabilities required for spatial and modelling analysis for site selection and the identification of transfer stations.

In this study GIS spatial modelling together with geospatial techniques were applied in the identification and selection of a suitable site for the development of a transfer station in Petaling Jaya. What could have turned out to be a complex decision-making process was simplified through a hierarchical modelling process. The process criteria were extremely relevant to public concerns about locating a waste separation close to residential areas. The GIS helped to limit environmental and socio-economic concerns to spatial factors that were further processed to isolate a potential area. The most suitable location for a transfer station was identified in the industrial area of Petaling Jaya. Locating the transfer station in an industralised area will allow the potential reuse of separated and recyclable items by other industries. The location was also in proximity of a major highway, thus waste meant for the landfill could be easily transported with little disturbance to the public and regular road traffic. The modelling processes that were developed are flexible enough to be implemented in a different study area with a different set of criteria and constraints. Over all, the GIS processes were effective and efficient for the collection, organisation, analyses and manipulation of the data and environmental conditions for the identification of the transfer station site.

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