# INVESTIGATION OF LANDFILL SUITABILITY BASED ON SEMI QUANTITATIVE RISK MATRIX AND GIS

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## Abstract

Open dumping is the most widely practiced method in Sri Lanka to dispose municipal solid waste (MSW) because it is the cheapest and easiest method compared to other methods available to manage MSW.Currently, there are no guidelines available for a proper selection of landfill dump site which may minimize the environmental, social and economic problems in the country. Site selection for landfill sites is an important aspect from both environmental conservation and social/economical point of view. Data was collected from the Udapalatha area for analyzing. Considering priority of all criteria in comparison with others, a specific risk rate was decided to each criterion according to their total influence on the whole process of decision making. Suitable landfill site was analyzed by using the Geographic Information System (GIS) together with risk assessment. To identify appropriate landfill areas in the study area, five input map layers including surface water bodies, distance from transportation routes, distance from urban areas, land use/land cover, and elevation were used in the mapping. Based on these data a risk assessment wascarried out with a semi-quantitative matrix. The findings obtained from this study could be used for preliminary information to develop criteria for new landfill site selection. Finally, suitable low-risk regions in the area have been proposed for solid waste landfill disposal.

**Keywords:** Open dumping, municipal solid waste (MSW), Geographic Information System (GIS), Landfill siting, Risk assessment

# 1. Introduction

Urban solid waste management is considered as one of the most serious environmental problems confronting municipal authorities in developing countries (Abeynayakaet al.2007). One of these impacts is due to location of landfill sites in unsuitable areas, such as in a valley adjacent to open water source or in a residential area. This heavily leads to the deterioration of surrounding environments.

Open dumping of municipal solid waste (MSW) has been recognized as the cheapest form for the final disposal of MSW and as such has been the most used method in the world (Abeynayaka et al. 2007). However, landfill siting is an extremely complex task mainly due to the fact that the identification and selection process involves many factors and strict regulations (Ball 2005, Gunarathna et al. 2010). For proper identification and selection of appropriate sites for landfills, careful and systematic procedures need to be adopted and be followed. Wrong siting of landfill may give rise to environmental degradation and arising of public conflict as well as unhealthier society.

During a landfill siting process, there are many factors that must be taken into consideration and carefully evaluated. Risk assessment was used for the identification of the proper landfill sites. The risk assessment process can involve a quantitative or semi-quantitative approach, comprising estimation of likelihood/frequency and severity/consequence (Bartram et al. 2006). As a result, the most suitable site to be selected should cause minimum impacts to the environment, society and economy as well as conforming with the regulations and generally accepted by the public. In addition, there are numerous data to process and sometimes it might be repeated for several times until the best site is found.

Open dumping is neither approved nor recommended disposal technique anywhere in the world including in Sri Lanka. This method is rejected because of many negative impacts associated with such open landfills of MSW (Visvanathanetal. 2005). However, the alternative sanitary landfill is considered one of the best low-cost disposal methods in such cases and has gained popularized across the world in the past few decades (Illeperuma and Samarakoon.2010). But due to many constrains; such as lack of awareness, lack of proper guidelines and many social issues this technique has not yet been practiced in Sri Lanka (CEA. 2005). These improper solid waste dumping practices in Sri Lanka have directly contributed to the deterioration of its environment especially by the by-product generations such as leachate production (Balasooriya et al. 2011). These by-products are believed to be causing extremely harmful conditions (Vidannaarachchi et al. 2006). Many of the dump sites are situated very close to the water sources, which are used for supplying drinking water for the downstream population. However, none of these have been taken into account with the existing landfill sites. There are no guidelines currently available for a proper selection of landfill dump site which may minimize the environmental, social and economic problems in the country.

The issue of landfill site selection is complicated and time consuming. Nowadays Geographic Information System (GIS) method used more than the others for landfill site selection (Donevskaet al.2011, Sener et al. 2011, Seneret al.2006). The GIS is a suitable tool for site selection, it has the capability to manage large amount of spatial data that comes from various sources (Mahamid and Thawaba2010). Large amount of spatial data can be processed using GIS and it potentially saves time that would normally be spent in selecting an appropriate site. This system also helps government bodies set guidelines and regulations, and evaluate prevailing strategies for handling and disposal of waste.

The objective of this study is to be focus on using the Geographic Information System (GIS) and semi quantitative risk assessment matrix for appropriate landfill site selection undertaking Udapalatha Divisional Secretariat region as a case study.

# 2. Material and methods

## 2.1. The study area

The study area is the Udapalatha divisional secretariat, located in central province, Kandy district. Gampola is a main town in the area situated in Valley Surrounded on all side by hills. It is about 470-m above the sea level with a temperature between $18^{0}C$ – $24\ ^{0}C$, and has an annual average rainfall of 1450 mm. So, Gampola is a town that receives the above mentioned rainfall because of the Monsoon rains.

The Nawadewita landfill site in Gampola is located at South-East of Gampola city and located in the narrow valley which slopes from east to west, it received MSW from Gampola as well as UdapalathaDS Divisions previously. Municipal solid waste dumped in relatively high elevated places of the landfill area. The Mahaweli River flows along the western boundary of the site. Mahaweli is the largest and longest river in Sri Lanka. The river is under threat because of uncontrolled open dump sites which are located very close to the river. However, now solid waste disposal site of this area has been re-located to Ambuluwawa area (Fig.1).

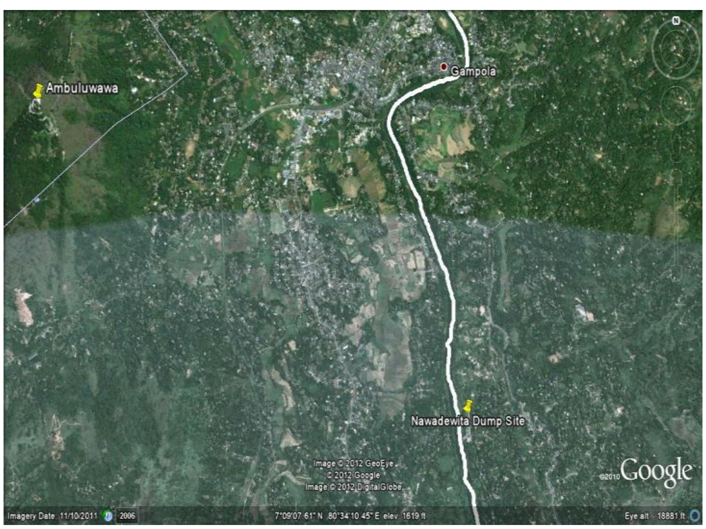



***Fig.1.The study area (Satellite image in Google Earth)***

# 3. Methodology

Data (Land use, Elevation, Surface water, distance to roads, railways) was collected from the Udapalatha area for analyzing using GIS. Considering priority of all criteria in comparison with others, a specific risk rating was decided to each criterion according to their total influence on the whole process of decision making. Suitable landfill site was analyzed by using the Geographic Information System (GIS) together with risk assessment (Gorsevski et al. 2012, Naset al. 2010, Sener et al. 2011). This method is useful foranalysing assess large amount of spatial data. To identify appropriate landfill areas in the study area, five input map layers including proximity to surface water bodies, distance from transportation routes, distance from urban areas, land use/land cover, and land elevation were used in mapping. Based on these data, a risk assessment iscarried out with semi-quantitative matrix (Table 1). The findings obtained from this study could be used to develop criteria for new landfill site selection. Finally, low-risk suitable regions in the area have been proposed for solid waste landfill disposal.

# 4. Results and Discussion

Landfill site selected by incorporating GIS together with risk assessments. This risk assessment was used to develop criteria for new landfill site selection. In this study five input criteria (surface water bodies, distance from transportation routes, distance from urban areas, land use/land cover, and elevation) were selected for risk assessments. The risk assessment process involves a semi quantitative approach, estimating likelihood/frequency and severity/consequences (Deere et al. 2001) (Table 1).

***Table1. Semi quantitative risk matrix (Deere et al, 2001)***

| | | *Severity or consequence* | | | | |
|---|---|---|---|---|---|---|
| | | *Insignificant or no impact – Rating:1* | *Minor implication impact-Rating :2* | *Moderate esthetic impact-Rating:3* | *Major regulatory impact-Rating: 4* | *Catastrophic impact-Rating: 5* |
| *Likelihood or frequency* | *Almost certain/ Once a day-Rating:5* | *5* | *10* | *15* | *20* | *25* |
| | *Likely/ Once a week- Rating: 4* | *4* | *8* | *12* | *16* | *20* |
| | *Moderate/ Once a month-Rating: 3* | *3* | *6* | *9* | *12* | *15* |
| | *Unlikely/ Once a year- Rating; 2* | *2* | *4* | *6* | *8* | *10* |
| | *Rare/ Once Every 5 year-Rating: 1* | *1* | *2* | *3* | *4* | *5* |
| *Risk Score* | | *<6* | *6-9* | *10-15* | *>15* | |
| *Risk rating* | | *Low* | *Medium* | *High* | *Very high* | |

Each hazard was categorized in to Social, Chemical, Topography/Morphology, Environmental Regulatory, Chemical/Environmental impacts. Then each risk distinguishes between significant and less significant risks by multiplying the likelihood/frequency and severity/consequences and given number when identifying potential hazardous event (Table 2)

***Table 2: Typical hazards identification in landfill sites***

| ***Hazard Event*** | ***Criteria*** | ***Hazard Type*** | ***Likelihood*** | ***Severity*** | ***Risk*** | ***Risk Rating*** |
|---|---|---|---|---|---|---|
| *Odor and diseases* | *Landfill within 500m-1km from an urban areas* | *Social* | *4* | *2* | *8* | *Medium* |
| | *Landfill within 500m from an urban area* | *Social* | *4* | *5* | *20* | *Very High* |
| | *Landfill >1km from an urban area* | *Social* | *2* | *2* | *4* | *Low* |
| | *Surface water bodies within <300m away from a landfill site* | *Accessibility* | *4* | *4* | *16* | *Very High* |
| | *Surface water bodies within >500m away from a landfill site* | *Accessibility* | *2* | *2* | *4* | *Low* |
| | *Landfill within 500m-1km from an urban areas* | *Accessibility* | *2* | *1* | *2* | *Low* |
| | *Landfill within 500m from an urban area* | *Accessibility* | *4* | *3* | *12* | *High* |
| *Surface water pollution* | *Surface water bodies within <300m landfill site* | *Chemical* | *5* | *5* | *25* | *Very High* |
| | *Surface water bodies within >500m landfill site* | *Chemical* | *2* | *2* | *4* | *Low* |
| *Ground water pollution* | *High elevation(>2000m)* | *Topography/ Morphology* | *5* | *5* | *25* | *Very High* |
| | *Elevation between 400m-1250m* | *Topography/ Morphology* | *4* | *2* | *8* | *Medium* |
| | *High vegetation cover around the dump site >50%* | *Social* | *5* | *5* | *25* | *High* |
| | *Low vegetation cover around the dump site <75%* | *Social* | *3* | *1* | *3* | *Very High* |
| *Social/Environmental impacts* | *Land use- Urban Centers* | *Social* | *4* | *5* | *20* | *Low* |
| | *Land use- Villages* | *Social* | *5* | *5* | *25* | *Very High* |
| | *Land use- Plantations* | *Environmental* | *3* | *5* | *15* | *Very High* |
| | *Land use- Pasture areas* | *Environmental* | *4* | *5* | *20* | *High* |
| | *Land use- Rocky Terrain* | *Environmental* | *2* | *3* | *6* | *Very High* |
| | *Land use- Bush lands* | *Environmental* | *1* | *3* | *3* | *Medium* |
| | *Land use- Agricultural land* | *Environmental* | *2* | *4* | *8* | *Low* |

Geographic Information System (GIS) was used for the identification of proper site for MSW landfilling in the Udapalatha divisional secretariat by risk assessment. If the area is very risky those areas avoided when making new landfill sites. The risk assessment is used to evaluate the importance criteria and generates risks according to likelihood and severity. Risk rate was given by considering the semi quantitative risk matrix.Based on that Geographic Information System software was used for identify the potential areas for landfill siting.

Various types of land uses are present in the study sites (Fig.2), forest considered as very high risk area and coloured as red to represent the high risk. Because when landfill sites are located in forested area it causes the catastrophic impact to the environment. So dense and sparse forest considered as very risk area while agricultural, unused land considered as low risks area while garden consider as medium risk area. Surface water within the area was taking in to consideration (Fig.3) and avoided for landfill site selection.

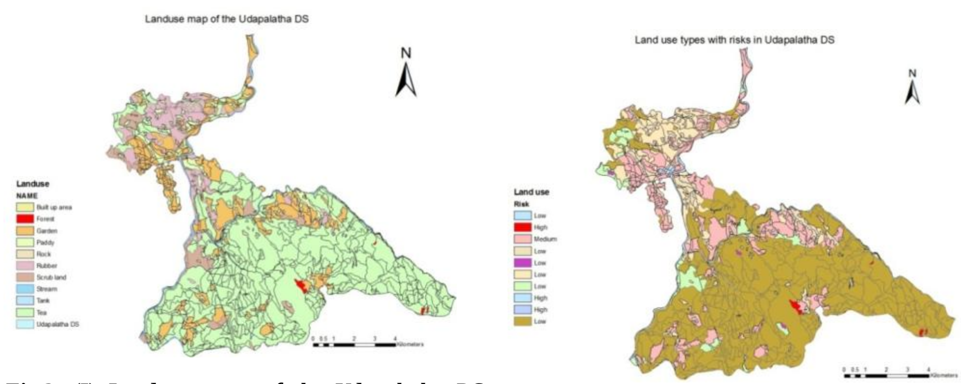
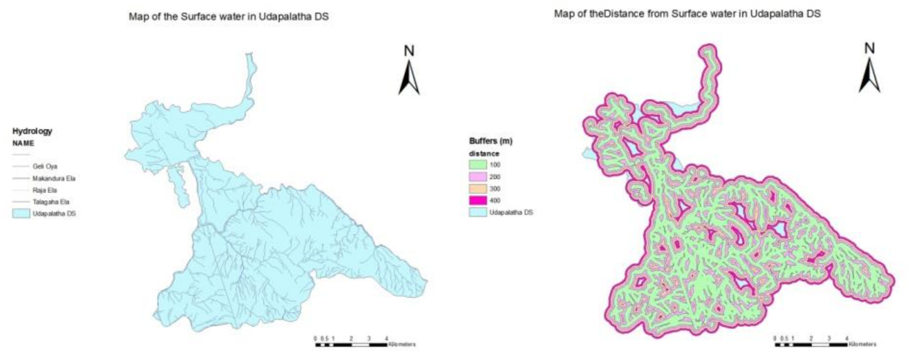



***Fig.2. (I) Land use map of the Udapalatha DS. (II) Land use types with risk***

The surface water bodies within the area are the most important factor for landfill site selection because landfill causes several impacts to the environment. The Mahaweli River flows along the western boundary of the Udapalathadivisional secretariat (DS). Mahaweli is the largest and longest river in Sri Lanka. It has a great importance for the whole country because of its utilization as drinking water, irrigation water, and for fishing and energy generation. The river is under threat because of uncontrolled open dump sites which are located very close to the river.

So, the waste dispose site should not be located in any streams, lakes nearby, because landfill is a potential source of large amount of leachate which has impact on surface water. Buffer zones were mapped by identifying risk associated with landfill site by using Arc GIS 9.3 software (Fig.3).Distance from surface water less than 300m causes very high risk, around 300m moderate and above 300m is low to the environment. Safe distance from surface waters and buffer zones were formed from 1000m.




(I) (II)

***Fig.3. (I) Hydrology map of the Udapalatha DS (II) Map of the distance from surface water***

Distance to road considered for site selection of a sanitary landfill as an economic criterion. If a landfill site is located far away from existing road networks that will increase the cost associated with construction of new access road, subsequent operation and odour, noise as well as dust . All these factors have negative impacts to the population.Buffer zones were created using Arc GIS 9.3 software. If roads are much closer to the landfill site, its impacts to the society induce high risks because of odour, vector associated with such landfill sites. Buffer zones were assigned 100, 200, and 300m along the every existing road on the Udapalatha DS. 200-m buffer zone was categorized as a moderate risk area while 300m buffer zone was assigned as a low risk area. Elevation of the land was taken in to consideration of the risk assessment. The best areas for landfill siting are the places with medium altitude. Sharifi et al. (2009) excludes areas over 2,100 m as potential sites for hazardous landfill, while Sener et al. (2010) consider areas at 400–1,250 m above sea level as most suitable as less risk areas and higher than 2,000 m as high risk for municipal solid waste landfill. The entire area mapped using Arc GIS software (The figures are not shown).

Urban areas as well as building of the area were considered for the risk assessment. Buffer zones were created around the every building. If a landfill is located in less than 500m, it causes very high risk to the people who live in nearby and above 1km is considered as low risk while between 500m into 1km considered as moderate risk(The figures are not shown).

According to the risk assessment, risk areas were classified in to three categories, low, moderate and high. Considering all the criteria, risks were identified and mapped by the Arc Geographic Information System. Theidentified areassuitable for landfilling are illustrated in Fig.4.

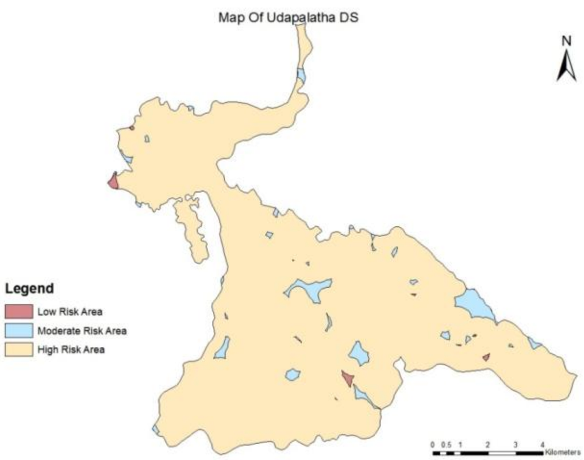



***Fig.4. Risk categorization map of the Udapalatha DS***

As it can be seen from Fig.4, the area belonging Udapalatha divisional secretariat, 99% of the area is very high risky, wherein there is small fraction of whole area is low and moderate risky and can used for landfilling. Because surfaces water bodies within the Udapalatha DS area is spread whole area and give more attention to conserve them.

## 5. **Conclusions**

Proximity to surface water bodies, distance from domestic settlements, existing land use/land cover, elevation, transportation routes, were considered as the prime criteria for risk assessment. Risk rate was given for each categories and final risk map was developed overlaying the each layer using GIS.

Accordingly, 99% of the area belongs to Udapalatha divisional secretariat (DS) comes under very high risk. Other areas are demarcated as moderate and low risk areas for landfilling. These areas generally satisfy the minimum requirements for the landfill sites considering the available data. Present dumping sites located in Ambuluwawa and past dump sites in Nawediwita also comes under high risk area. Mitigations measures are required for these dumping sites to control the risk hazards.

The selection of the final MSW site, however, requires further geotechnical and hydrogeological analyses towards the protection of groundwater as well as surface water. Further research is needed to incorporate the land suitability on the basis of economic and social viability.

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