GIS application in locating suitable sites for solid waste landfills

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Abstract

In Sri Lanka solid wastes are haphazardly dumped in unsuitable locations frequently. This research identifies the optimal sites for landfills in Matara and Weligama divisional secretary divisions according to existing Sri Lankan regulations by using GIS techniques. The capability of GIS to manage large amounts of spatial data makes it an indispensable tool for site selection processes. Criterion and factor maps regarding landfill siting were prepared on ArcGIS 9.2 platform with the aid of proximity analysis. Finally, weighted overlay analysis was applied to constructed maps to arrive at optimal sites for landfills. Research findings indicate that 2.10 km^2 and 3.82 km^2 area of Matara and Weligama DSDs respectively were highly suitable for landfill siting, according to the chosen criteria. Since solid waste dumping is a global environmental concern, municipal authorities all over the world could use a similar approach to dispose solid wastes an in environmental sustainable manner.

Introduction

The process of solid waste disposal management mainly consists of collection, processing, recycling and disposing. At present, waste disposal in most cities is done in simple form of landfill deposing (Akbari *et al.,* 2008). However finding a good waste disposal area is difficult since land is a scarce resource. An increasing environmental awareness, increasing cost, community and political opposition and public health concerns have made choosing suitable land for landfills quite difficult (Din *et al.*, 2008).

Landfill siting is a complex process involving the processing of massive amounts of spatial data. Technological development in computer science has introduced geographic information system (GIS) as an innovative tool in landfill process (Kontos *et al.,* 2005). GIS is a digital database management system that is ideal for advanced site-selection studies because it can efficiently store, retrieve, analyze, and display information according to user-defined specifications (Kao and Lin, 1996 , Sener, 2004 and Shamshiry *et al.*, 2011).

The Analytic Hierarchy Process (AHP) is a multi-criteria decision technique that helps the decision maker to set the priorities and make the best decision by reducing complex evaluations to a series of pairwise comparisons (Casini *et al.*, 2006). AHP technique can be used in combination with GIS to arrive at optimal solutions in landfill siting process.

Matara divisional secretary division (DSD) and Weligama DSD have the highest populations in Matara district and therefore generate high waste loads. The intention of this study was to find optimum sites for landfills Matara DSD and Weligama DSD, according to existing environmental rules and regulations in Sri Lanka with the help of GIS and AHP.

However when it comes to disposal of this wastes, there is no properly placed landfill site in Matara the DSD. Most existing landfill sites are haphazardly placed (Jayawickrama and Weerasinghe, 2011). Siting the best available location for the landfills requires an extensive evaluation process to find a site which protects the public and the environment.

Methodology

Study area

Matara DSD and Weligama DSD in Matara district (Figure 1) were selected for the study as these areas are the highly populous DSDs within the district.

Landfill area calculation

Matara DSD is t Data on population and amount of waste generated were collected and the expected population and waste amounts up to 2020 were estimated. From these data areas needed for landfills that should last till 2020 in each DSD was calculated

GIS methodology

The suitable criteria for landfill site selection process were extracted from national regulations and international guidelines. Ten important criteria were identified for landfill siting namely; surface water, forest reserve, wetland, coastal zone, town centre, residential area, important building, major road and railway, slope and soil. Digital data were obtained from different government authorities. ArcGIS 9.2 software package was used to create landfill siting layers. The GIS method used in this paper is outlined in Figure 2.

Landfill siting criteria were divided into constraint and factor criteria. Constraint criteria represent the unsuitable areas according to the regulations while factor criteria enhance the placement of landfill of being placed within an area.

According to different regulations constraint criterion maps were created for all the ten criteria. The unsuitable areas according to constraint criteria are indicated in Table 1. All constraint criterion maps were overlaid to create the final factor map.

The acceptable areas were extracted from constraint maps and were further classified into classes of high, medium and low priority for being used as landfill sites (Table 2). Each map layer was both internally weighted based on their direct distance to features and environmental judgement and externally weighted using AHP, based on the relative importance of the criterion. To obtain the external weights, the method described by Saaty, 1980 was used. First all the criteria were compared against each other according to the comparison judgement scale from Saaty (2006) which is indicated in Table 3

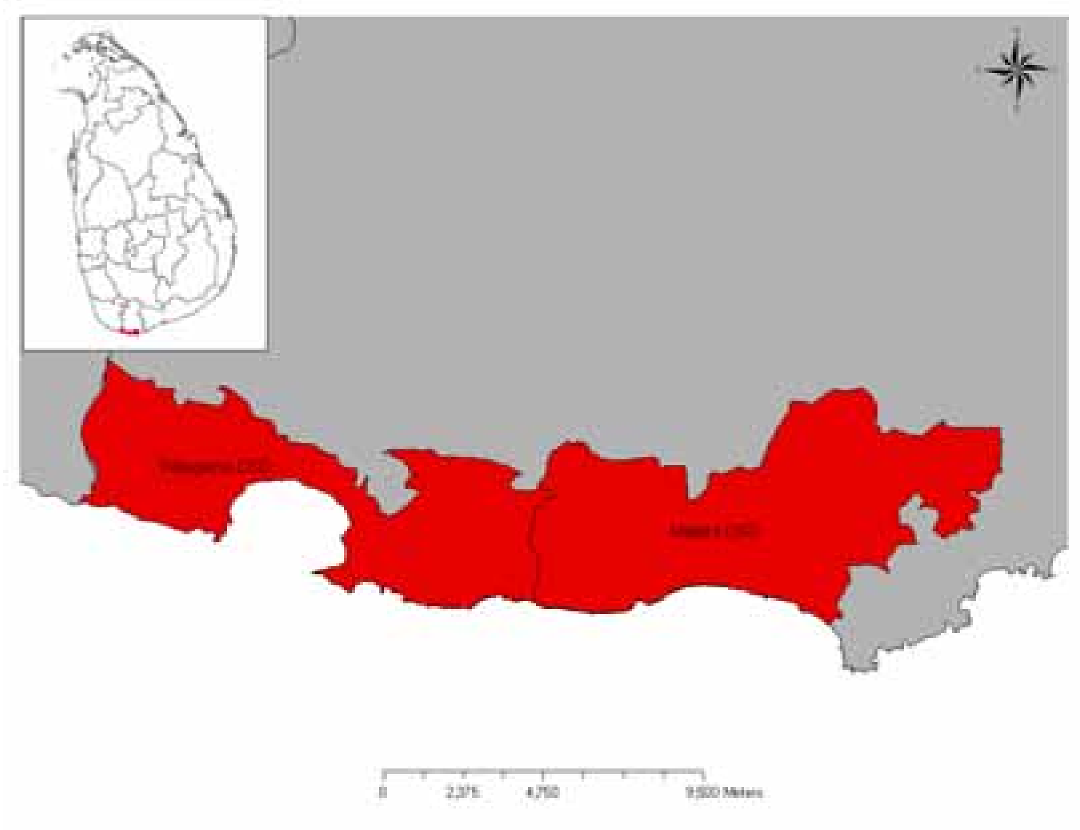

Figure 1: Map of the study area

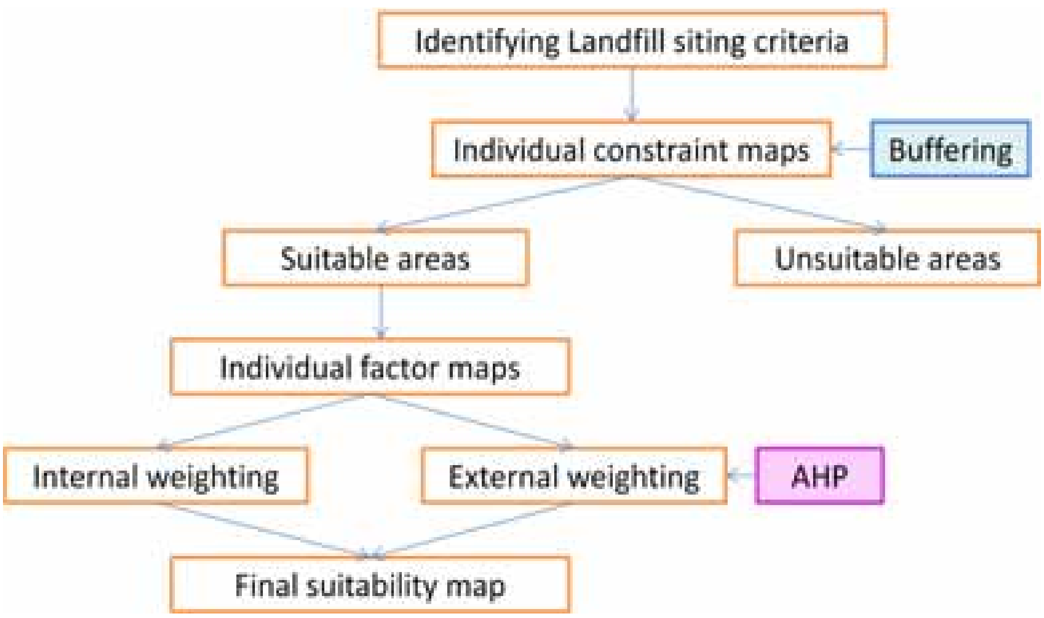

Figure 2: GIS procedure

Table 1: Constraint criteria

Criteria	**Unsuitable areas**
Surface water body	160 m buffer zone
Forest reserves	100 m buffer zone
Coastal belt	300 m buffer zone
Town centre	500 m buffer zone
Residential area	300 m buffer zone
Wetland	100 m buffer zone
Transportation network	100 m buffer zone
Important buildings	300 m buffer zone
Slope	Areas with slopes greater than 15°
Soil	Areas with alluvial soils

Table 2: Factor criteria

Factor map	**Low suitability**	**Medium suitability**	**High suitability**
Surface water body	160 - 480 m	480 - 960 m	> 960 m
Forest reserves	100 - 200 m	200 - 300 m	> 300 m
Coastal belt	300 - 600 m	600 - 900 m	> 900 m
Town centre	500 - 1000 m	>2500 m	1000 - 2500 m
Residential area	300 - 500 m	500 - 800 m	> 800 m
Wetland	100 - 200 m	200 - 300 m	> 300 m
Transportation network	>2000 m	1000 - 2000 m	100 - 1000 m
Important building	300 - 500 m	500 - 800 m	> 800 m
Slope	10^o - 15^o	5^o- 10^o	0^o - 5^o
Soil	Sandy soil	Mixed soil	Silty soil

Table 3 Comparison judgments scale for assigning values (Saaty, 2006).

Value	Importance
1	Equal
3	Moderately dominant
5	Strongly dominant
7	Very strongly dominant
9	Extremely dominant

The final landfill area suitability map was created by overlaying all ten factor criteria.

Finally according to the minimum landfill area requirement in each DSD, suitable sites for landfills were selected. These sites were visited for field validation.

Results and Discussion

According to the cumulative waste amounts estimated for 2020, Matara divisional secretary division requires a minimum area of 52800 m^2 for a landfill. Weligama needs an area of 27800 m^2.

Figure 3 to 12 show all the constraint maps while from Figure 13 to 22 the ten factor maps are shown.

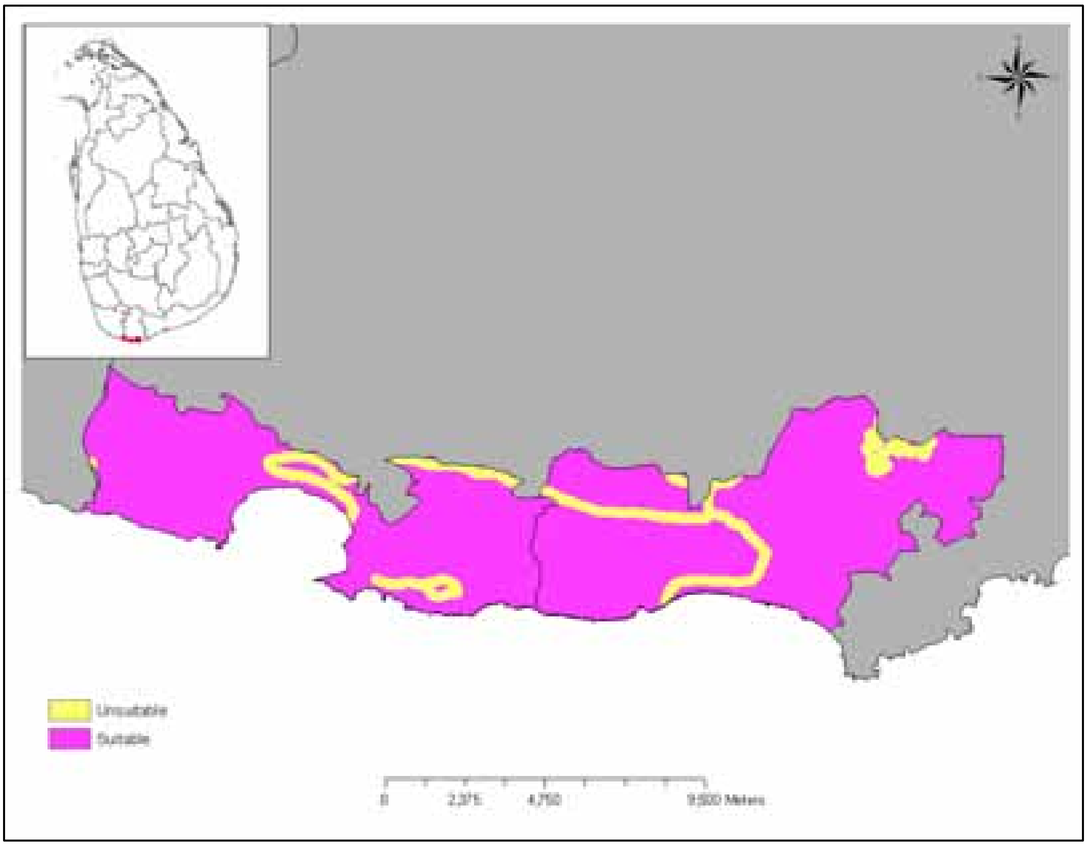

Figure 3: Surface water constraint map

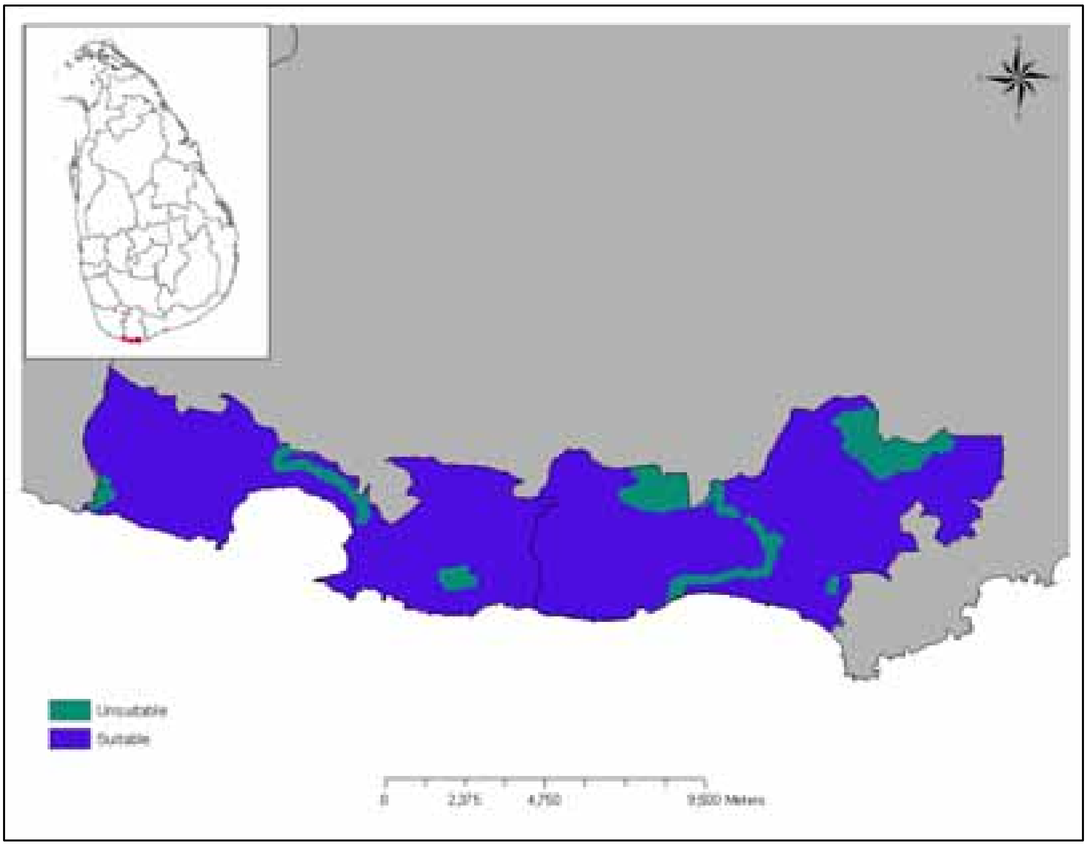

Figure 4: Forest constraint map

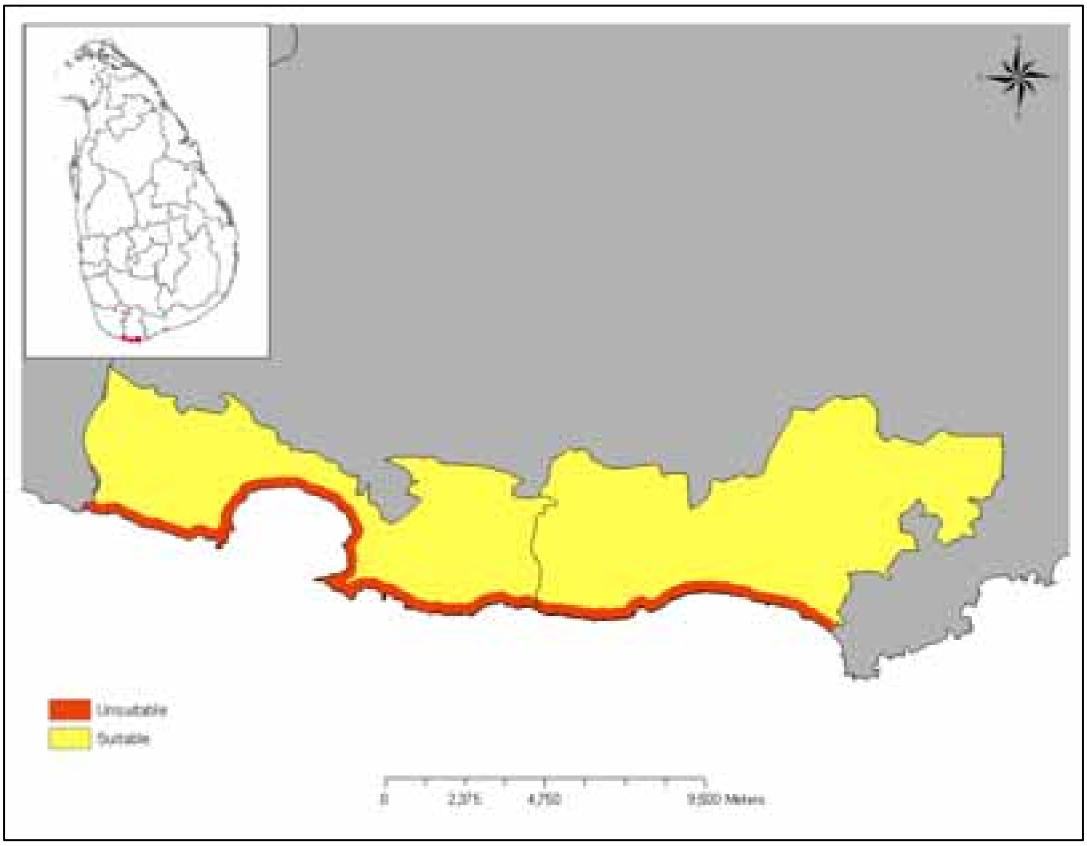

Figure 5: Coastal belt constraint map

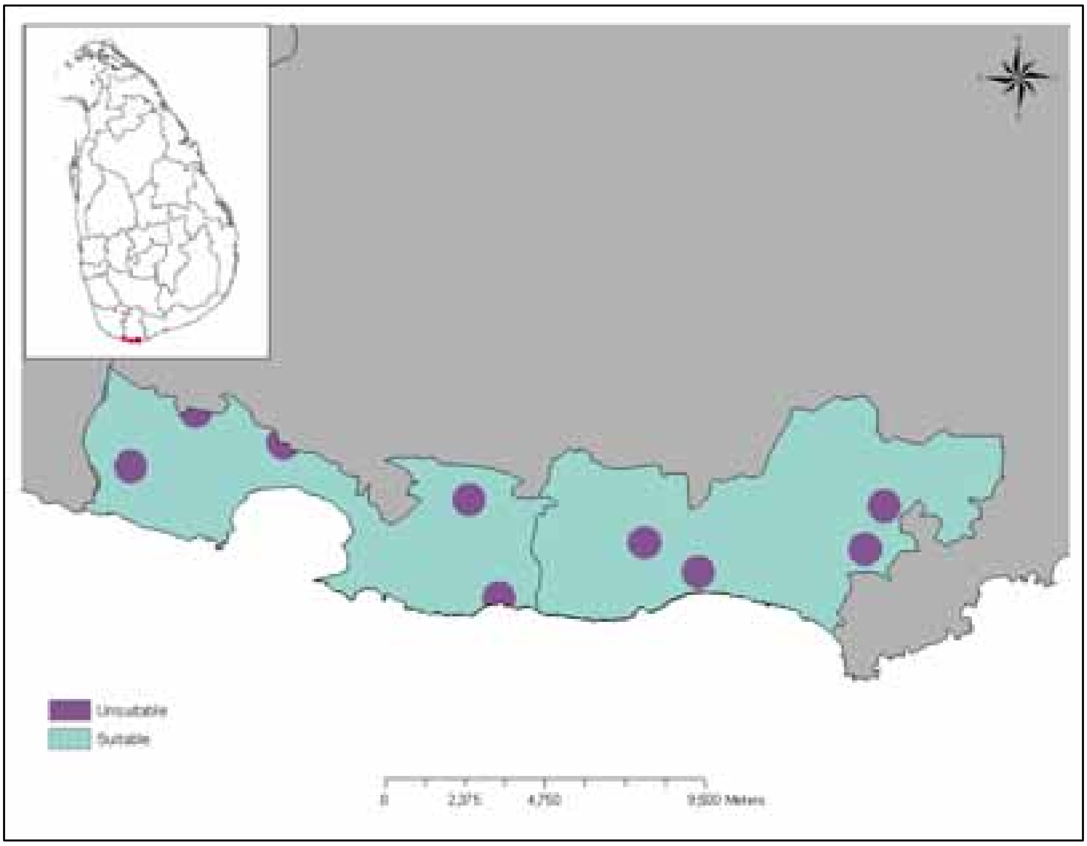

Figure 6: Town centre constraint map

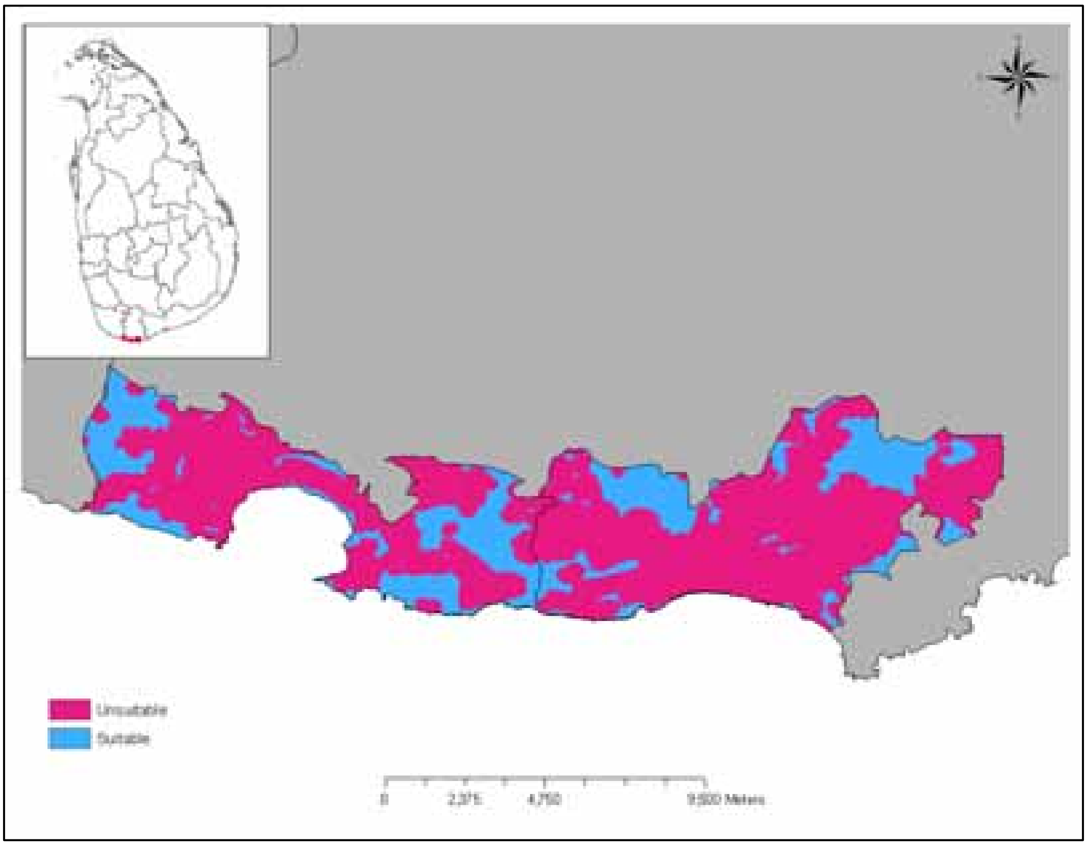

Figure 7: Residential area constraint map

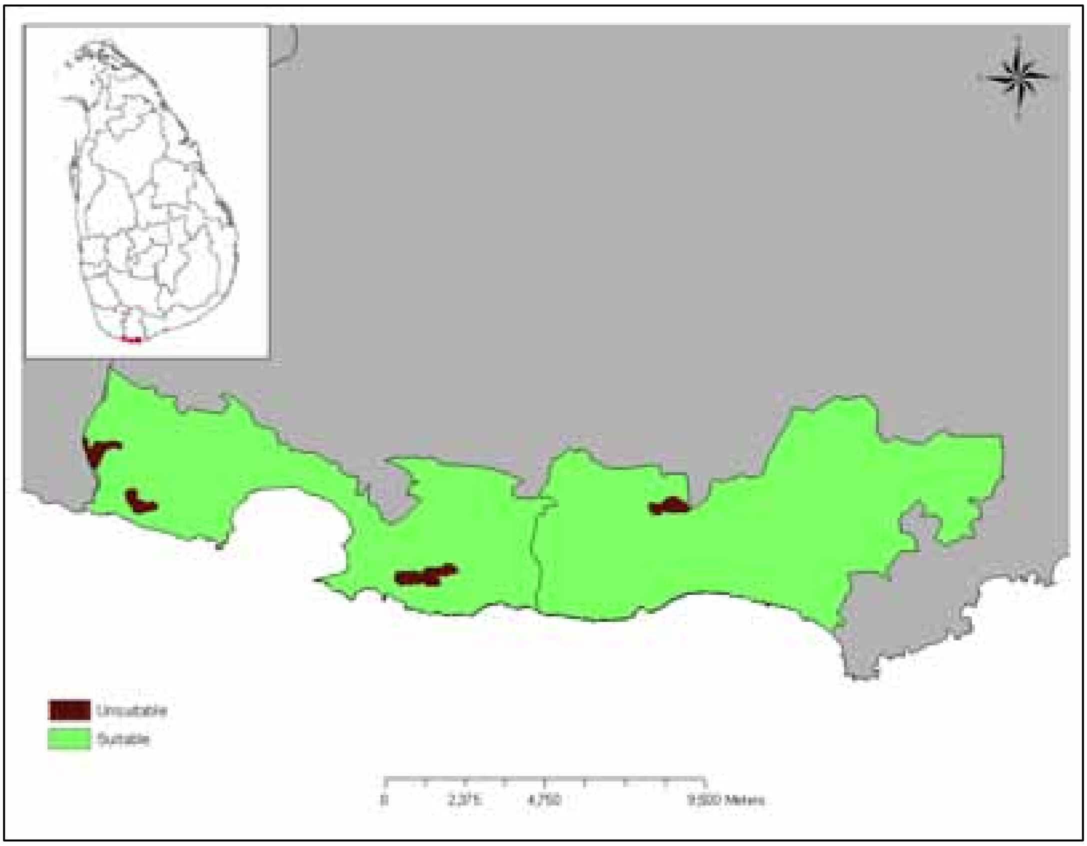

Figure 8: Wetland constraint map

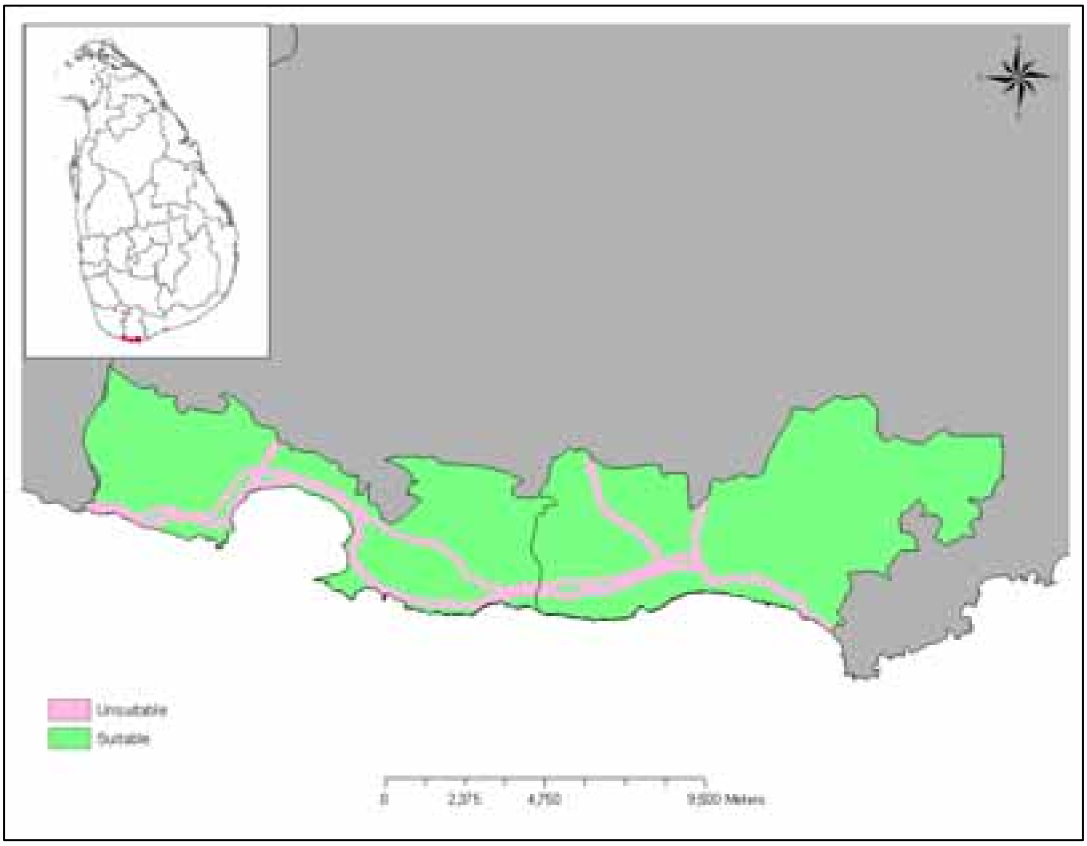

Figure 9: Transportation network constraint map

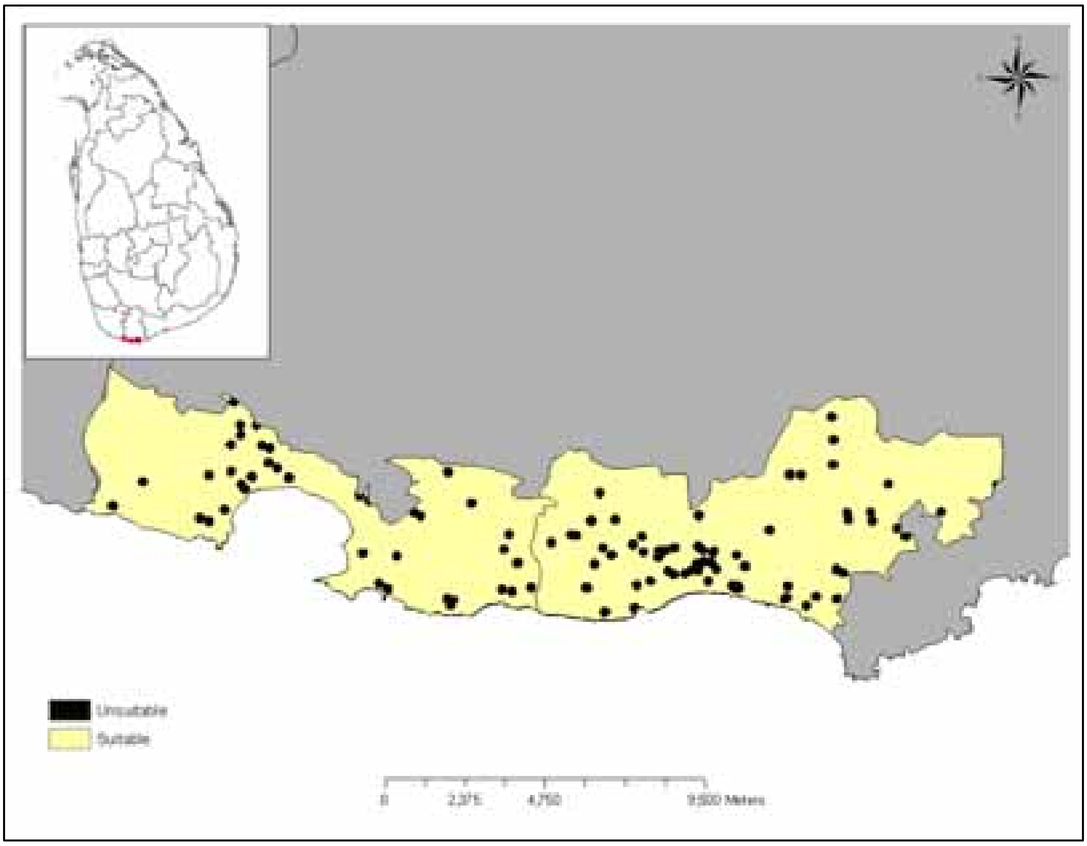

Figure 10: Important buildings constraint map

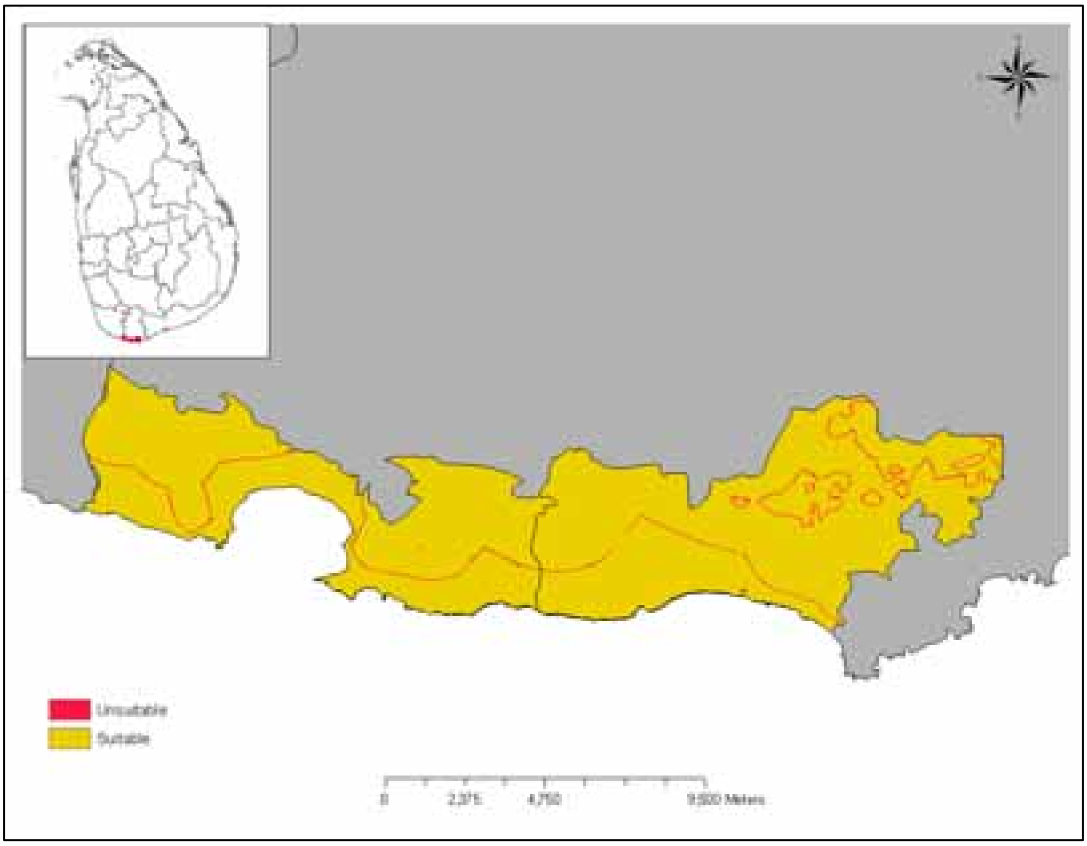

Figure 11: Slope constraint map

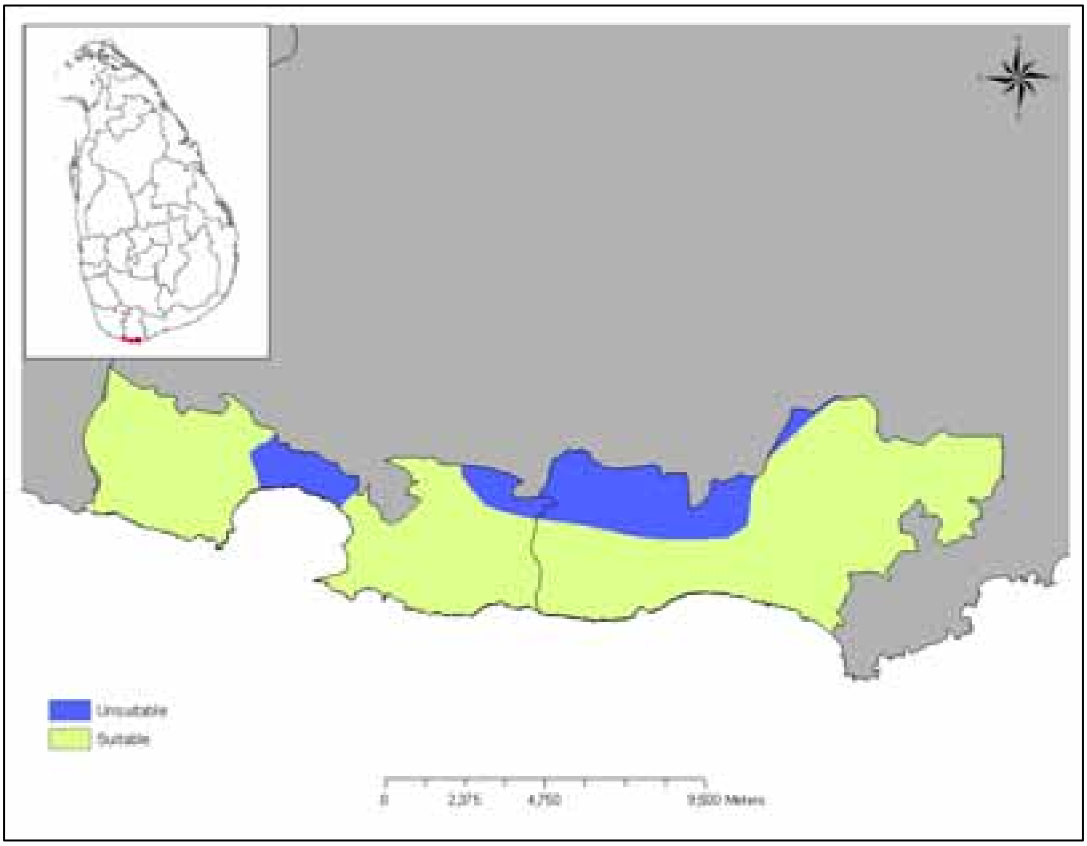

Figure 12: Soil constraint map

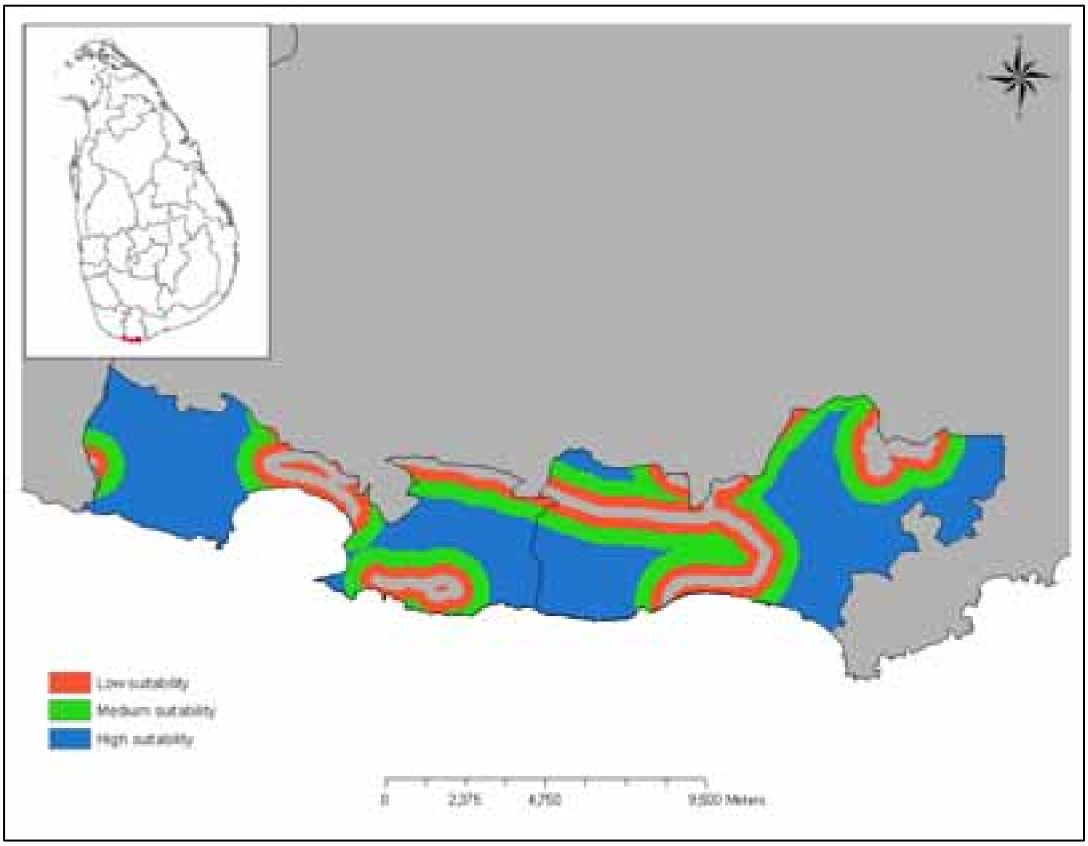

Figure 13: Surface water factor map

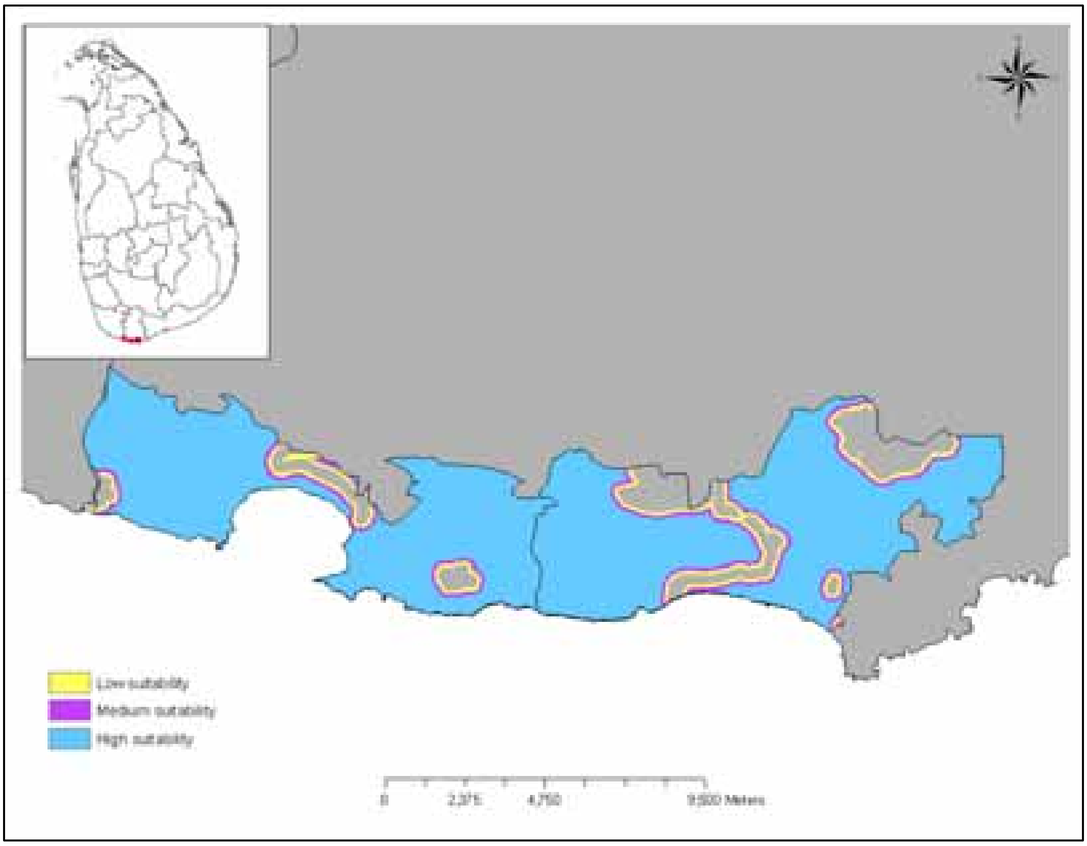

Figure 14: Forest factor map

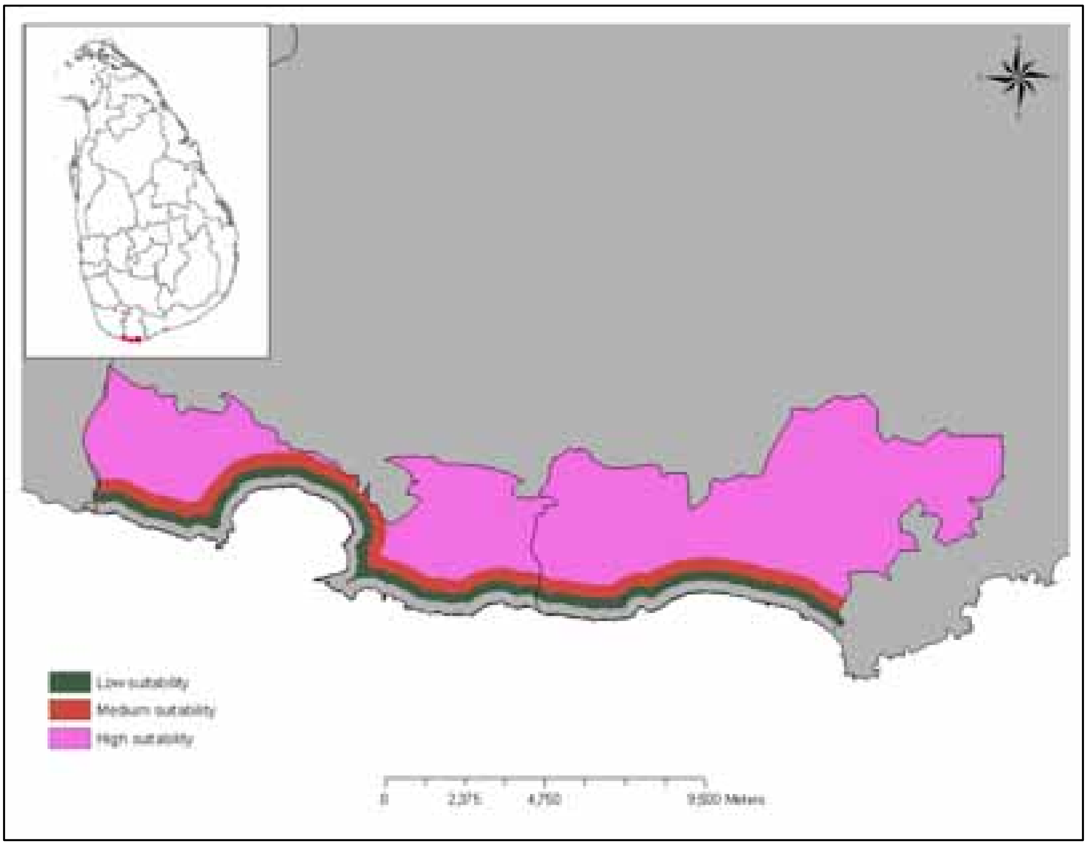

Figure 15: Coastal belt factor map

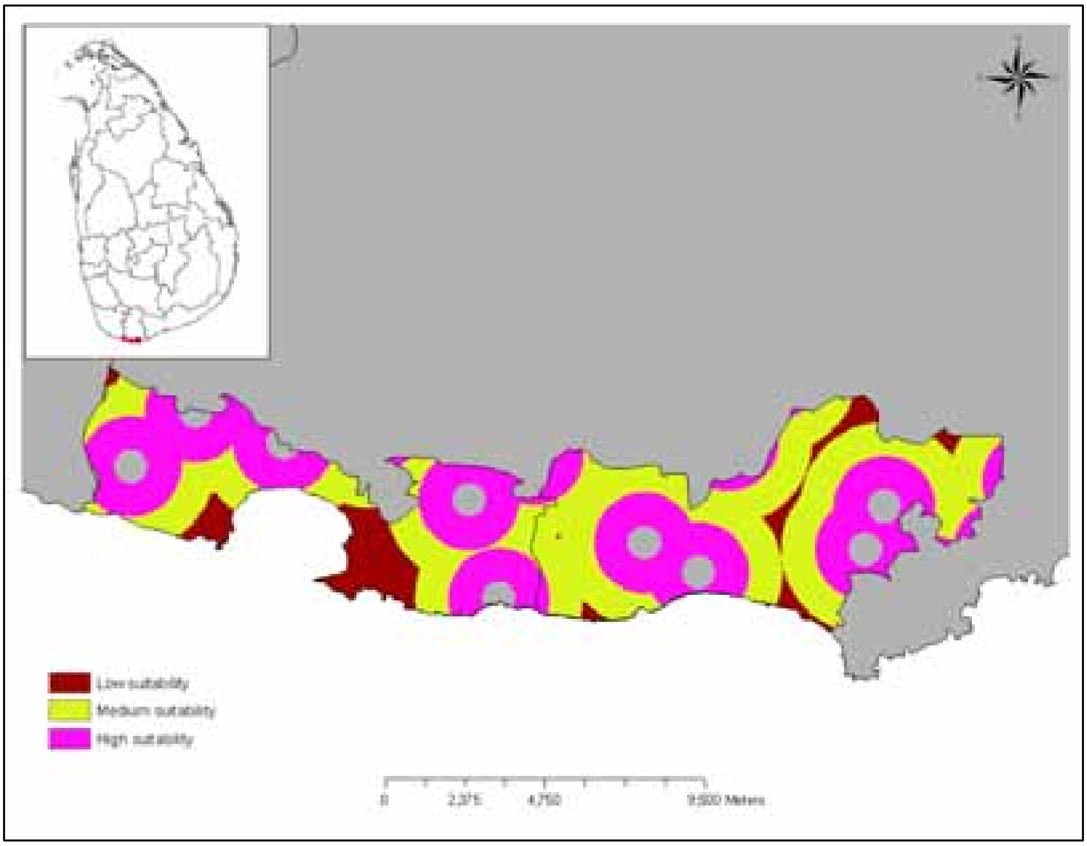

Figure 16: Town centre factor map

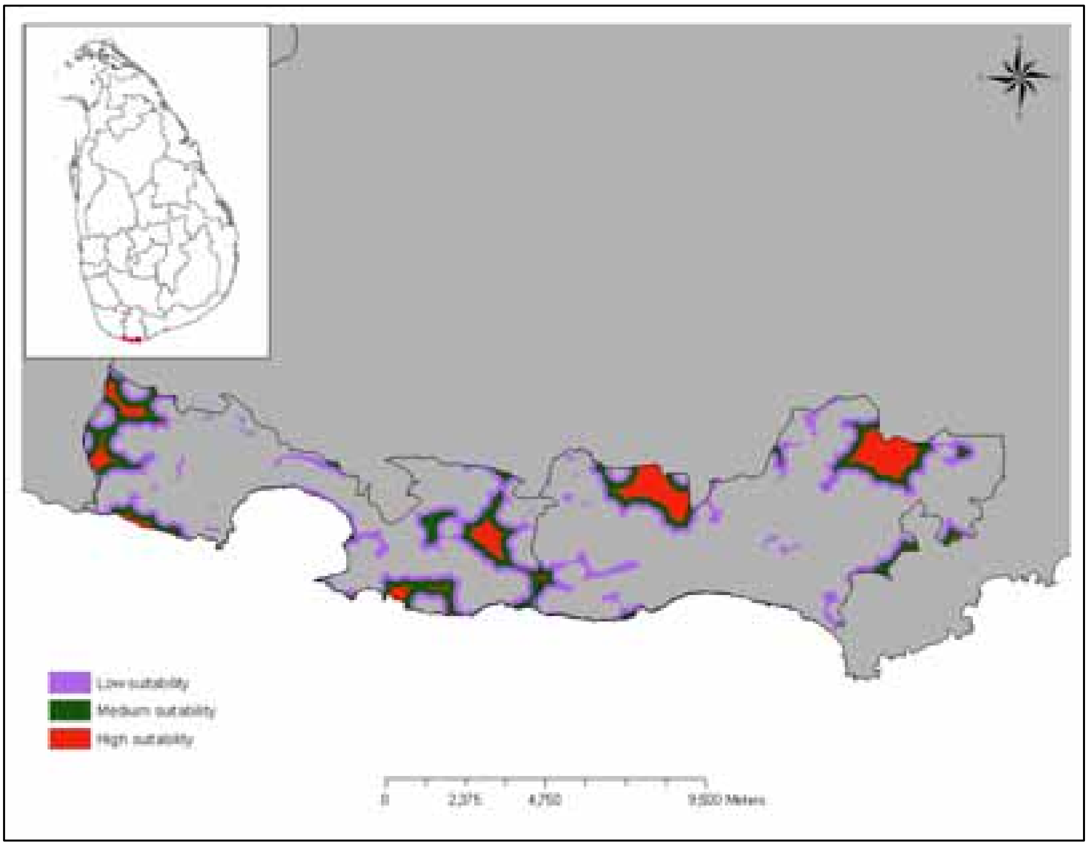

Figure 17: Residential area factor map

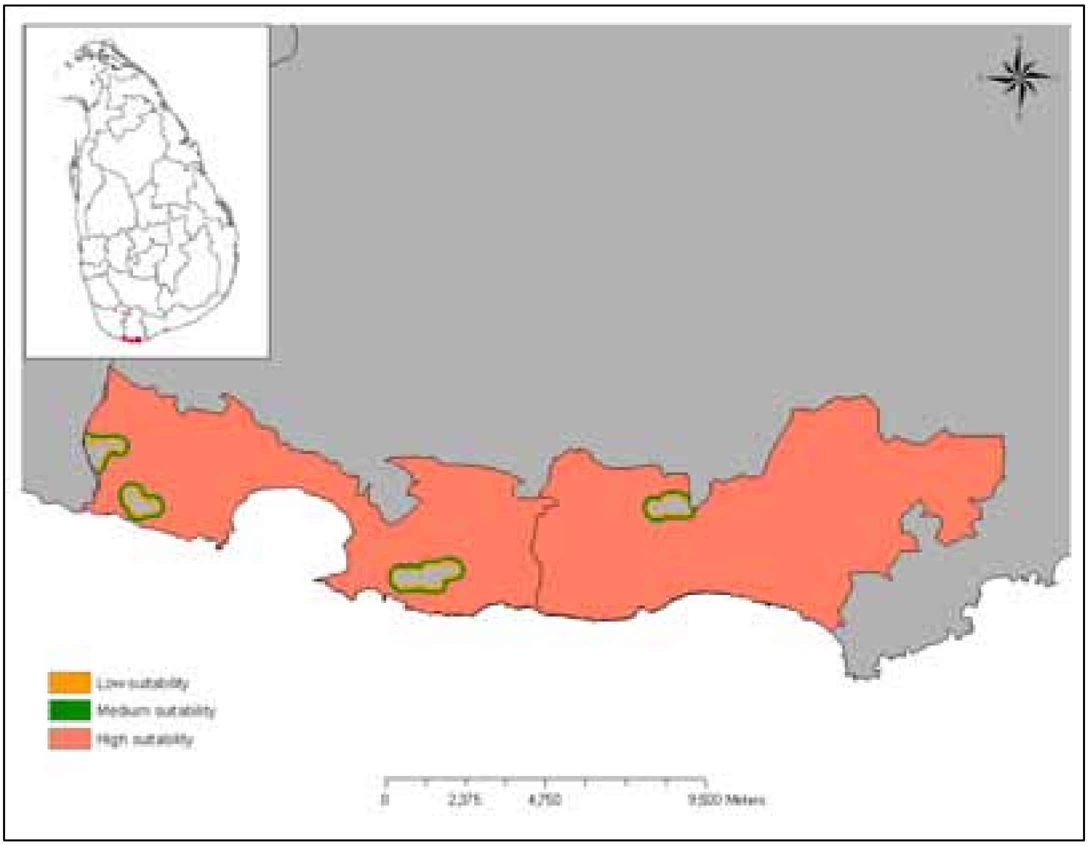

Figure 18: Wetland factor map

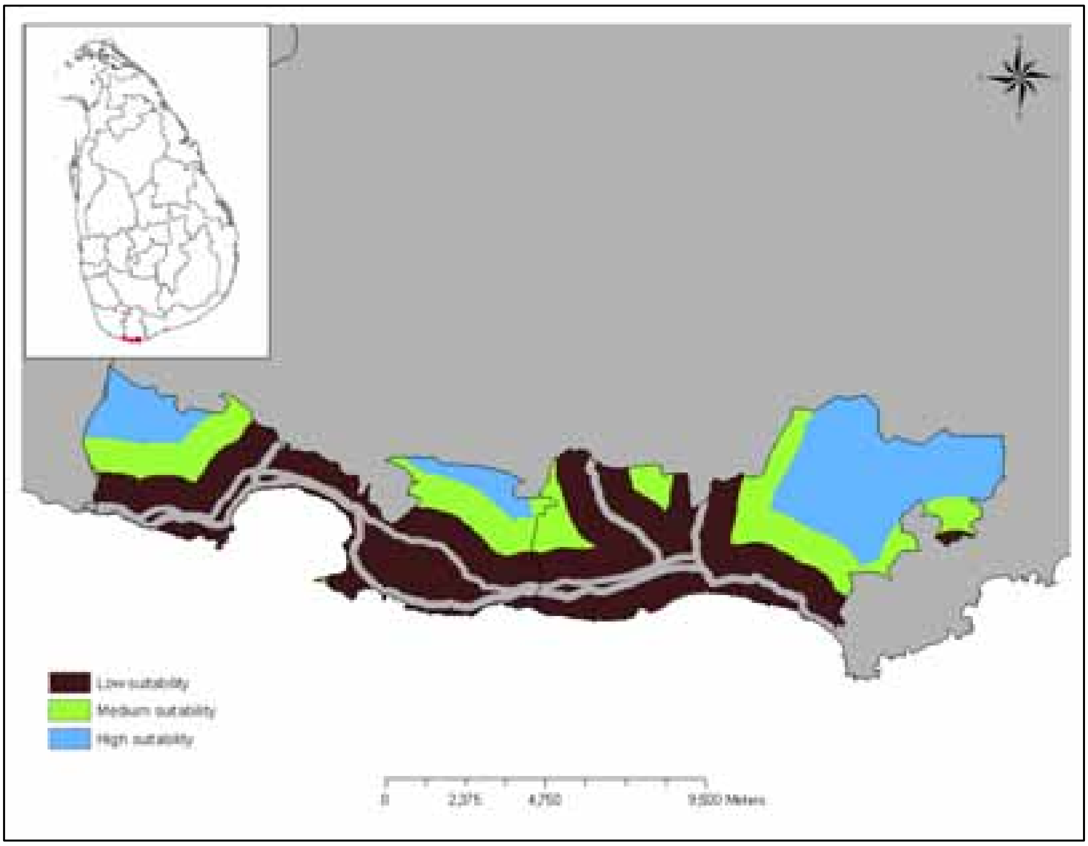

Figure 19: Transportation network factor map

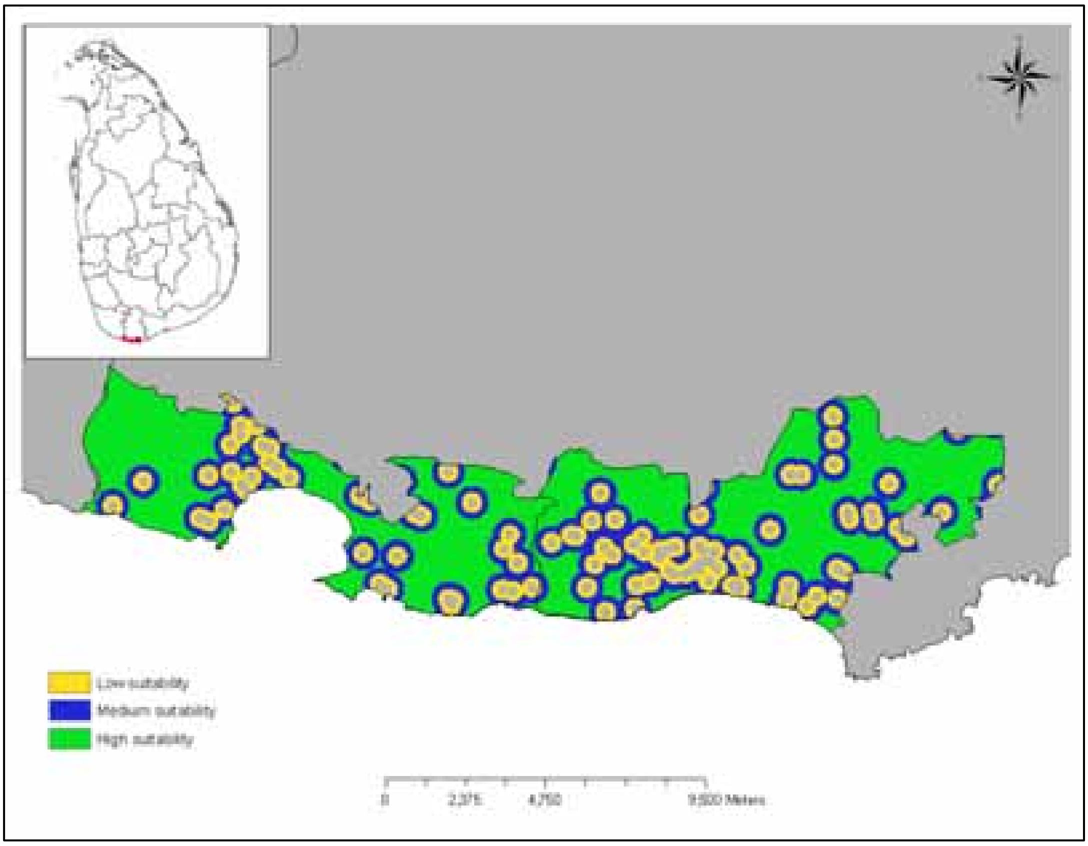

Figure 20: Important building factor map

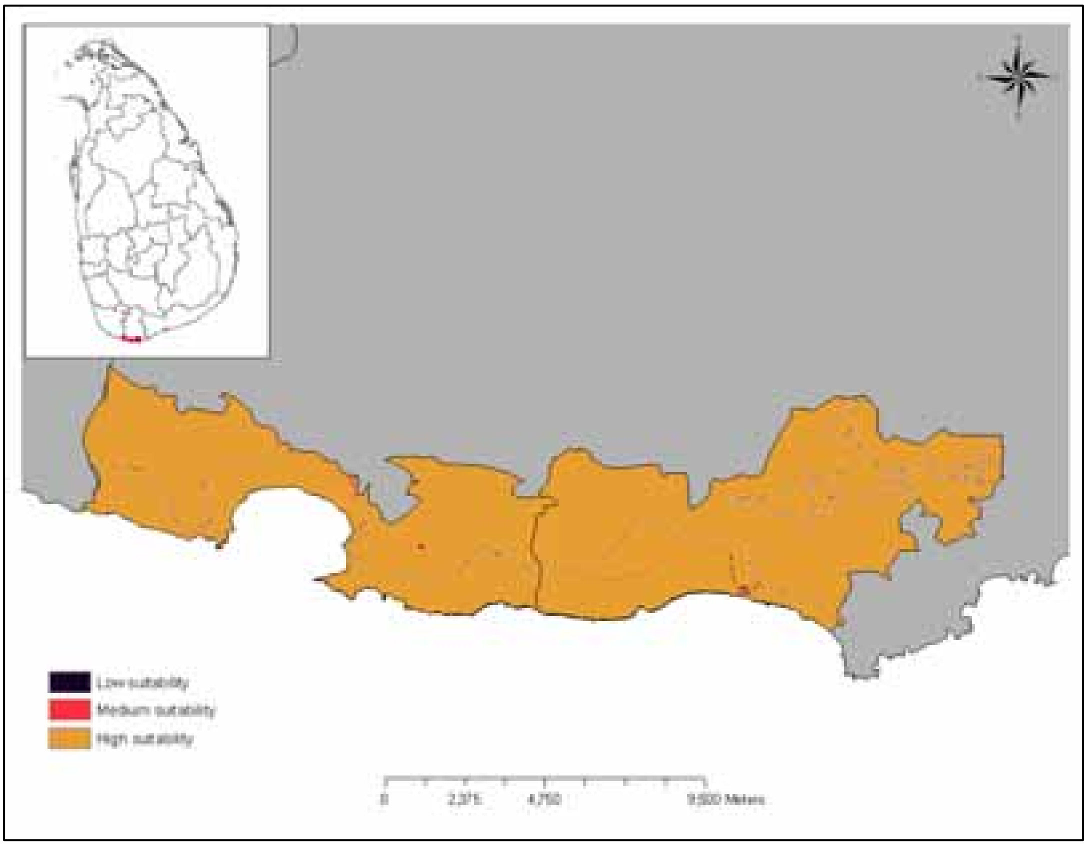

Figure 21: Slope factor map

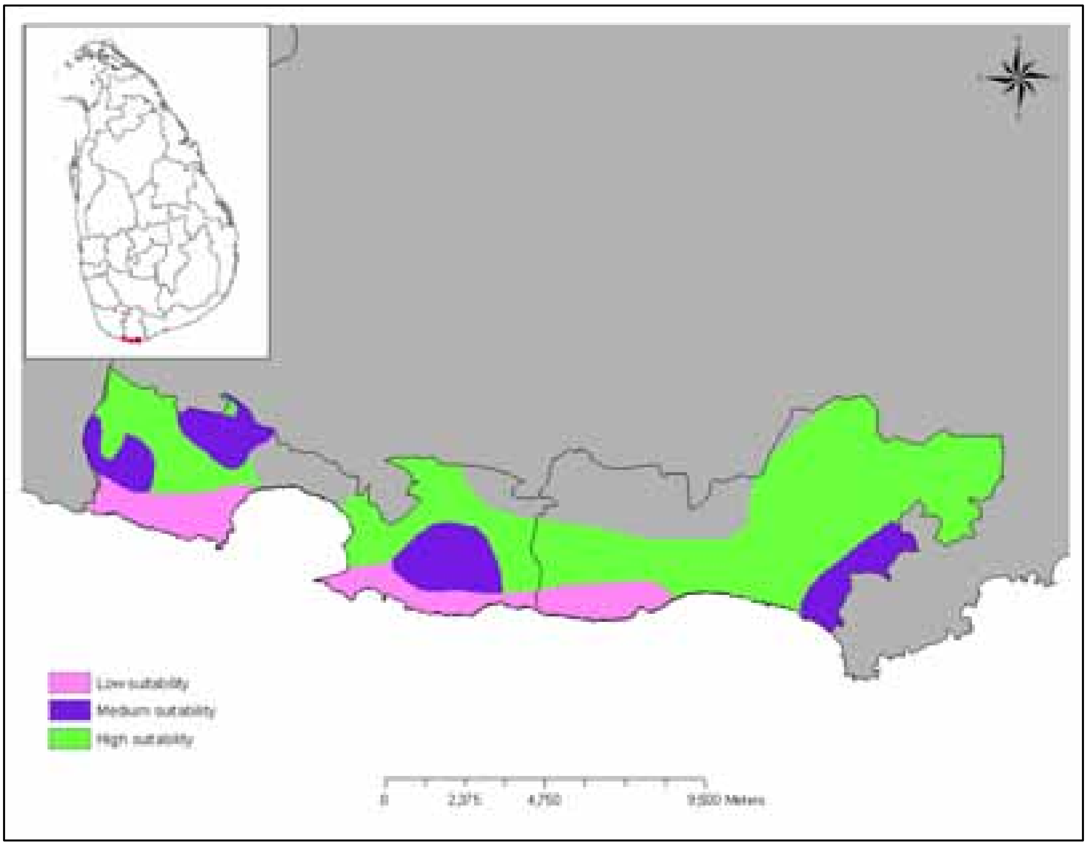

Figure 22: Soil factor map

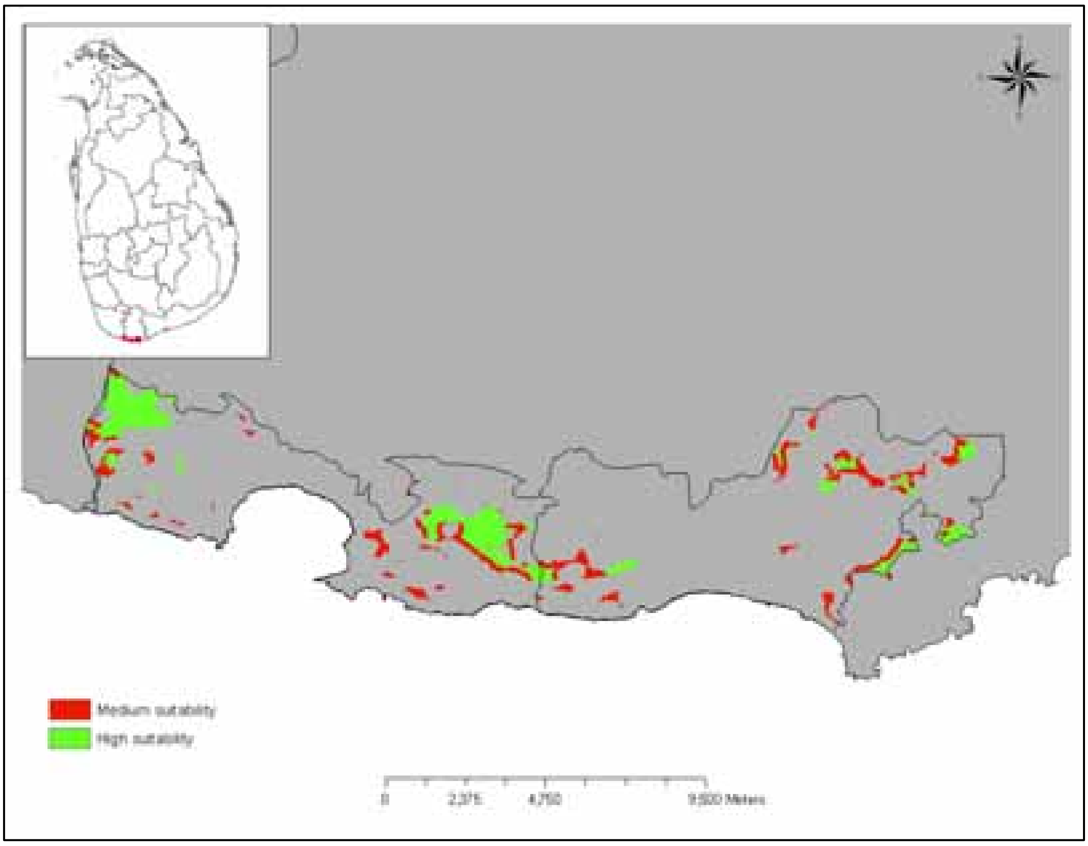

Figure 23: Final suitability map

The final suitability map (Figure 23) indicates that an area amounting to 49.53 km^2 (91.88 %) of the Matara DSD and 36.40 km^2 (82.72 %) of the Weligama as restricted from landfill placement according to constraint criteria used. The residential area and the forest reserve constraint criteria had a major influence in eliminating such a considerable area from landfill placement.

According to the external weights generated by the AHP method, the maximum weight (0.2070) was placed on residential area factor map. The slope had the second highest weight (0.1569) since there is a risk of leachate contamination in the case of a slope failure. The third highest significance (0.1395) was attributed to surface water factor criterion as the runoff or pollutants could pollute the water bodies. The descending order of the weights were assigned to soil, forest reserves and sanctuaries, wetlands, coastal zone, town centres, important buildings rainfall and major roads and railways factor criteria

According to final factor map a land area of 2.10 km^2 from Matara DSD can be considered as highly suitable for landfill areas where as an area of 3.82 km^2 falls under the highly suitable category for Weligama.

Only four potentially suitable sites were found for Matara DSD; one site at Thalpwila another at Parawahera and two other sites in Kekanadura were suitable for landfill placement. As for Weligama DSD sites situated at Midigama North, Wekada, Pathegama and Kotawila South are suitable candidates for landfilling.

Conclusion

The methodology described in the present paper is an efficient approach in a landfill siting process. The methodology combines the evaluation abilities of AHP method and the analytical tools of GIS. The evolution of GIS has made landfill siting process much easier and manageable by giving the ability and functionality to find best locations. The criteria used in this study are not fixed factors since it can vary from area to area and these criteria can be changed accordingly in the analysis process. In future, decision makers can incorporate GIS technology in site selection process to select sites that comply with the existing regulations.

References

1. Akbari, V., Rajabi, M.A., Chavoshi, S.H. and Shams, R., 2008. Landfill site selection by combining GIS and fuzzy multi criteria decision analysis, Case study: Bandar Abbas, Iran. *World Applied Sciences Journal,* Volume 3, 39-47 pp.
2. Casini, M., Mocenni, C., Paoletti, S. and Pranzo, M., 2006. A model-based DSS with application to the management and control of coastal lagoons, *45th IEEE Conference on Decision and Control,* Stockholm, Sweden, 26 -28 September,
3. Din, M.A., Jaafar, W.Z.W., Obot,M.M. and Hussin, W.M.A.W., 2008. How GIS can be a useful tool to deal with landfill site selection. *International symposium on*

Geoinformatics for spatial infrastructure Development in Earth and Allied Sciences. 5-7th May, 2008.

4. Jayawickrama, N. T. and Weerasinghe, V. P. A., 2011. Identification of alternative landfill sites to safeguard the surface water bodies in Matara district, *An Analysis Using Geographical Information Systems (GIS),* Symposium Proceedings of Water professional's day, Water Resources Research in Sri Lanka, 35 – 46 pp.
5. Kao, J.J. & Lin, H.Y., 1996. Multifactor spatial analysis for landfill siting. *Journal of Environmental Engineering* 122(10): 902-908 pp
6. Kontos, T.D., Komilis, D.P. and Halvadakis, C.P., 2005. Siting MSW landfills with a spatial multiple criteria analysis methodology. *Journal of Waste Management* 25 (2005): 818-832 pp.
7. Saaty, T. L., 1980. The Analytic Hierarchy Process, McGraw-Hill
8. Saaty, T.L., 2006. Rank from comparisons and from ratings in the analytic hierarchy/network processes. *European Journal of Operational Research* 168 (2), 557–570.
9. Sener, B., 2004. Landfill site selection by using geographic information systems, M.Sc. Thesis Graduate School of Natural and Applied Sciences, Middle East Technical University
10. Shamshiry, E., Nadi, B., Mokhtar, M.B., Komoo, I. and Hashim, H. S Urban solid waste management based on geoinformatics technology, 2011, Journal of Public Health and Epidemiology Vol. 3(2), pp. 54-60,