CRP 514: Introduction to GIS

Section 1

Term Paper-Final Report

APPLICATION OF GIS IN ENVIROMENTAL ENGINEERING

(LOCATION OPTIMIZATION OF WASTEWATER TREATMENT PLANTS USING GIS: A Case Studyin Upper Mahaweli Catchment, Sri Lanka)

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Abstract

The concepts GIS has been used widely in different disciplines and has been proved successful. This study was to investigate application of GIS in environmental engineering with emphasis on the use of GIS in sitting a wastewater treatment plant and its has been successfully studied in different case studies with our main case study here as Upper Mahaweli Catchment, Sri Lanka in which Multi-criteria and Boolean analysis in GIS were the main concept that were used to achieve this task.

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INTRODUCTION

GIS concepts have been applied to numerous water and wastewater engineering facilities, particularly in their planning, design and control before construction and maintenance after construction. It should be noted that a lot of information used environmental engineering are very geographic in sense. Environmental engineering deals with water hydrology and hydraulics,

Water and wastewater engineering, water quality and quantity, Air quality analysis, municipal waste and their management which all of this in a way deals with spatial data.

GIS application gives a simple way of integrating and analyzing this environmental data for efficient and successful implementation of environmental project. It devises a means of capturing, manipulating, managing and analyzing the environmental data. The measured flow, location, flow and distances used by different instruments are integrated through either manual, scanning or other forms of digitizing into the database. GIS application in any field with available location data and attributes has been used widely in processing data, synthesizing and modeling the data activities as well as analysis result can also be collected. The information on the database having the spatial data and attributes helps in generating important reports and maps used in proper decision making for infrastructure optimum planning and design and the subsequent impacts of such the design to the environment. The continued used of maps have been one of the best media to portray information on engineering designs. The different map formats and scales are frequently used in planning and design of environmental engineering structures [1]. The different aspect of environmental engineering, that is surface water hydrology, groundwater hydrology, water supply systems, solid waste management, water quality, wastewater systems, Air quality and environmental pollution and control; all these

aspects deals with spatial data that can be manage by GIS softwares within short period of time which could otherwise take ample time if it were to be done manually. All these type of discussed data are captured and filed in a given GIS database which can be browsed and retrieved any time in a colored map styles. It has the ability to relate, analyze and manipulate spatial relationship between mapped features. All these GIS capabilities enable decision-makers to critically analyze, visualize and foresee outcomes of projects so they can strategize their goals in advance [2]

Problem Statement

Different fields of expertise deals a lot with spatial information, GIS as a tool has help a lot in capturing, analyzing and managing different geo-referenced data in various fields of study. Environmental engineering has a lot of this geo-referenced information which needs handling a in professional way in other to take better decision when planning, sitting, constructing and managing environmental systems. Thus, the use of GIS in environmental engineering becomes very important in conjunction with other application packages. This term paper is therefore, intended to cover GIS in environmental engineering especially the use of GIS in sitting wastewater and a case study to support that.

Objectives:

The following are the objectives of this term paper:

- Reviewing literature on GIS application in environmental engineering fields

- Discuss some packages that work synergistically with GIS in solving environmental engineering problems
- Highlights some GIS use in sitting wastewater treatment systems found in literature.
- Discuss a detailed case study on location optimization of wastewater treatment plants using GIS

LITERATURE REVIEW

General Application of GIS in Environmental Engineering

The planning, designing, construction, maintenance and management of environmental engineering systems widely use GIS databases and supporting packages. The use of these packages includes the financial and the administrative aspect [3]. As mentioned earlier that GIS is used in link with other softwares in environmental engineering, that following are some of this packages [1]: watershed assessment model with Arcview interface(WAMView) [4], GeoMedia [5], ArchFM; models and manages water and wastewater facility data [6], Municipal Infrastructure Management System (MIMS) [7], GISAREG: a GIS application package aimed at improving scheduling of irrigation system [8], amongst others. Looking at the different sub-field of environmental engineering, an exhaustive list of application packages can go on.

Reference [9] made a research about waste related pathogens where he monitors and analyzes the fate of such microbes using the concept of GIS.

Reference [10] after undergoing a study on dairy waste and its degradation on surface and groundwater developed software called Generic Interactive Dairy Model used for alternative evaluation and management plans on the effect of such waste on quality of surface and groundwater. In another study by [11], EVIAVE; a landfill diagnosis method developed at Grenada University and GIS were investigated in sitting optimum location for municipal landfill in Southern spain. Remote sensing, GIS and water quality model were used to predict the water quality for short- period of time [12].

Fuzzy multicriteria decision and GIS in joint venture were used in locating landfill [13, 14, 15].

GIS in locating wastewater treatment systems

Proper treatment of generated wastewater mostly in rural areas and highly populated urban is very crucial to safe guarding people's health and conducive environment for living, as such proper and good approaches need to be considered in making sure that good site for treating municipal and industrial wastewater is chosen to ascertain this healthy coexistence in the environment. Site selection is particularly crucial when planning a wastewater land application scheme [16]. A very good approach that can easily consider all the factors that will help site a good treatment plant is GIS which has been in use in different fields of endeavor including sitting wastewater treatment systems as will be in some reviewed literature.

Reference [17] studies a "site suitability analysis for a central wastewater treatment plant(s) Accra Metropolitan Area" in Ghana Using GIS for an area of approximately 231km^2 with a population of using ArcGIS Multi-criteria decision making and stake holder's interview as the two approaches with variables considered as slope, land cover, distance to airport facilities, distance to rivers and lagoon, distance to existing major roads and distance to populated communities. At the end a composite map was arrived at which shows areas that satisfied all the suitability criteria, then final analysis was carried out using the overlay function in ArcMap and total suitable area was found to be 20km^2 in the land north of Accra Metropolitan Area.

Reference [18] did a study on the use of GIS in sitting areas suitable for constructing natural wastewater treatment systems in Thrace; a Northeastern municipality in Greece for domestic wastewater, here several variables were considered such as land use, type of geologic formation, monthly temperature, distance to rivers, distance to settlement and other wastewater effluent characteristics were analyzed using GIS. The suitable area was finally found as a function of population, temperature and wastewater effluent characteristics. Another study by [16] was

carried out on similar trend to site land for wastewater application in Christchurch Newzealand with a slight difference as this study has extra factors like soil pH, soil depth and soil type which might bring about a better result.

A study by [19] on GIS based optimization for locating sewage treatment system considers ecological factors which were usually neglected in most studies and it has proven to facilitate decision making of the policy makers.

CASE STUDY

LOCATION OPTIMIZATION OF WASTEWATER TREATMENT PLANT USING GIS [20]

Introduction

Wastewater treatment problems have been an ever increasing concern in most developing countries due to the accelerated rate increasing population. Thus many activities either domestic, industrial, agricultural or commercial leads to production of more wastewater which if handled with care can cause lots of harm to the environment. Therefore appropriate sites must be located for wastewater treatment systems to avoid contaminating the surface and groundwater especially those use for as a source of drinking, irrigation and perhaps hydropower generation. For instance, the Upper Mahweli Catchment of (UMC) in Sri lanka is an area of watershed which covers about 3118km2 where about four reservoirs exist as a result of Rantembe dam, these reservoirs contributes 60% of the electricity supply through hydropower generation, irrigation water for rice cultivation in low lands and some of these reservoirs serve as sources of drinking water. The increasing urban and sub-urban population along the Mahweli River and its tributaries has affected the quality of water drastically in the water bodies which in part is as result of direct waste disposal by local community and soil erosion. Industrial waste like sawmills and agricultural waste also contributes to water quality deterioration in the Upper Mahweli Catchment. The need to safeguard these water resources in the Upper Mahweli which is of vital importance to the county necessitates a proper Optimization of location of wastewater treatment systems through analysis of the socio-economical, technical and environmental variables. Recent technological developments has simplified the way information are captured, manipulated and

managed, one technology that is very good at that is GIS which has made it very easy through computer application that handle a pool of data. Studies in recent years have identified GIS systems to have been used in the field of wastewater management.

Thus, this study was intended to optimize the location of wastewater treatments plants in a given study area which is based on using GIS integrated with other local factors.

The study area

The study area covers a land of 210km^2 at Gampola (a portion of Mahaweli River) as a pilot study to be scaled to the entire area of 3118km2 of Upper mahawelli. The catchment was defined by Digital Terrain Model (DTM) using GIS as seen in Fig. 1 (see Appendix I). The altitude of the terrain varies greatly between 520m to 1400m. Apart from the Gampola and Pussallawa sub-urban towns that exist, all other population are distributed as normal village settings and tea state work communities as tea plantation and vegetable cultivation are the major economic activities. Also medium and small scale industries are distributed over the catchment.

Methodology

The whole task was divided into four steps and carried out using GIS-based multi-criteria analysis:

- **Identifying and mapping the entry point of pollutants sources**

  Two major pollution sources are identified and mapped;

  Point sources: are sources in which wastewater is disposed of by pipe, ditch, channel or other one path ways means of sources. This sources were identified by transect walks along the river and points coordinates were recorded using the GPS, then introduced to

the ArcGIS and converted into point layers. With the geo-referenced map prepaid using the GIS, all point sources were able to be located.

Non-Point sources: are sources which continually distributed over a given area and can be collected at micro-catchment outlet along with run-off or storm water. The micro-catchment end points are properties of geo-morphology, as such the watershed area belonging to each entry point where indentified using accurate DTM (Digital Terrain Model) as in fig.2 (see Appendix I)

- **Selection Criteria and their defined upper or lower limits**

The selection criteria were came up with based on, technical, environmental and social aspect as below:

- **Technical criteria**: slope should be less than 15% to minimize cost and avoid instability.
- **Environmental criteria**: Forest and protecting areas and potential flood zones to be excluded
- **Social criteria**: minimum of 300m should be maintained from settlements to avoid odors and mosquito problem.

- **GIS spatial data preparation**

ArcGIS 9.2 was used for selecting wastewater treatment plant by thematic vector layer analysis.

- Slopes were determined from Digital Elevation Model produced by digitizing 1:10000 contour maps.

- Polygon layer was created for slope values less than 15% as shown in brown color in fig.3 (see Appendix I)
- Land use map helped in obtaining Forest cover polygon.
- ArcGIS vector analysis was used in creating 300m buffer zone.
- The GIS participation during the transect walk help in creating the flood zone as in fig. 4 (see Appendix I)
- Settlements areas where obtained from 1:50000 land use map and polygon layer obtained from 300m buffer zone in ArcGIS analysis as in fig. 5 (see Appendix I)

- **Boolean Maps analysis for each criteria Using GIS tools**

Here, Flooding area, slope more than 15%, buffered human settlements and buffered forest area were merged using the overlay tool in ArcGIS and excluded from the study area. Fig. 6 (see Appendix I) shows the suitable and non suitable areas for sitting the wastewater treatment plants.

Discussion

Using the GIS concept with a ArcGIS as the supporting software, a map was produced with the help of multi-criteria analysis resulting in feasible area of about 23% ($48km^2$) of the study area ($210km^2$). Non-point pollutant sources treatment plants can be located close the streams where most feasible areas are available. Several of the point sources are clustered within buffered settlement as such mechanical or systems should be used instead of land based systems.

Conclusions

The optimum site for constructing wastewater treatment systems were successfully identified in this study and all other studies presented which are not discussed in detail by multi-criteria analysis using GIS approach. Thus, GIS has proven to be a very useful tool in capturing, storing, manipulating, analyzing, managing and visualizing spatial data in various discipline. In all the case studies discussed about locating site for wastewater treatment system, it is paramount to conduct field verification with the host communities and get a final feedback, so as to select the best among the suitable area considering other factors that compete with land such as ecstatic, land values and so on.

Reference:

[1] Johnson L.E., 2009, *Geographic information systems in water resources engineering*. CRC Press.

[2] Malczewski, J., 2004, GIS-based land-use suitability analysis: A critical overview. *Progress in Planning* **62** (1): 3 – 65.

[3] ESRI (Environmental Systems Research Institute), 2007, GIS technology for water, wastewater, and storm water utilities. (http://www.esri.com/water)

[4] Bottcher D. and Hiscock J.G., 2002, A new GIS approach to watershed assessment modeling. *In Proceedings of the seventh biennial stormwater research and watershed management conference*, 15 – 24.

[5] http://www.intergraph.com

[6] http://www.miner.com

[7] http://www.albertamims.org

[8] Fortes P.S., Platonov A.E. and Pereira L.S., 2005, GISAREG: A GIS-based irrigation scheduling simulation model to support improved water use. *Agricultural water management*, **77**: 159 – 179.

[9] Diallo M.B.C., Anceno A.J., Tawatsupa B., Tripathi N.K., Wangsuphachart V. and Shipin O.V., 2009, GIS-based analysis of the fate of waste-related pathogens *Cryptosporidium parvum, Giardia lamblia* and *Escherichia coli* in a tropical canal network. *Journal of water and health*, **7** (1): 133-143.

[10] Fraisse C.W., Campbell K.L., Jones J.W., and Boggess W.G., 1996, GIDM: A GIS-based model for dairy waste management analysis. *AWRA symposium on GIS and water resources*, Ft. Lauderdale, FL.

[11] Zamorano M., Molerob E., Hurtado A., Grindlay A., Ramos A., 2008, Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology. *Journal of hazardous materials*, **160**: 473–481.

[12] Yang M., Merry C.J. and Sykes R.M., 1996, Adaptive short-term water quality forecasts using remote sensing and GIS. *AWRA symposium on GIS and water resources*, Ft. Lauderdale, FL.

[13] Changa N, Parvathinathan G., Breeden J.B., 2008, Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. *Journal of environmental management*, **87**: 139–153.

[14] Sumathi V.R., Natesan U., Sarkar C., 2008, GIS-based approach for optimized siting of municipal solid waste landfill. *Waste Management*, **28**: 2146–2160.

[15] Sharifi M., Hadidi M., Vessali E., Mosstafakhani P., Taheri K., Shahoie S., Khodamoradpour M., 2009, Integrating multi-criteria decision analysis for a GIS-based hazardous waste landfill sitting in Kurdistan Province, western Iran. *Waste Management*, **29**: 2740–2758.

[16] Meinzinger F. 2003 "Gis-based site identification for the land application of wastewater Christchurch city", New Zealand: *linclon University*

[17] Paulina A. A. 'Site Suitability Analysis for a Central Wastewater Treatment Plant(S) In Accra Metropolitan Area Using Geographic Information System': *Department Of Geography And Resource Development, University Of Ghana, Legon.*

[18] Alexandra G. et al 2006 'Use of GIS in siting stabilization pond facilities for domestic wastewater treatment' *Journal of Environmental Management* 82.155–166

[19] Zhao Y. W. et al 2009 "GIS-based optimization for the locations of sewage treatment plants and sewage outfalls" – A case study of Nansha District in Guangzhou City, China *ScienceDirect (14) 1746-1757*

[20] Ratnapriya E. A. S. K. et al 2009 "Location Optimization of Wastewater Treatment Plants Using GIS: A Case Study In Upper Mahaweli Catchment, Sri Lanka" *Applied Geoinformatics for Society and Environment*

APPENDIX I

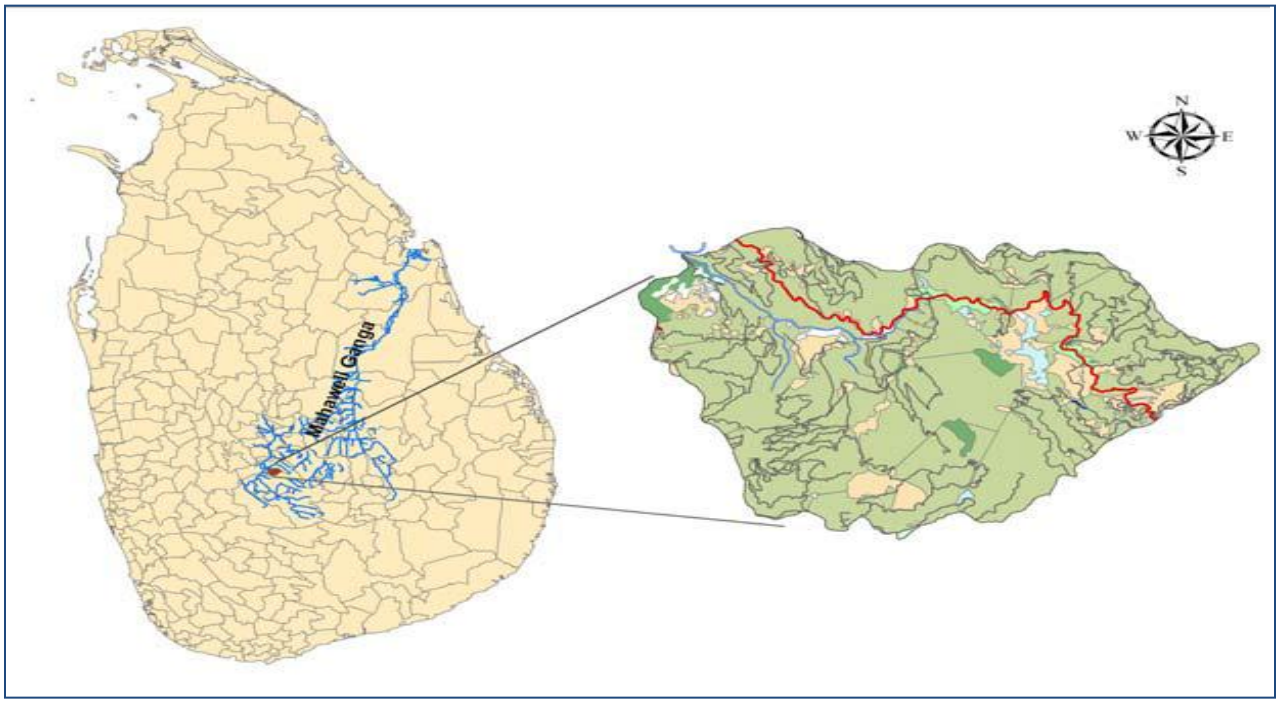

Figure 1: Study Area

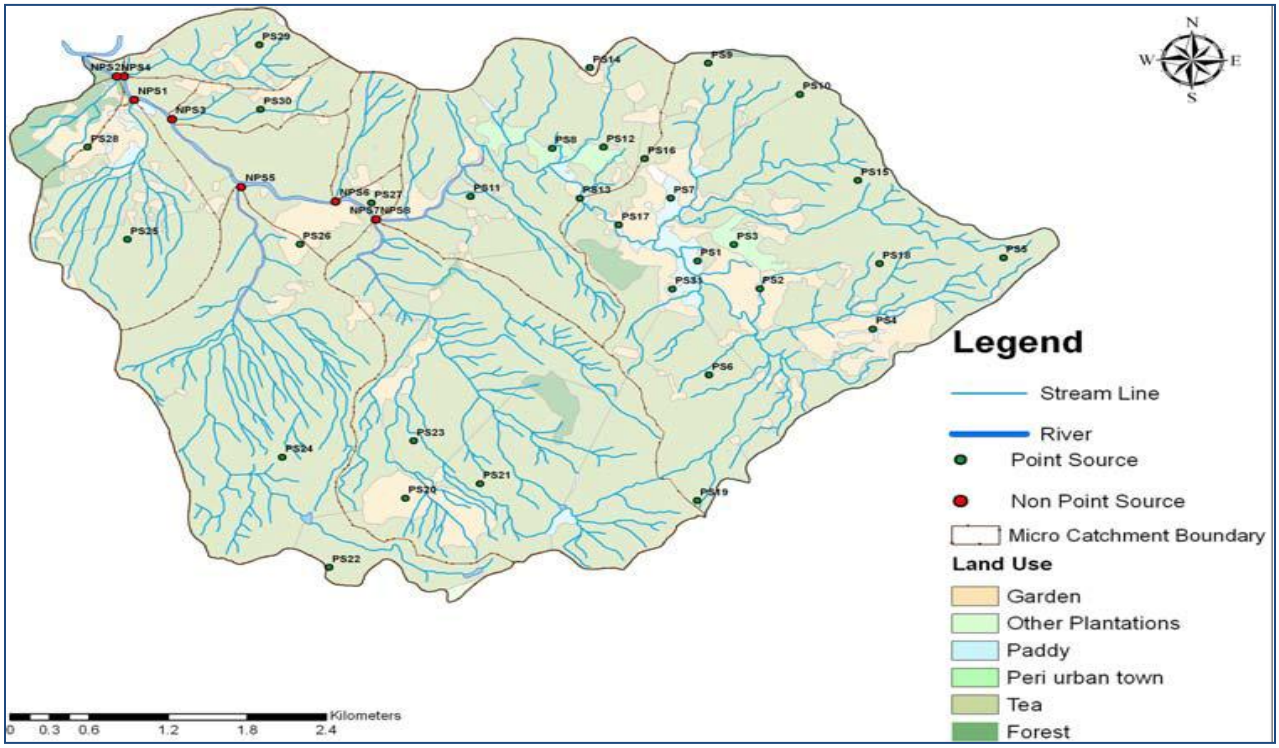

Figure 2: Map showing with red circles showing entry points non-point sources and Green showing locations of point sources

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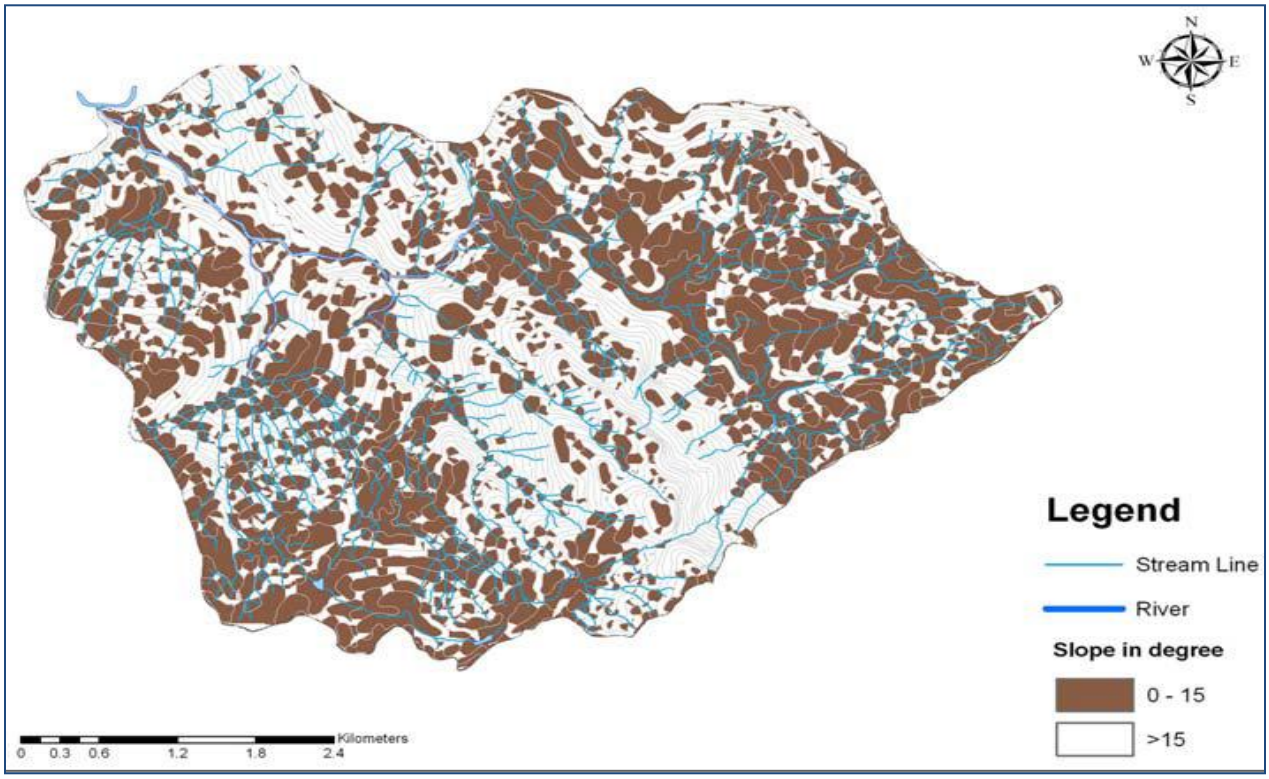

Figure 3: Land with suitable slope for wastewater treatment plant construction

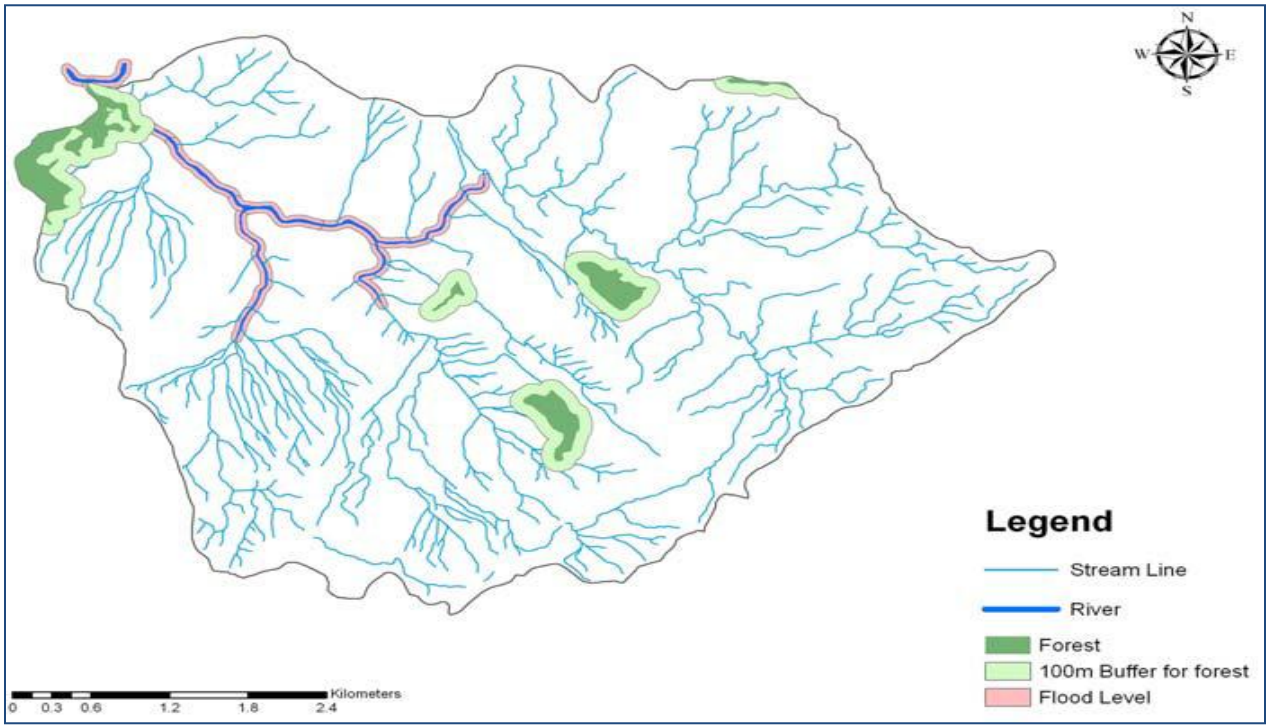

Figure 4: Forest with buffer and flood level Map.

APPENDIX I

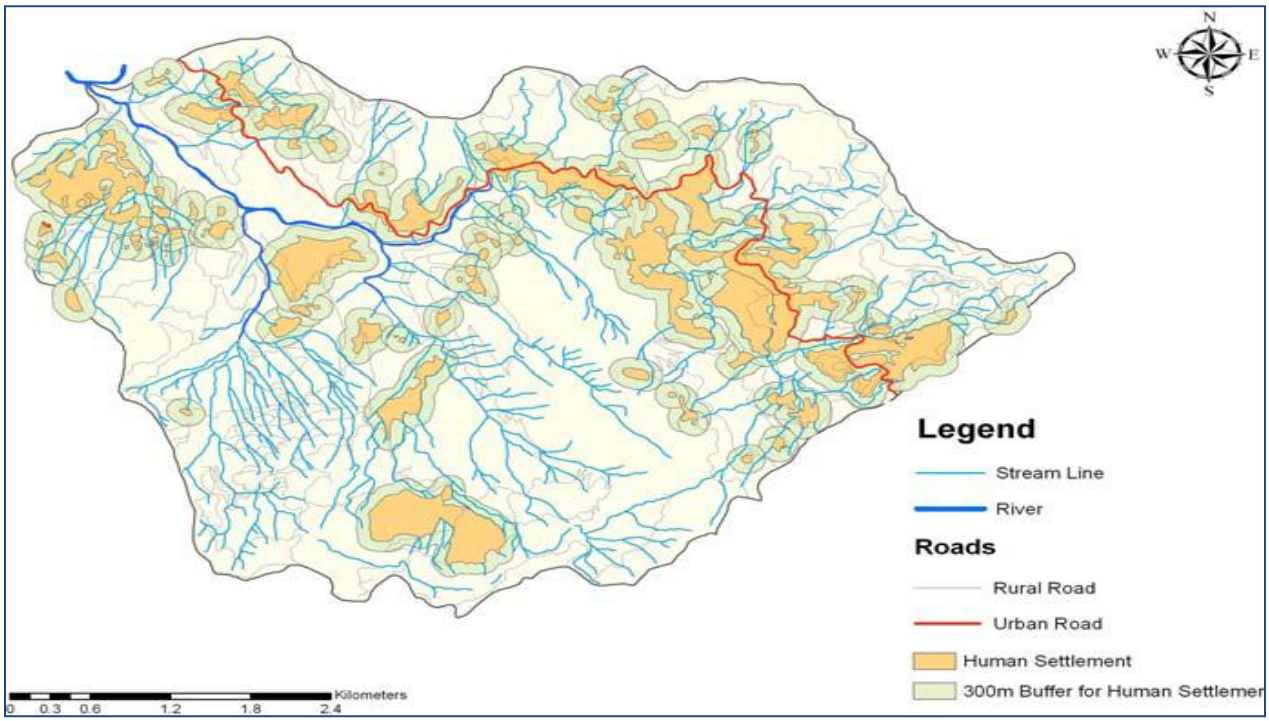

Figure 5: Human settlements and 300m buffer zone

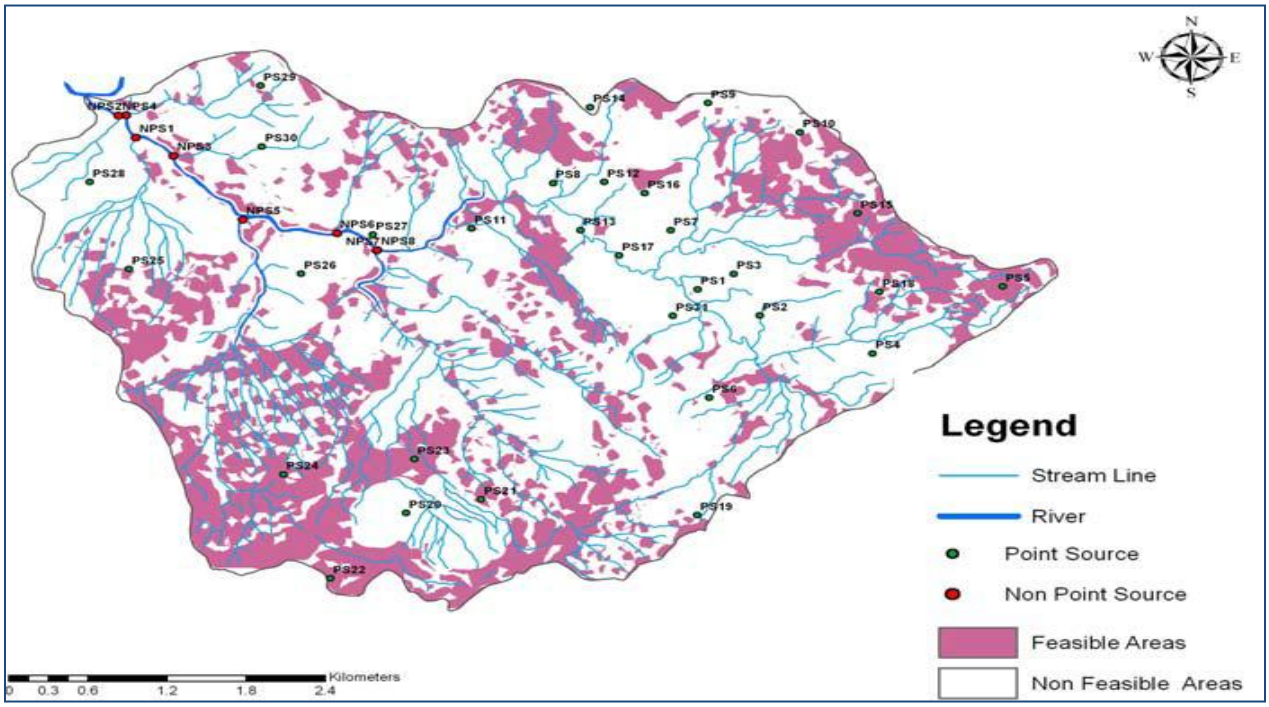

Figure 6: Suitable areas for locating wastewater treatment plants