ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF GEOMATICS ENGINEERING

GIS-BASED MULTI-CRITERIA ANALYSIS FOR OPTIMAL SITE SELECTION FOR WASTEWATER TREATMENT PLANT: (THE CASE OF BAHIR DAR TOWN, ETHIOPIA)

A Thesis

Submitted to Adama Science and Technology University

Department of Geomatics Engineering

In Partial fulfillment of the requirements for the award of

The Degree of Master of Science in Geodesy and Geomatics Engineering

By:

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Adama, Ethiopia

CANDIDATE'S DECLARATION

I, Abinet Addis, do hereby declare that this thesis is a product of my original research work, and it has not been submitted before partially or fully by any other person for an award of a degree in any other University.

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CERTIFICATE

I certify that the thesis entitled: "GIS-based multi-criteria analysis for optimal site selection for wastewater treatment plant: (the case of Bahir Dar town, Ethiopia)." is a work carried out under my guidance and supervision. This is the actual work done by **Abinet Addis** for the partial fulfillment of the award of the Degree of Master of Science in Geodesy and Geomatics Engineering, Adama Science and Technology University, Adama, Ethiopia.

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ABSTRACT:

The siting of wastewater treatment plant is an extremely complex task mainly due to the fact that the identification and selection process involves many factors and strict regulations. For proper identification and selection of appropriate sites for wastewater treatment plants careful and systematic procedures need to be adopted and followed. The main objective of this research was to find the optimal location of wastewater treatment plant by using the GIS-based MCA approaches in Bahir Dar town, which are environmentally and economically suitable. The present study had integrated environmental and economical criteria considering road networks, rivers/streams, lake, geology, soil, slope, elevation, wind direction, groundwater wells, groundwater table, rural settlements, urban settlements and land use/ land cover for selecting a suitable wastewater treatment plant site with in the study area. The relative weights of criteria were estimated using AHP and criteria maps were developed by using GIS spatial operations. Weighted linear combination was used to integrate weight with the factor maps. The final integration of weighted factor map and constraint map produced an overall wastewater treatment plant suitability map. The wastewater treatment plant site suitability map was presented in four suitability index such as highly suitable, moderately suitable, low suitable and unsuitable. The result shows that around 6.08% area is highly suitable for wastewater treatment plant site, 1.83% is moderately suitable, 0.61% of study area has low suitablility and 91.48% area is unsuitable for wastewater treatment plant site. Among the highly suitable areas, five sites were selected and revaluated in terms of road network, river/streams, lake, geology, soil, slope, elevation, wind direction, groundwater wells, groundwater table, rural settlements, urban settlements and land use/land cover to select the optimal suitable site. Finally, site 4 was proposed as the most preferable option for the construction of the wastewater treatment plant site with the minimum effects on economic, environment risk and public health.

Keywords: GIS, MCA, site selection, wastewater treatment plant, Bahir Dar Town.

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LIST OF ACRONYMS

AHP	Analytical Hierarchy Process
a.m.s.l	above mean sea level
ASTER	Advanced Space borne Thermal Emission and Reflection
ASTU	Adama Science and Technology University
AWWDEO	Amhara Water Well Drilling Enterprise Office
BOPED	Bureau of Planning and Economic Development
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
ENMSA	Ethiopia National Meteorological Service Agency
EPA	Enviromental Protection Agencey
ERDAS	Earth Resource Development Application System
FAO	Food and Agriculture Organization
GDEM	Global Digital Elevation Model
GIS	Geographic Information System
IDW	Inverse Distance Weighting
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Analysis
MCE	Multi Criteria Evaluation
MOWE	Ministry Of Water and Energy
RGB	Red Green Blue
USEPA	United States of Enviromental Protection Agency
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WLC	Weighted Linear Combination
WWTP	Waste Water Treatment Plant

1. INTRODUCTION

1.1. Back ground of the study

Wastewater problems have been an ever increasing concern in most developing countries due to the accelerated rate of increasing population. Thus many activities either domestic, industrial, agricultural or commercial leads to production of more wastewater which if not handled with care can cause lots of harm to the environment (Abdullahi U., 2013). Therefore, appropriate sites must be selected for wastewater treatment systems to avoid contaminating the surface and groundwater especially those used for drinking and irrigation water. Globally around 90% of wastewater produced remains untreated causing widespread water pollution especially in low income countries (Benujah.B.Ra. and Devib, 2013). More than half of the population of developing countries does not have access to sanitation and more than 80% of the wastewater generated is directly discharged into surface water bodies (UN HABITAT, 2008).

In Bair Dar town, there are problems of wastewater treatment plant sites. Nearly two-thirds of all households in Bahir Dar discharge wastewater into streets and flood water drainages. They also discharge wastewater into Lake Tana and Abbay (Blue Nile) river through tubes and open ditches. Such discharges pollute the environment and create offensive smell and aggravate the conditions for the spread of communicable diseases (Fesseha H., 2012).

The wastewater treatment plant siting is an extremely difficult task to accomplish, because the selection of the most suitable treatment plant site, as multiple factors have to be considered and there is no universal formula (Malczewski, 1999). The various input factors need to be considered in treatment plant site selection, the conventional processing approach for treatment plant siting analysis becomes difficult, complex, and tedious. For instance, spatial data pertaining to the environmental, social and economic factors need to be assessed, which is very time consuming. In addition, the siting process may need to be repeated several times until the most suitable site is selected (Kao and Lin, 1999). To ensure that an appropriate site is chosen, a systematic process should be developed and followed. The major problem is that in addition to natural, environmental and economic factors, complex political and social issues often influence the selection process. The selection of an appropriate wastewater treatment plant sites would minimize environmental damage to natural resources and public health and forms sound basis for its further management.

The integration of GIS and MCDA is a powerful tool to solve the treatment plant site selection problem, because GIS provides efficient manipulation and presentation of the data and MCDA supplies consistent ranking of the potential treatment plant areas based on a variety of criteria (BSAK SENER, 2004). The Geographical Information System (GIS) is widely used in treatment plant site selection to achieve the combination of the identified criteria in order to generate suitability maps. It is the most reliable tool, as it is capable of storing, retrieving, and analyzing a large amount of data, as well as providing output visualization. Furthermore, treatment plant siting analysis using GIS allows greater time-effectiveness. Consequently, GIS has been utilized to conduct initial screenings in order to find suitable areas for locating treatment plant site. Several techniques using GIS for treatment plant site selection were found in the literatures.

Multiple criteria decision analysis approaches are used to deal with the difficulties that decision-makers encounter in handling large amounts of complex information. The principle of the method is to divide the decision problems into smaller understandable parts, to analyze each part separately and then to integrate the parts in a logical manner (Malczewski, 1997). The purpose of this study is to develop a treatment plant siting methodology that integrates a multi-criteria decision analysis method, which consists of the analytical hierarchy process (AHP) and weighted linear combination (WLC) methods, within a GIS environment. The presented methodology is applied to the Bahir Dar town, as a case study area, in order to evaluate the potential areas for treatment plant siting and to identify the best area for locating wastewater treatment plant site.

1.2. Statement of the problem

Problems concerning water sanitation stem from the rise in urban migration and the practice of discharging untreated wastewater. The uncontrolled growth of urban areas has made planning and expansion of water and sewage systems very difficult and expensive to carry out. In addition, many of those moving to the city have low income, making it difficult to pay for any water system upgrades (Jhansi & Mishra, 2013).

More than half of the population of developing countries does not have access to sanitation and more than 80% of the wastewater generated is directly discharged into surface water bodies. This discharge pollutes the environment and is damaging the ecosystem especially the lake (UN HABITAT, 2008).

The habit of open field discharge of liquid waste is one of the main causes of soil and water contamination and consequently a cause of many communicable diseases (Nanda R., 1988).

Bahir Dar, the high population growth rate and rapid rural to urban migration contributed to the growth of the town and currently, the town has more than 300, 000 inhabitants. Rapid urbanization and public service implies rapid growth of the wastes, which in turn affects human health and environmental conditions. The problems of this town is the waste generated simply discharge on the road, open fields and waterway area unknowingly or carelessly of the residents and also the lack of discharge wastewater sites. In Bahir Dar town, 64% wastewater discharge into the streets and open fields. The inadequacy of sanitation services resulted in defecating in open fields and discharging of raw wastewater into inappropriate places and these, in turn, have created environmental problems (Fesseha H., 2012). Therefore, to minimize the negative effects on environmental hazards and public health, a construction of wastewater treatment plant has its own necessary in Bahir Dar town.

1.3. Objectives of the study

The main objective of this research is to find environmentally and economically suitable optimal location of wastewater treatment plant by using the GIS-based Multi-criteria analysis approaches in Bahir Dar town.

In order to achieve the main research objective, the following specific objectives were defined in this research.

The specific objective of the study is to:

- Determine the criteria for considered in selecting a wastwwater treatment plant site.
- Generate GIS based multi criteria analysis model builder.
- Identify the suitable areas for wastewater treatment plant using the weighted overlay tool in ArcGIS and Multi-criteria Analysis.
- Recommend the possible optimal locations of wastewater treatment plant sites in Bair Dar town.

1.4. Research Questions

The Research questions of the study include:

I. What are the criteria that should be considered in selecting a suitable site for wastewater treatment plant?

II. What is essential to generate GIS-based Multi-criteria analysis model builder?

III. Which areas are suitable for siting wastewater treatment plant?

IV. How many optimal wastewater treatment plant sites recommended in study area?

1.5. Significance of the Study

The study of this research will be a significant for the sustainable treatment and reuse of wastewater that it reduces the social and environmental impacts. The findings from the study will be used by urban planners and decision makers to implement ecologically sound waste management scheme in the town. In addition, it will help the health sector the public in general as well as managers to cut down the time spent debating location based problems as well as reduce costs. Furthermore, the product of the study can be used by academicians, researchers, practitioners and urban decision makers either for academic purpose or decision making.

1.6. Scope of the Study

The study will cover the entire administrative boundary of Bahir Dar town. Optimal site selection for wastewater treatment plant is the focus of study and siting the criteria such as elevation, slope, wind direction, groundwater table, surface permeability (geology /soil), land use land cover, proximity to groundwater wells, roads, surface water and settlement areas of the various methods that are commonly used in Geographical information system (GIS) and Multi-criteria analysis. The Analytical Hierarchy Process (AHP) adopted for the study, gained high popularity because of easiness in obtaining the weights and capacity to integrate heterogeneous data in decision making process. In this study, the design, operations and maintenance of wastewater treatment plant is out of the scope of this research.

1.7. Organization of the thesis

This organization of the thesis is included to give the reader a brief overview of the thesis and to give an understanding for how the work was structured. There are five chapters of the thesis that follows by ASTU format. Details of each chapter are given below:

Chapter 1: Introduction- which introduced the background of the study, problem statements, and the general objective of the research include the specific objectives and the research questions, significance of the study, scope of the study and organization of the thesis.

Chapter 2: Literatures review - The second part of the research is literature study, reviewed related papers to find the scientific support and the theories.

Chapter 3: Materials and Methods - The chapter three gives an account of geographical study area, method of data collection and source of data, software used, methods, data analysis and GIS based MCA model used for the research.

Chapter 4: Results and Discussion **-** The results of the research work are discussed in chapter four.

Chapter 5: Conclusion and Recommendations**-** Finally chapter five concludes the thesis with some recommendations.

2. LIETRATURE REVIEW

2.1. Historical background on wastewater treatment

The existence of wastewater and the need for wastewater treatment is not a new problem. The production of excreta and urine is a natural part of human life, and has a history as long as mankind. In parallel to growing civilizations and increasing urbanity, and with the introduction of the water closet and centralized wastewater collection, problems related to large accumulations of wastewater has arisen. In centralized systems for wastewater collection one could also find other sources to wastewater than only domestic, such as storm water and industrial wastewater sources (Britannica, 2012).

Wastewater is generally looked upon as a negative resource, both from an aesthetic perspective and because of its characteristic bad odor, and the fact that its main component is human waste. The greater importance when considering the need for treatment is the fact that untreated wastewater led into a natural water body constitute a great hazard for the environment and a health risk for human and animal life. The environmental risk is mainly due to overloading of physical and chemical components associated with human activity into an aquifer, while the health risk is mainly the result of pathogenic contamination (Eivind, 2012).

The problem of the contamination of water bodies through wastewater discharges was understood back in the time of the Romans. The first sewer in Rome was built about 400 BC under the name Cloaca Maxima (Great Sewer), a system mainly for transportation of drainage water. During the middle ages there was little progress in urban drainage and sewerage, until the introduction of water closets in the early 19^{th} century. At first these were usually connected to cesspools instead of sewers. In parallel with growing population density in urban areas, and problems of overflowing of cesspools, the problem of wastewater discharge became intolerable. Another factor that attracted the attention to the need of wastewater collection and treatment was the global cholera outbreaks in the 19th century. The disease was gradually traced back to well-water supplies contaminated with human waste from cesspools and privy vaults. As a result of this development, water closets in larger towns were to a larger extent connected to storm sewers. On the other hand, the handling of one problem led to the introduction of another one: surface water pollution. A receiving water body will up to a certain level be able to render harmless the contaminants of discharged wastewater through dilution. Nevertheless, when the quantities of pollutants exceed the recipients critical level, they will possibly do harm to the surroundings. In densely populated areas this is much likely to happen. The solution to this problem is through treatment of the raw wastewater (Eivind, 2012).

During the late 19th and the early 20th century, there was an awakening in the development of centralized wastewater treatment systems, mainly in the United Kingdom and the United States. As an addition to collection and discharge of wastewater, physical, biological and chemical processes for the wastewater treatment were introduced, for the removal of pollutants. The idea of separated systems also sprung up at this time, as mixing of storm water and domestic wastewater lead to overloading of the treatment plants. Through the 20th century, there was an increasing public concern for environmental issues, leading to a wider focus on wastewater disposal practices (Britannica, 2012).

2.2. Municipal wastewater

Municipal wastewater is a combination of water and carried wastes removed from residential, institutional and commercial establishments together with infiltration of water, surface water and runoff water (Al-Enezi et al., 2004). The methods of wastewater treatment were first developed in response to the concern for public health and the adverse conditions caused by the discharge of wastewater to the environment (Jamrah, 1998).

When untreated municipal wastewater accumulates, the decomposition of the organic matter present in the wastewater will lead to nuisance conditions including the production of malodorous gases. In addition, untreated wastewater contains numerous pathogenic microorganisms that dwell in the human intestinal tract. Wastewater also contains nutrients which can stimulate the growth of aquatic plants (eutrophication) and may contain toxic compounds or compounds that potentially may be mutagenic or carcinogenic. For these reasons, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment, reuse, or disposal into the environment is necessary to protect public health and the environment (Metcalf and Eddy, 2004).

Municipal wastewater is comprised of domestic (or sanitary) wastewater, industrial wastewater, infiltration and inflow into sewer lines, and storm water runoff. Domestic wastewater refers to wastewater discharged from residences and from commercial and institutional facilities (Metcalf and Eddy, 2004). Domestic water usage, and the resultant wastewater, is affected by climate, community size, density of development, community affluence, dependability and quality of water supply (Metcalf and Eddy, 2004).

2.2.1. Source of Municipal Wastewater

In a given geographic area or community, several types of wastewater are possibly led to the WWTP through the collection system. The components found in a wastewater flow depend on the type of collection system that is used. The major flow of wastewater to a conventional WWTP is normally domestic wastewater, which refers to "wastewater discharged from residences and from commercial, institutional, and similar facilities" (Metcalf & Eddy, 2004). The various type of human waste in household is generated, combined sewage and discharge as shown in (fig. 2.1).

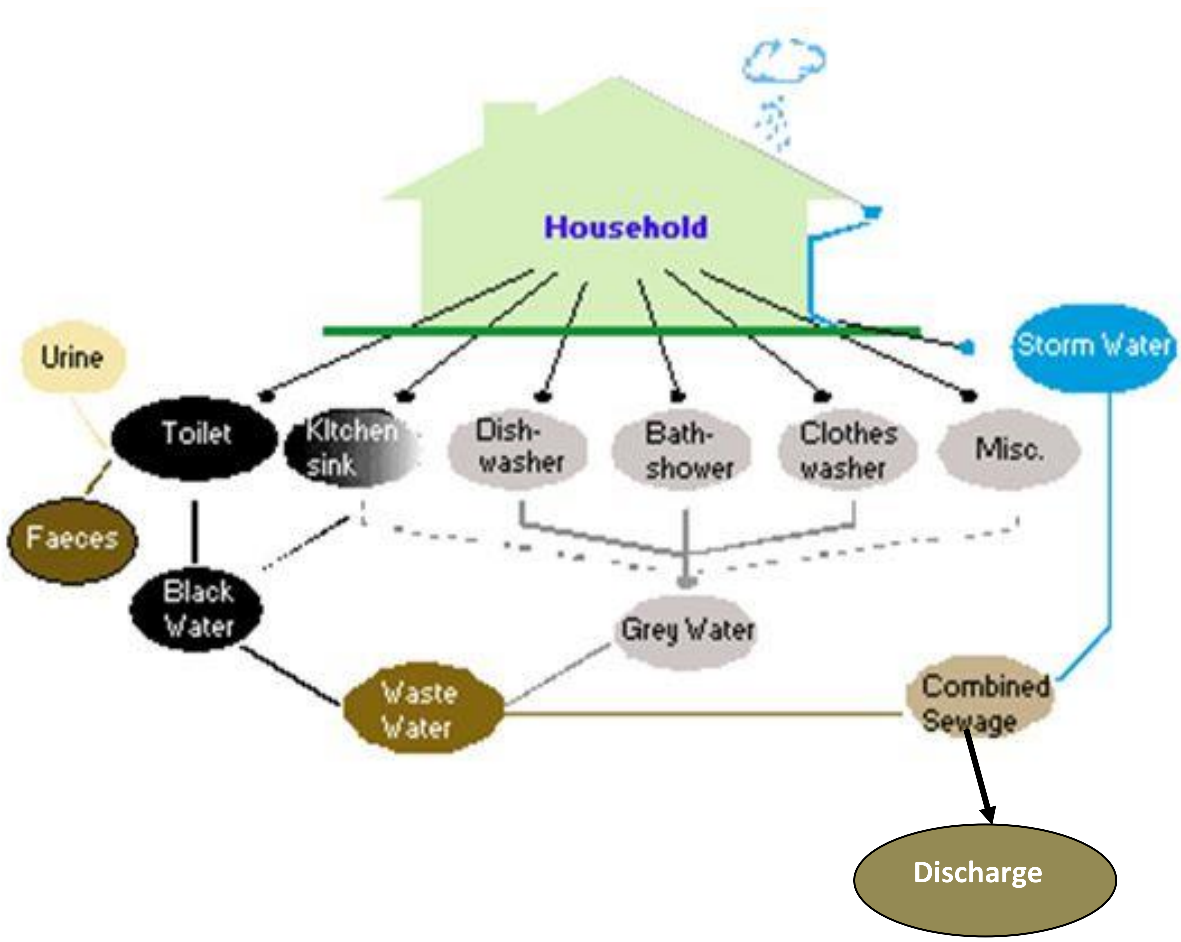


Fig.2.1. A range of possible sources of household wastewater

The wastewater from toilet is called black water. The amount of this water is very small but contain high in solid and significant nutrients (as nitrogen and phosphorous). Other wastewater that generated and discharged from living activities of human such as cooking, bath, washing are called grey water. The grey water is high volume and contain high amount of organic matter but low in nutrients. The black water can be separated into two types that are faeces and urine before it is mixed in the toilet. Faeces are known as brown water and urine is called yellow water.

Industrial wastewater could also be led into the collection system, even though many industries have their own treatment facilities for their wastewater. Where large scale industries have their wastewater connected to the collection system, it is of great importance to know the characteristics of the wastewater, as it may contain chemical or physical components that might interrupt conventional processes. Infiltration water refer to water that enters the collection system through indirect means, principally through the ground and via leakages in the collection system. Cracks, porous walls or joints in the piping system together with other weak points in the system, such as manhole walls are a main reason for this. Inflow is the water that are discharged directly into the system through service connections such as cellar and foundation drains, cooling water discharges, and drains from springs and swampy areas. The last category, storm water, comes directly into the collection system as runoff from rainfall or possibly snowmelt (Eivind, 2012).

Combined sewer systems are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. Some designs utilize an overflow at the treatment plant that diverts the excess flow to chlorination facilities for disinfection prior to discharge (Metcalf & Eddy, 2004).

A typical household in developed countries discharges approximately 35 liters of black water, and 105 liters of grey water per person per day (USEPA, 2000). The potential for on-site treatment and reuse will depend on the quality of discharged wastewater. Grey water contributes about 65% of the volume of domestic wastewater, 70% of the phosphorus, and 63% of the BOD (biochemical oxygen demand), whilst black water contributes about 35% of the volume of wastewater, 61% of suspended solids, 82% of nitrogen and 37% of BOD (USEPA, 2000). The potential presence of pathogens in grey water is substantially lower than in black water. However, several authors have shown that grey water may contain pathogens. Thus, both grey water and black water require adequate treatment before onsite reuse (Martin I., 2011).

2.3. Municipal wastewater in Bahir Dar town

Municipal Wastewaters are the main sources which contaminate the water resource systems either through the surface water networks such as rivers, lakes, canals and drains, or into groundwater aquifers because they can easily migrate downward into the permeable soils and fractured rocks to the groundwater reservoirs (Soliman, 1998).

Currently Bahir Dar has no municipal sewerage system. Only few households have flushed toilet facilities and septic tanks. Majority 70 percent of the population uses dry pit latrines, 30 percent still uses the open field (Yewendwesen M., 2003). The town has a total of 25 public toilets constructed by Municipality (9) and UNICEF (16). However, most those toilets are not properly managed and well-functioning, as result people prefer to use open field defecation. The number and distribution of the toilet is not sufficient for those people who don't have private or common toilet. As a result, open field defecation is a common practice in the town. This has contributed to the deterioration of the urban environment due to poor sanitation.

According to Yewendwesen M., (2003) the proportion of piped water user, though not totally safe, constitutes 93.8 percent, those of traditional source users is 4.3 percent, while the remaining 1.9 percent are not specified. This indicates that the possible contamination of surface water bodies easily by urban run–off and the people exposed to different water borne diseases who are using traditional water sources like river, lake and hand dug wells. Poor sewerage system coupled with high population density at the center of the town aggravated the sanitation problem. The existing storm water sewers are very limited in extent and are not effective at present because of small diameters and frequent blockage by rubbish carried by the floodwater. The problem became sever especially, during rainy season when there is high flood and liquid waste from drainage over flooding the street of Bahir Dar. Due to flat topography the stagnant wastewater usually create bad odor and affects the local residents. Besides, it creates favorable condition for malaria growth and because of this the population of the town is frequently affected by outbreak of malaria. Moreover the movement of cattle in the town and the garbage thrown from houses into the streets also damages the sewer system.

The sediment carrying capacity of the lines in the network is very low due to their comparatively mild slope. The pipes and ditches usually be clogged and the town's drainage problems would prevail, in addition to the sanitation problems the town may face, unless there is no efficient way for their collection and disposal. Thus, their persistent cleaning and maintenance is also very important (Yewendwesen M., 2003).

The study conducted by Devecon in 1992 indicates that 59.7 percent of the existing sanitary facilities are used individually and 14.7 percent are shared. Some 33.5 percent of the households are not satisfied with their present latrine system because of lack of privacy and sanitation problem of the facilities. Regarding dislodging of pits the study indicates that 40.3 percent of the households use the vacuum truck. 14 percent of the households dug new pits and connect them with the old facilities when they get filled up. Besides, every corner of the city seems a legally accepted place and common practice to discharge liquid excreta (urine) at any moment. In Bahir Dar it is common to hear outbreak of typhoid and typhus fever due to contamination of municipal water by seepage and poor sanitation.

Municipal wastewater is composed of human excreta (faeces and urine), which is the wastewater from sinks and baths etc. These wastes are principally organic; there are tens of thousands of different organic compounds preset in sewage and it is impossible (and indeed meaningless) if it were possible to characterize them all. All organisms produce wastes but none produce as many wastes of such diverse composition as humans (Chiras, 1992).

The most important primary concerns in all municipal wastewaters that need to be noticed is that their final destination. They are end in surface or groundwater sources. Therefore it is important to set legal minimum requirement of wastewater characteristics setup in Bahir Dar for sewer connection contributes for illegal discharge of wastewater in the river, streams or lake as shown in (fig. 2.2).

Fig. 2.2. Photo of wastewater in Bahir Dar town (2015)

2.4. Definitions

Decision is a choice between alternatives. The alternatives may represent different courses of action, different hypotheses about the character of a feature, different sets of features and so on.

Criterion is some basis for a decision than can be measured and evaluated. It the evidence upon which a decision is based. Criteria can be of two kinds: factors and constraints.

Factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore measured on a continuous scale. For example, a forestry company may determine that the steeper the slope, the more costly it is to transport the wood. As a result, better areas for logging would be those on shallow slopes the shallower the better. Factors are also known as decision variables in the mathematical programming literature (Fiering, 1986) and structural variables in the linear goal programming literature (Ignizio, 1985).

Constraint serves to limit the alternatives under consideration. A good example of a constraint would be the exclusion from development of areas designated as wildlife reserves. In many cases constraints is expressed in the form of a Boolean (logical) maps: areas excluded from consideration being coded with a 0 and those open for consideration being coded with a 1. Constraints are used to limit the alternatives under consideration.

Decision Rule is the procedure by which criteria are combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon, is known as a decision rule. A decision rule might be as simple as a threshold applied to a single criterion (such as, all regions with slopes less than 35 percent will be zoned as suitable for development) or it may be as complex as one involving the comparison of several multi-criteria evaluation.

Objective represents *d*ecision rules that are structured in the context of a specific purpose. The nature of that objective, and how it is viewed by the decision makers (i.e. their motives), will serve as a strong guiding force in the development of a specific decision rule.

Source: Definitions are taken from (Eastman et al., 1995).

2.5. Criteria for wastewater treatment plant site selection

Site selection of a wastewater treatment facility should be based on careful consideration of region’s land use and development patterns as well as social, environmental, economical and engineering constraints. It is important to remember that the selection of a site for a wastewater treatment plant will have long-lasting social, economic, and political effects on the affected community and neighborhood. Therefore, public involvement in decision-making is crucial (Yongmin Pan, 2006).

All possible sites for a wastewater treatment plant should be fully evaluated on the basis of topography, environmental impacts and economics of wastewater collection and treatment. Often an interdisciplinary team approach may be necessary to cover all these aspects. The following is a list of some basic principles that must be considered during site evaluation (Yongmin Pan, 2006).

1. A wastewater treatment plant should be located at a low elevation in order to permit gravity flow.
2. The site should be fairly isolated from presently built-up areas or areas that have potential for future developments. All plants should be designed with aesthetic consideration and odors in mind. For instance, the drying beds for sludge require areas and are potential sources of bad odors.
3. A site on a large land area is helpful in maintaining isolation (buffer areas) and the wastewater treatment plants the needs for future expansion.
4. A site that may provide opportunity for local disposal of end products such as effluent, grit, screenings, sludge, and ash is highly desirable.
5. A site within a flood zone should not be selected unless proper flood protection measures are taken. Such measures include raising the units above flood level or constructing earthworks around the site. Storm drainage systems with pumping equipment to discharge the storm water and effluent above the flood level should be provided. Auxiliary power equipment may be necessary in the event of power outages.
6. The ability of the ground to support structures without extensive piling is important consideration in site selection. Common foundation problems are low bearing capacity, excessive settlement, differential settlement, and flotation caused by high groundwater table.
7. The site should have year-round, all-weather access roads. Railroads may be helpful for delivery of bulk chemicals and transport of sludge from large facilities.
8. The site should be near a large body of water or irrigable land capable of accepting the treated effluent.

9. A site with a flat slope will assist in locating various treatment units in their normal sequence without excavation or filling. This will provide gravity flow, least disruption to the natural topography, and least erosion control measures.

10. The sites should be evaluated and checked for presence of archaeological, historical, or other properties included in or eligible for inclusion in the National Register of Historic Places. The site should also be investigated for the presence of endangered or threatened species of flora or fauna or their critical habitats.

11. Site selection and planning of wastewater treatment facilities should be done with prime consideration of preservation of shorelines, particularly in urban areas. Shoreline preservation involves public pathways along shore, public parks, recreation facilities, and protection against erosion of banks, siltation of the waterway, and preservation of valuable ecological niches.

2.6. Geographical Information System (GIS)

Geographical Information Systems (GIS) have emerged as useful computer-based tools for spatial operations. It's a computer-based technology for collecting processing, managing, analyzing, modeling and presenting spatial data for a wide range of applications. Due to their ability to manage large volumes of spatial information from a various resources, GIS are ideal for site selection studies (Kao et al., 1996). It has been widely applied in the past for site selection studies (Curtis et al., 2000). GIS is an important to because it not only reduces time and cost of the site selection but also provides a digital data storage for long term management and planning.

Geographic Information Systems (GIS) are ideal for preliminary site selection studies because it can manage large volumes of spatially distributed data from a variety of sources and efficiently store, retrieve, analyze and display information (Siddiqui, 1996). Using GIS for site selection not only increases the objectivity and flexibility but also ensures that a large amount of spatial data can be processed in a short time. Relatively easy presentations of GIS siting results are also one of the advantages (Kao and Lin, 1996).

GIS has been found to play key role in the domain of site selection. The potential advantage of a GIS-based approach is reductions time and cost of site selection, but also provides a digital data base for long-term monitoring of the site (Sumathi et al., 2008).

GIS-based site selections have been widely used recently in Ethiopia. In 2013, Tirusew A. and Amare S. did a research of siting evaluation of municipal solid waste landfill areas in

Bahir Dar town. Seven factors were considered in the study, they are Distance from river, urban center, rural settlement, road, Lake, Protected area and identified slopes and land use types. Those seven factors were modeled and reclassified, the areas with high possibility was marked in yellow, which represents the best locations for constructing a municipal solid waste landfill (Tirusew A. and Amare S., 2013). Gizachew K. and K.V.Suryabhagavan did a research of site selection of municipal solid waste landfill areas in Addis Ababa city. Eleven factors were considered in the study, they are proximity to rivers, faults, airport, roads, well and ground water level, Hydraulic conductivity, soil type, land use/land cover, slope and Geology. Those Eleven factors were modeled and reclassified, the areas with high possibility was marked in Green, which represents the best sites for constructing a municipal solid waste landfill (Gizachew K. and K.V.Suryabhagavan, 2012).

GIS software supports spatial data analysis, which could be applied in much traditional location selection analysis. Traditionally GIS use was associated static data, longer time and involved only a few specialized users. Today that is all changing. GIS can now associate and utilize relatively dynamic data, short time, and involve many users. Geographic information can facilitate decision support system and can even solve a variety of complex problems. The spatial output obtained from a GIS is virtually boundless, limited only by the adeptness of the user and data availability (Filemo et al., 2008).

2.7. GIS with multi-criteria decision analysis

GIS-MCDA is a process that combines and transforms criteria map (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker's preferences and the manipulation of data and preferences according to specified be transformed into final ranking of alternatives (Baban et al., 2003).

A decision maker frequently faces the problem of identifying a solution from a finite set of alternatives. GIS-MCDA deals with the problem of site selecting an alternative from a set of alternatives characterized by multiple attributes. The integration of GIS and MCDA is a powerful tool to solve the site selection problem because GIS provide efficient manipulation and presentation of the data and MCDA supplies consistent ranking of the potential waste areas based on a variety of criteria (Suzen & Doyuran, 2006).

Many studies have used GIS-based multi-criteria analysis for site selection. For site selection, based on different geographic features, GIS could do several works like integration, visualization, management and analysis, it could find useful information from a large amount of data; it is a valuable tool for optimal site selection and natural decision making (Cheng et al., 2007). In 1997, Gordon and Womersley were using GIS techniques to select the location of public health service (Gordon & Womersley, 1997). Hare and Barcus were using the geographical distributions of heart-related hospitals along with travel times to figure out the accessibility of heart-related hospitals in Kentucky (Hare & Barcus, 2007). In 2008, a study of selecting optimal site for the supermarket has been done. In this study, it discussed the main factors affecting the supermarket location and the methods for determining the location. In the study, geographic information system (GIS) as analysis platform for analysis and neural network analysis is also introduced in this study (Wei et al., 2008).

2.8. Related works on GIS-based MCA for WWTP Site Selection

A study introduced by Paulina *et al.*, (2012). In their study, "site suitability analysis for a central wastewater treatment plant(s) Accra Metropolitan Area" in Ghana Using GIS for an area of approximately 231km2 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 Arc Map and total suitable area was found to be 20km2 in the land north of Accra Metropolitan Area.

Alexandra (2006) 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 (Meinzinger, 2003) was carried out on similar trend to site land for wastewater application in Christchurch New Zealand 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 Zhao (2009) 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.

Another case study performed by Ratnapriya and De Silva (2009) optimized wastewater treatment plant location using in Upper Mahaweli, Sri Lanka; here several criteria were considered as Technical criteria, environmental criteria and social aspects. They used Boolean analysis to overlap the data layers. At the end of 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% (48km2) of the study area (210km2).

Site suitability evaluation for waste management is becoming a major criterion for defending the environmental degradation. If proper location for the treatment plant is not selected then it may lead to soil degradation and ground water pollution. The study area is situated in the southern portion of Tamil Nadu, India that is currently experiencing high rates of population growth and economic development. Potential sites for the treatment plant are evaluated using suitability score based on planning and design constraints, including ground slope, land use pattern, and distance to river and roads. Spatial analyst tool of ArcGIS software is used for selection of suitable reclamation plant site. Finally based on weightage value, suitable site for treatment plant have been selected and classified into good, moderate and poorly suitable areas respectively (Benujah and Devib, 2013).

Deepa and Krishnaveni (2012) using analytic hierarchy process (AHP) method and GIS tried to determine a suitable site for decentralized wastewater treatment plant in Shollinganallur region. In their study, they used five criteria: Topography, slope, land use, population, and soil. By reviewing the literatures, we found that each of researchers has used a certain set of criteria for determining suitable site for wastewater treatment plant.

Another case study performed by (Mansouri et al., 2013) using GIS and AHP method tried to determine the Wastewater treatment plant site selection Falavarjan district, northwest of Esfahan province. For this the nine parameters that were selected as main criteria, seven parameters were considered to define the buffer zones in the natural and artificial terrains. At the first stage of the study, unsuitable zones were excluded and the weights of the main and subclasses were calculated using AHP method. Then, each parameter was mapped into a GIS system as an individual data layer. The final susceptibility map, which had been produced by overlapping all data layers, was divided into four categories. Then, the three top ranked areas were selected from the very suitable class. In order to locate the site with the minimum effect on the environment, the Leopold Matrix was used. Finally, area 1 was selected, as the most preferable option for the construction of the wastewater treatment plant.

Anagnostopoulos and Vavatsikos (2007) performed GIS based on support decision system in evaluation of wastewater treatment plant site by selection of environmental, economic and social criteria. The factors used in this investigation include slope, topography, geology, land use, distance from road, railroad, river, settlements, faults, coastline, etc. They categorized suitable sites for constructing wastewater treatment plant in Rodopi City and identified fuzzy model and network analysis process as a combined suitable model for decision makers in determining a suitable site for wastewater treatment plant.

Anagnostopoulos et al., (2008) in another study tried to find the most suitable location for wastewater treatment plant of a region using FAHP method. They found out that the combination of multi-criteria decision making model and geographic information system (GIS) is a valuable tool for determining the treatment plant site. In their study, they used four indices (twelve criteria) to achieve their goal.

Shahmoradi et al., (2013) study tries to find the most suitable site for constructing wastewater treatment plant in Kahak city, Iran; using integrated fuzzy logic and multi-criteria decision model. We used super decision software and a geographic information system (GIS) for scoring the parameters. Based on these studies, twelve criteria were categorized in the form of two general groups of discrete and continuous indices, such that discrete indices included six criteria (soil, slope, topography, geology, land use, and wind) and continuous indices included 6 criteria (distance from main city, underground water, surface water, roads, and settlements). At the end a composite map was arrived at which shows areas the western part of Kahak was found to be a suitable place for constructing municipal wastewater treatment plant. Our findings indicated that decision makers and policy makers would be able to achieve better results concerning the most suitable location for wastewater treatment plant easily through combining these two models.

2.9. Analytical Hierarchy Process (AHP)

The AHP method which is developed by (Saaty, 1980) is an effective approach to extract the relative importance weights (RIW) of the criteria. It is based on the pairwise comparisons which are used to determine the relative importance of each criterion. The pairwise comparison method involves three steps:

I. Development of a pairwise comparison matrix: the method uses a scale with values range from 1 to 9.

Empirical applications suggest that pairwise comparison method is one of the most effective techniques for spatial decision making including GIS-based approaches (Eastman, 1993; Malczewski, 1997).

II. Computation of criteria weights: The computation of weights involves three steps. First step is the summation of the values in each column of the matrix. Then, each element in the matrix should be divided by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix). Then, computation of the average of the elements in each row of the normalized matrix should be made. This includes dividing the sum of normalized scores for each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared (Saaty, 1980).

III. Estimation of the consistency ratio: The aim of this is to determine if the comparisons are consistent or not. It involves several operations. First, Determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, finally sum these values over the rows. Second, Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously. Third, Compute lambda (λ) which is the average value of the consistency vector and Consistency Index (CI) which provides a measure of departure from consistency and has the formula below:

$$CI = (\lambda - n) / (n-1)$$

Finally, to ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR that is,

$$CR = CI / RI$$

Table 2.1. RI table values (*Adopted* Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Where, RI is the random consistency index. The RI values for different numbers of **n** are shown in table 2.1.

If CR is < 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparison, however, if CR ≥ 0.10, the values of the ratio indicates inconsistent judgments (Saaty, 1980). The advantages of this method can be summarized that only two criteria have to be considered at a time, it can be implemented in a spreadsheet environment (Kirkwood, 1997) and it is incorporated into GIS based decision making procedures (Eastman, 1993 and Janskowski, 1995).

3.0. Weighted Linear Combination (WLC)

The weighted linear combination (WLC) approach is the most commonly used GIS-based decision rules technique (Malczewski, 1999). One of its most common applications is to solve land use/ suitability analysis, site selection, and resource evaluation problems (Hobbs, 1980 and Han and Kim, 1988).

WLC, otherwise known as weighing, is based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined using a weighted average. The decision maker determines and assigns the weights of relative importance directly to each attribute map layer. The total score for each alternative is the product of the importance weight assigned to each attribute multiplied by the scaled value given for that attribute to the alternative and then summing the products over all attributes. The scores are calculated for all of the alternatives. The one chosen is that with the highest overall score. The method can be executed using any GIS system with overlay capabilities. The use of the method allows the evaluation criterion map layers to be combined in order to determine the resulting composite map layer. Both raster and vector GIS environments can be used to implement this technique.

With the weighted linear combination, factors are combined by first applying a weight to each factor, followed by a summation of the results to yield a suitability map:

$$S = \Sigma\, wi\; xi$$

Where S is suitability, wi is weight of factor i, and xi is the criterion score of factor i.

This method is highly popular mainly due to the ease associated with its implementation within the GIS environment using map algebra operations and cartographic modeling (Tomlin, 1990). The method is intuitive, simple to comprehend and thus appealing to decision makers (Hwang and Yoon, 1981). However, GIS implementation to WLC is often used without a thorough awareness of the assumptions underlying the method. In addition, it is occasionally utilized without full understanding of the meaning of two elements of WLC, i.e., the weights assigned to attribute maps and the procedures for deriving commensurate attribute maps (Malczewski, 2000).

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Geographical location

Bahir Dar town is located in the northwestern part of the country at a distance of approximately 565 kms by road from Addis Ababa on the Gondar high way. The town is the center of the Amhara National Regional State and it is bounded to the north by Lake Tana and marks the sources of the great Blue Nile river. Previously the town was the city of west Gojiam zone. Now it is Bahir Dar special zone. According from UTM coordinate system, the location of the town is aproxmatily between 312000m – 334000m East direction and 1273000m – 1289000m North direction as shown in fig.3.1. The town has nine administrative kebels with a total area covers about 213.41 square km. Bahir Dar is one of the leading tourist destinations in Ethiopia, with a variety of attractions in the nearby Lake Tana and Blue Nile river.

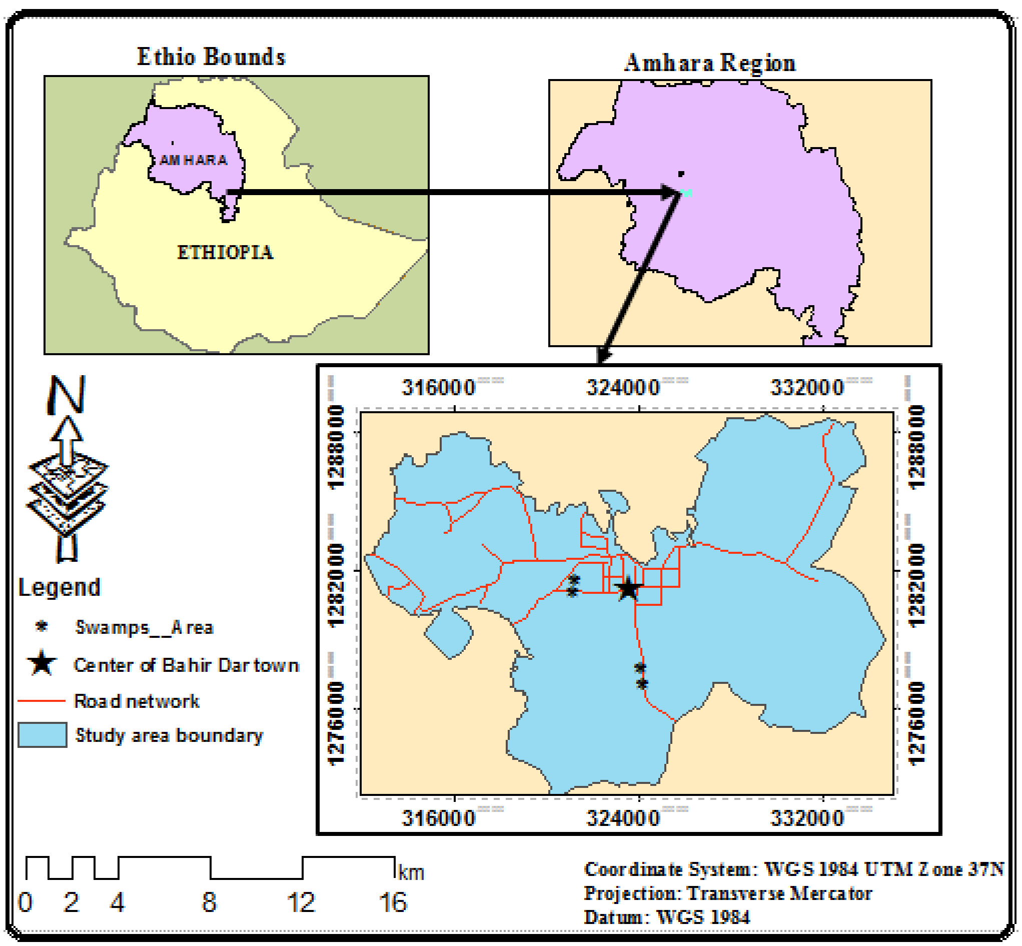


Fig. 3.1. Location Map of the study area

3.1.2. Topography and land use

3.1.2. 1.Topography

Topography of study area the terrain type contains flat at the south, south western part and the central and the north – eastern part of Bahir Dar town the terrain type is steep plain and altitude ranges from 1705m a.m.s.l to the south eastern and 2017m a.m.s.l to the eastern part of the area as shown in fig. 3.2. According to Tirusew A. and Amare S. (2013), about 90.7% of their terrains having gradients slope between 0 - 10%. The part of town, stretch on areas below 2% slope. The natural drainage is very poor and there are also scattered and slightly depressed areas within the town's boundary, which form temporary swamps when rainwater settles for short to prolonged period of the year.

The general slope orientation of the town is slightly towards Abbay river, which crosses the town from northwest to southeast and serves as the only outlet for surface water runoff from the town. Although there is no well-defined course of surface water, the direction of drainage is dominantly towards Abbay river except for some areas, which drain into Lake Tana. Because of its extreme flatness, the town has been affected by flood problem. As a result, streets will be partly inundated and shallow depressions changed into big ponds during the rainy seasons, which create serious difficulties in traffic movement (Yewendwesen, 2003).

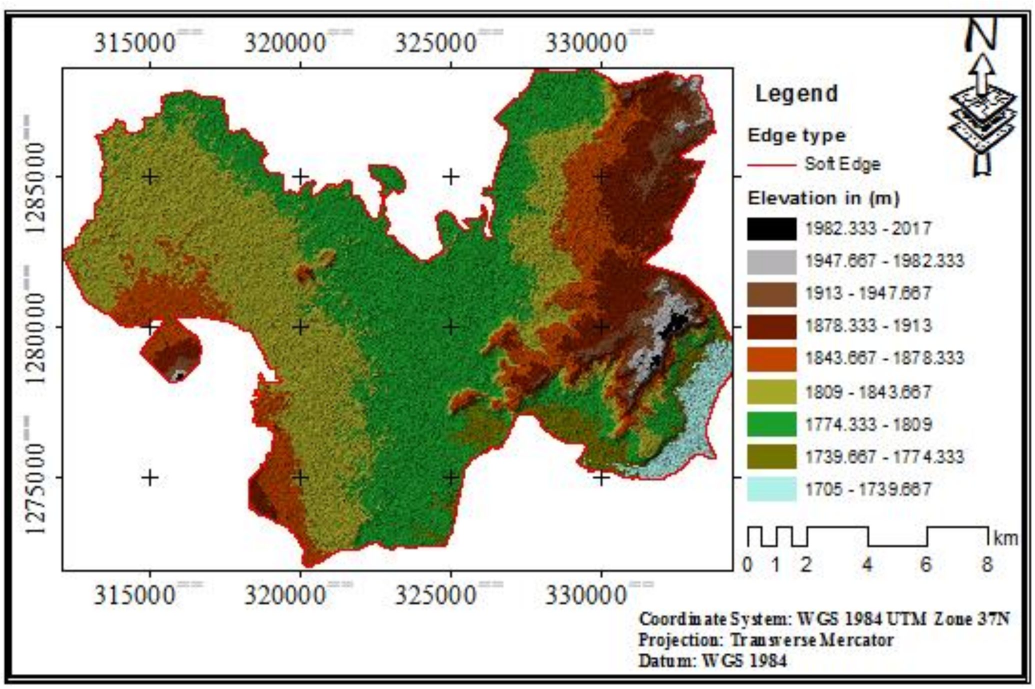


Fig. 3.2: Topographic Map of the study area

3.1.2.2. Land Use

According to from the master plan in 2006, the core city covers an estimated area of 160 km^2 and has a possibility to expand in all directions except to the side of Lake Tana. The city is divided into 9 administrative kebeles. Most of the administrative kebeles comprise mixed land use i.e. residential; commercial, institutional etc. this has difficulty to set clear the boundaries of different sectors and waste generators with respect to various waste streams.

In Bahir Dar area significant numbers of the urban dwellers and about 26% of the rural residents are engaged in agricultural activities. Water body of Bahir Dar accounts just over 31% of the total land. Human settlement accounts to about 30% of the total land area of the city (including rural, urban and informal settlements) as shown in table 3.1.

Table 3.1. Land cover of Bihar Dar town and its surrounding

No.	**Land use classification**	**Area (km^2)**	**Area (%)**
1	Agriculture	65.88	23.72
2	Formal urban settlement	42.14	15.17
3	Forest & Woodland	0.70	0.25
4	Marshy land	18.80	6.77
5	Vacant & Rocky	23.27	8.38
6	Water Body	87.18	31.39
7	Rural Settlement	29.82	10.74
8	Informal settlement	9.92	3.57
Total		**213.41**	**100.00**

Source: Bahir Dar municipality cadaster studies office (2009), *Adopted.*

3.1.3. Demographic Details

According to the population and household census of 2007, the population of Bahir Dar is 221,991 including rural kebeles. When disaggregated by place of settlement, the rural population of Bahir Dar constituted 41,817 while the urban population is 180,174. In terms of gender composition the female population of Bahir Dar is slightly higher than the number of male population. Out of 180,174 urban populations 93,014 are female and 87,160 are male.

According to the Amhara National Regional State Bureau of Planning and Economic Development (BOPED, 2008**)** population estimates, the population of Bahir Dar has grown from 193,455 in 2008 to 216,066 in 2010 as shown in (fig.3.3 and table 3.2). And the projected population of Bahir Dar for the year 2016 will be 301,987. Taking the 2007 population size of the town as a base year population, the population size of Bahir Dar has been projected.

Table 3.2. Population /kebeles 10 years projected data based on 2007 census data.

Kebele	**Population by administrative kebeles /year**									
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
SHIBIT	14754	15728	16766	17872	19052	20309	21650	23079	24602	26226
TANA	13703	14610	15574	16602	17697	18865	20110	21438	22853	24361
FASILO	19905	21219	22619	24112	25703	27400	29208	31136	33191	35382
SEFENE SELAM	21250	22653	24148	25741	27440	29251	31182	32400	35434	37772
GISH ABAY	17874	21186	22584	24074	25663	27357	29163	31087	33139	35326
SHUM ABO	24484	26100	27823	29659	31616	33703	35927	38299	40826	43521
HIDAR 11	30000	31980	34091	36341	38739	41296	44021	46927	50024	53326
BELAY ZELEKE	20000	21320	22727	24227	25826	27531	29348	31285	33349	35550
GINBOT HAYA	16796	17905	19086	20346	21689	23120	24646	26273	28007	29855
Total	180174	193,455	204,894	216,066	228,562	240,723	255,392	270,472	286,017	301,987

Source: (BOPED, 2008)

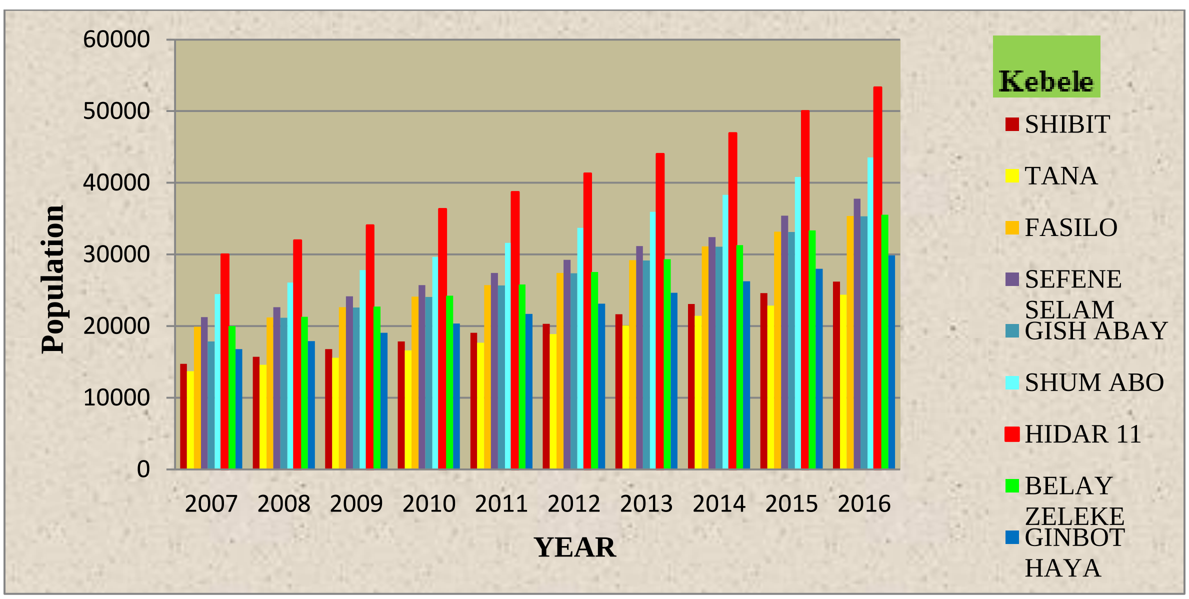


Fig. 3.3. Projected population size of Bahir Dar town (2007-2016)

3.1.4. Climate

Climate, which is a long-term view of the weather pattern of a particular locality, is frequently more useful as an environmental tool. In order to understand the environment and the possible impact of human activity on it a basic knowledge of climate is required.

The climate of the study area comes under the influence of the Inter-Tropical Convergence Zone, a zone of low pressure marking the convergence of dry tropical easterlies and most equatorial westerlies. The explanation of the seasonal rainfall distribution with in the area lies in the annual migration of the Inter-Tropical Convergence Zone across the area. Moist air mass is driven from the Atlantic and Indian Ocean during summer. During this time the Inter-Tropical Convergence Zone lies around north of Lake Tana. During the rest of the year the Inter-Tropical Convergence Zone shifts towards south and dry condition persists in the region (Yewendwesen, 2003).

The climatic seasons are often referred to as kiremt (long rains), bega (dry period), belg (small rains) and meher (a spell between the long and small rains). Their lengths and intensities vary from year to year. However, the kiremt can usually be considered to occur in June–September.

3.1.4.1. Precipitation

Precipitation is moisture that falls from the atmosphere as rain and snow. Rain is the most common form of precipitation in the study area. Concerning the type of precipitation in Ethiopia, there are very few areas in the country where snow is an important type of precipitation, but hailstorms are quite common in the rainy season, especially in areas above 2000 m above mean sea level (Yewendwesen, 2003).

In this study, monthly total rainfall records of National Meteorological Service Agency Station at Bahir Dar for the year between 1984 and 2014 is used to monthly mean and annual mean rainfall. As it was shown in table 3.3, the precipitation occurs throughout the years and shows variation in amount from season to season. This seasonal variability of rainfall is related to the direction of moisture bearing seasonal air current.

The mean annual precipitation depth recorded for the station at Bahir Dar is 1388.8 mm for almost 31 years period from 1984 to 2014. This value is taken to characterize every point in the entire study area or taken as a representative value owing to the small size of the area and minor topographic variation in it. Moreover, the maximum amounts of rainfall occur in the months of July while the minimum amount of rainfall occurs in January.

Table 3.3. Average monthly Rainfall of the study area for 31 years

Month	J	F	M	A	M	J	J	A	S	O	N	D	Ann. Mean
Rainfall in mm	1.6	1.9	10.7	24.9	77.4	199.2	401.4	368.7	199.9	89	11.7	2.4	1388.8

Source: (ENMSA, 2015)

As can be seen from fig. 3.4; there is a significant seasonal variation in the amount of rainfall. Almost 55.5 per cent of the mean annual rainfall occurs in the two rainy months of July and August. December, January and February on the other hand, are the driest months, which account for less than 0.5 percent of the annual total.

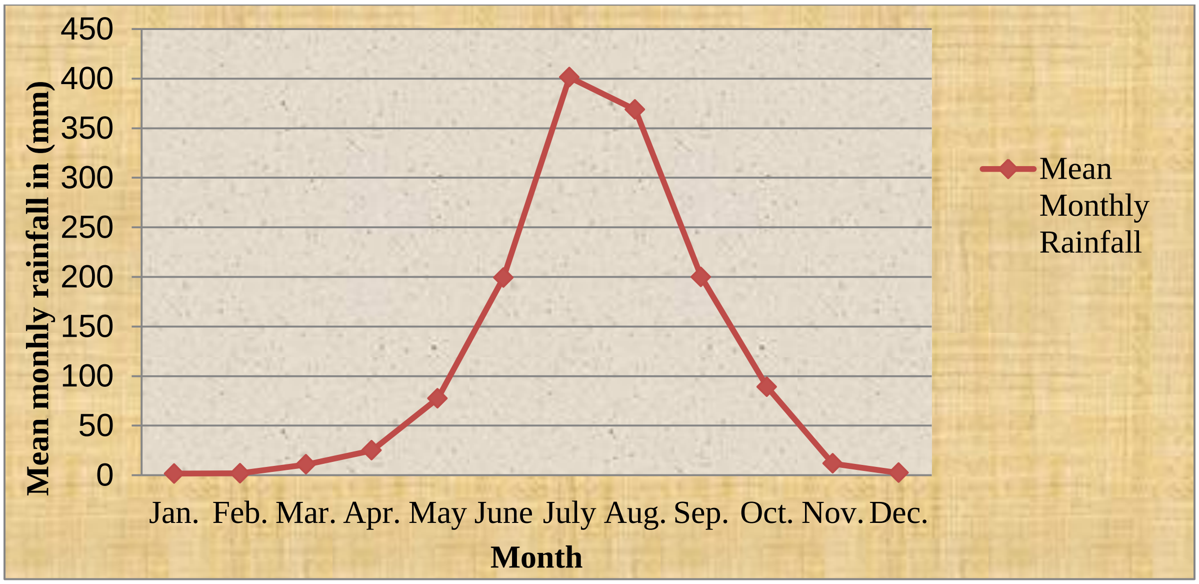


Fig.3.4. Mean monthly rainfall at Bahir Dar town (1984-2014)

3.1.4.2. Temperature

The monthly mean maximum and minimum *temperature* records of Bahir Dar town for the year between 1984 and 2014 have been used to calculate monthly and annual average temperature. The computed monthly and annual average temperature is presented in Table 3.4. As it was shown on the below table the highest mean monthly temperature occurs in the months of April (23.1 $^{0}{}_{c}$) and the lowest is in the months of July (17.7 $^{0}{}_{c}$).

Table 3.4. Average monthly temperature of the study area for 31 years

Month	J	F	M	A	M	J	J	A	S	O	N	D	Ann. Av.
Average	19.8	19.2	21.9	23.1	21.7	20.6	17.7	18.6	20.1	20.6	19.6	20	20.2

Source: (ENMSA, 2015)

For the past 31 years (1984-2014) the lowest mean monthly temperature recorded in the month of January 1991 is (6.3 $^{0}{}_{c}$), while the highest mean monthly temperature (35.3 $^{0}{}_{c}$) recorded in June 2013. The average monthly temperatures are given in Fig. 3.5.

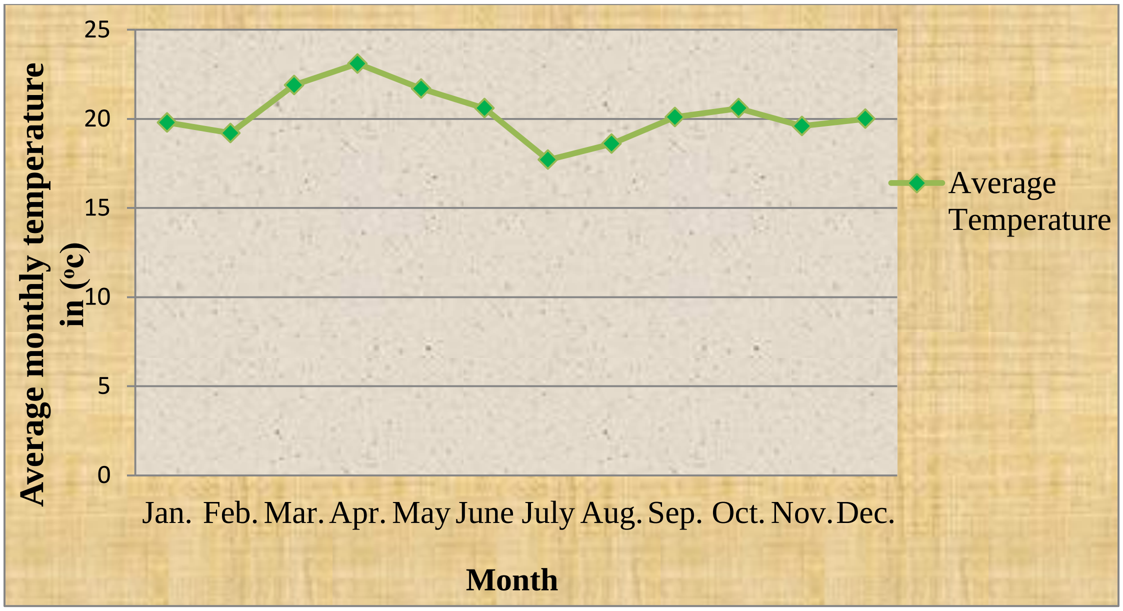


Fig. 3.5. Average monthly total temperature at Bahir Dar town (1984-2014)

3.1.4.3. Winds Direction

The wind frequency percentages data records 2014 from the National Meteorological Agency of Ethiopia, the most frequently encountered winds in Bahir Dar town are the north winds. The least encountered winds in Bahir Dar town are the south and southwest winds.

The daily six time interval of winds direction monthly records at Bahir Dar station for a year of 2014 have been used to compute the number of monthly and annual percentage of winds direction. The computed annual percentage of winds direction is presented in table 3.5.

Table 3.5. Annual percentage of winds direction

Directions	N	NE	E	SE	S	SW	W	NW
Percentage	24.42	16.42	13.42	7.42	4.67	2.67	7.08	8.5

Source: (ENMSA, 2015)

The highest winds direction frequency percentage is 24.42 in north and the lowest winds direction frequency percentage is 2.67 in southwest direction. The percentage wind directions are given in Fig. 3.6.

Fig. 3.6. Annual percentage of winds direction at Bahir Dar town in (2014)

3.1.5. Geology and soil type of the study area

Geology types of the area are Basalts related to volcanic center, Termaber Basalts, Alluvium and Ashangi Basalts. The dominate type of geology in the study area is Basalts related to volcanic center, it covers more than 75 percent, but the remains of geology type in the study area, it covers below 25 percent. The geology and soil data were obtained from minster of water and energy of Ethiopia. The major types of soil in the town are Chromic Luvisols, Haplic Luvisols and Eutric Vertisols that cover more than 97 percent of the total area of the town. The dominant type of soil in the town is Chromic Luvisols; it covers more than 90 percent of the town area. The Chromic Luvisols found in the whole part of the study area. Haplic Luvisols and Eutric Vertisols are found in south eastern and north southern part of the town, respectively. Another soil types in the town are Eutric Regosols, Eutric Leptosols and Lithic Leptosols that covers less than 3 percent of the total area of the town.

3.1.6. Surface water

3.1.6.1. River and streams

The major river in the study area is Abbay River that emanates from Lake Tana. The river flows first to the south and then to the southeast out of the sub basin shortly after leaving the lake, the river reaches the Tiss Abbay falls, thereafter flowing in a deep and rugged gorge. The town has developed on both sides of this main river.

The Part of the surface drainage from the town flows to Abbay River mainly through artificial ditches. Bahir Dar is located on a flat land with poor natural drainage and it also lacks an adequate and properly constructed surface drainage network. Moreover, the existence of shallow depth to groundwater in the area facilitates the saturation of the soil cover. As a result, frequent floods affect the town particularly during the rainy season, and there are many surface water poundings within the town. These swampy areas sometimes cover wide useful urban lands such as those in kebele 15, 16 and kebele 08 (Yewendwesen, 2003).

However, it is possible to upgrade those sites by improving the existing drainage ditches and preparing additional ones, and use them particularly for larger construction projects. In general the study area does not have well defined natural drainage pattern, however, in the eastern and northeastern parts of the town there is relatively well-defined stream channels and sloppy areas. Intermittent streams like Chimble and Amora woniz drains to Lake Tana and Abbay river respectively in this part of the study area. Moreover, significant increase in the gradient of the topography, maximum flow velocity, higher eroding activity and transporting of soil material during rainy season occur in this part of the town. As the area is found within the southern Lake Tana Sub-basin, all the streams either flow into the lake or Abbay River. To words the south and east almost all perennial or intermittent streams found in the study area join Abbay River.

3.1.6.2. Lake Tana

Lake Tana is the largest lake in Ethiopia, consisting half of the freshwater in the country. Lake Tana, which is the source of the Blue Nile River, covers more than 3,600km^2 of the total drainage area of 15, 320 km^2 above the outlet. The Lake is a shallow with maximum depth 14 m and mean depth 8m has a volume of 28 km^3. More than 40 rivers feeding the lake, of which Gilgel-Abay, Ribb, Gumera, Megech, Gelda and infranz contribute more than 95% of the inflow.

The lake level data for the last 21 years (1994-2014) at Bahir Dar gauging station is used in computation of the mean monthly lake levels and the data has been presented in table 3.6.

Table 3.6. Mean monthly Lake Tana levels in (m)

Months	J	F	M	A	M	J	J	A	S	O	N	D	Ann. mean
Lake levels	1.74	1.70	1.69	1.69	1.62	1.60	1.74	1.97	2.36	2.19	2.03	1.85	1.85

Source: (MOWE, 2015)

The lake has a significant effect on the outflow, both in quantity of total annual discharge and in the peak discharge each year. The average annual Lake level is about 1.85m, reaching a low level each year near the end of June and a higher level near the end of September or the beginning of October as shown in (Fig.3.7). The peak outflow to the Abbay River is naturally recorded around the time that the surface level of Lake Tana reaches its maximum.

Lake Tana feeds the Blue Nile, which in turn provides 85 percent of the water supply to Sudan and Egypt through the Nile (Howell and Allan, 1994). It also provides some of the water supply for Bahir Dar, and is a significant source of water supply for the rural population around the Lake. It is, however, also now used as a sink for dumping industrial, municipal and domestic waste from Bahir Dar. Solid waste and effluent discharges from homes, hotels and factories pass untreated into the lake and river. This process of pollution is assisted by the urban runoffs, which are heavy during the rainy season.

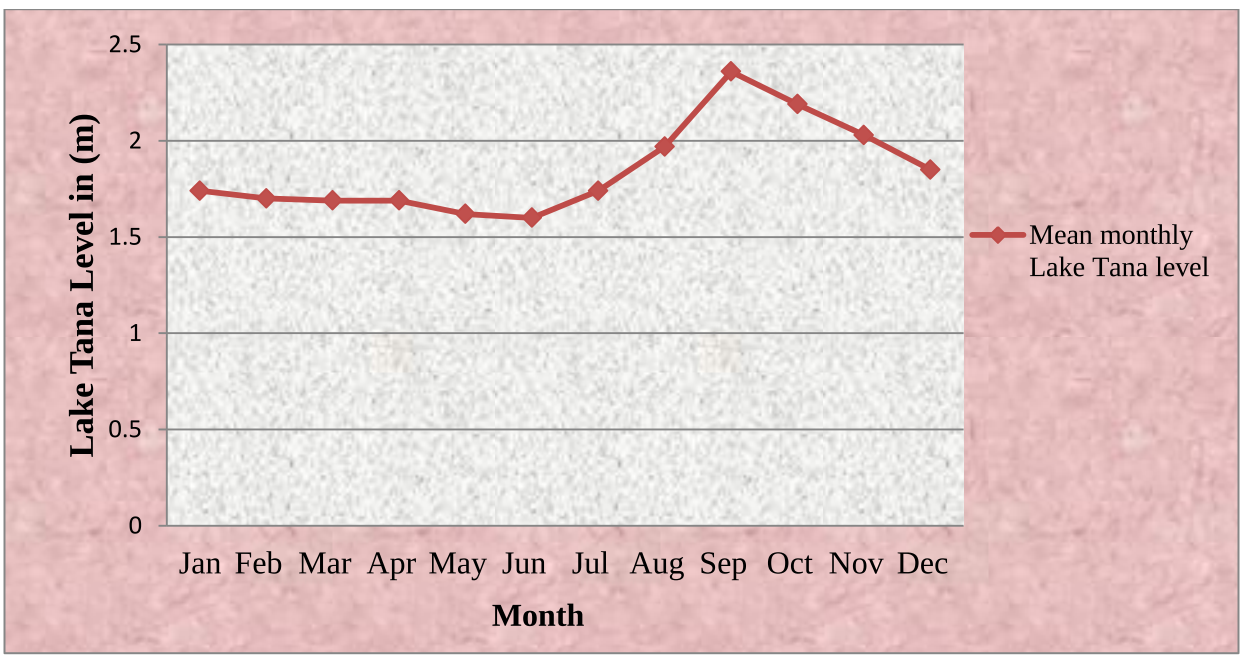


Fig. 3.7. Mean monthly Lake Tana level (1994-2014)

3.2. Method of data collection and source of data

During this research, the main and specific objectives were achieved after using primary and secondary data. The primary data were collected from field survey and observation. Whereas, the secondary data for the study was acquired from governmental institutions, reports, books, journals, internet and other documents. The main data used for this study were land satellite imagery and ASTER GDEM of the town with spatial resolution of 30m, Google earth map and topographical map of the town.

The data used for this study were Landsat8 image of the town with spatial resolution of 30m were used. Landsat 8 image obtained from USGS website, this image already geo-rectified. Landsat 8 images are available for download (http://earthexplorer.usgs.gov) free of charge. So in this study, a set of cloud- free Landsat 8 images covering Bahir Dar town was downloaded from USGS website.

The ASTER GDEM data used in this study is Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model of the town with spatial resolution of 30m was used. ASTER GDEM data used to create the slope, Elevation, Aspect and drainage patterns (river and streams) data layers and their extents through spatial analysis tools. In this study, ASTER GDEM images covering Bahir Dar town was downloaded from USGS website.

Another data were used in this study Groundwater wells, Geological and Soil maps of the study area. Geological and Soil maps were used to create geology and soil layers of the study area. Geology and Soil data were obtained from Ethiopian Minister of Water and Energy, Addis Ababa (Abbay Basin Geology and Soil shape files). The Groundwater wells data was obtained from Amhara Water Well Drilling Enterprise office, Bahir Dar and also the groundwater tables data was obtained from the existing groundwater wells.

In the present study, various thematic maps were prepared by digitizing from land satellite imagery, Google earth and Topographical map of the town. The Lake Tana shoreline was digitized from the study area of landsat 8 images and incorporated in GIS environment. The main road networks of the town were digitized from the study area of Topographical map of the town. The study area of Topographical map of the town was obtained from Ethiopian Mapping Agency (EMA), Addis Ababa. Other data sets of urban and rural settlements area layers were digitized from the study area of Google Earth Map (2015) of the town. The summary of data type, format and source of data are shown in table 3.7.

Table 3.7. Types of Datasets, format and Sources

No.	Types of Datasets	Format	Sources
1	Land use land cover	Raster	Interpretation of Landsat 8 image (2015) from USGS website
2	Slope	Raster	Interpretation of ASTER GDEM image (2015)
3	Soil texture	Vector, Shape file	Minister of Water and Energy, Addis Ababa
4	Geology type	Vector, Shape file	Minister of Water and Energy, Addis Ababa
5	Surface water (river/streams)	Vector, Shape file	Interpretation of ASTER GDEM image (2015)
6	Groundwater wells	Vector, Shape file	Amhara Water Well Drilling Enterprise office, Bahir Dar
7	Groundwater tables	Vector, Shape file	Amhara Water Well Drilling Enterprise office, Bahir Dar
8	Road network	Vector, Shape file	Interpretation the study area of Topographical map from (EMA), Addis Ababa
9	Settlements	Vector, Shape file	Interpretation the study area of Google earth map (2015)
10	Aspect	Raster	Interpretation of ASTER GDEM image (2015)
11	Elevation	Raster	Interpretation of ASTER GDEM image (2015)

3.3. Soft wares used

In this study, three soft wares were used to process the data. Some of the soft wares employed here are ArcGIS10.1, ERDAS Imagine10 and IDRISI32. ArcGIS was used to transferring vector data to raster data. Almost all the maps derived from the raw data were in Shape file vector format. ArcGIS tool was applied throughout the whole process in this study. ERDAS Imagine is a remote sensing application basically used for spatial raster data processing and display. It was used for the satellite image processing and display, while IDRISI32 is specifically used for the weight setting of factor criteria. The relative importance of each factor weight is calculated by the method of pairwise comparison in AHP.

3.4. Methods

In the presented methodology, spatial analysis tools provided by the ArcGIS software has been integrated with the multi-criteria analysis procedure to facilitate wastewater treatment plant siting for the entire study area. The process of wastewater treatment plant site selection employed in this study is shown in (Fig. 3.8).

In this study, there are three stages to locate the best suitability area of wastewater treatment plant. Stage I is identify the WWTP siting criteria related to environmental and economical issues, based on the relevant literatures. Thirteen criteria were identified in this research, including environmental criteria such as land use land cover, surface water (river/streams and lake), settlements, groundwater wells and water tables, geology, soil and wind direction, and economical criteria such as slope, elevation and road networks. While these criteria were divided into two categories of constraint and factor criteria map in stage II. Constraint criteria represent the restricted areas according to the regulations, which prohibit wastewater treatment plant sites from being located within these areas due to possible conflict with the regulations and/or threat to the environment. Factor criteria were used to evaluate the remaining areas for wastewater treatment plant based on their suitability. The factor maps, calculating each criteria weights and consistency ratio using AHP principal of input data based on the related to international literatures, while the constraint maps were used logical unsuitable values (0) or suitable values (1) and then eliminated unsuitable area to analyze further the suitable area. Finally, stage III is accomplish to producing the final suitability map by overlay final potential constraint map with final weighted factor map, which has the wastewater treatment plant site and with little visualization effort and chose better options to propose the optimal location of wastewater treatment plant sites were determined.

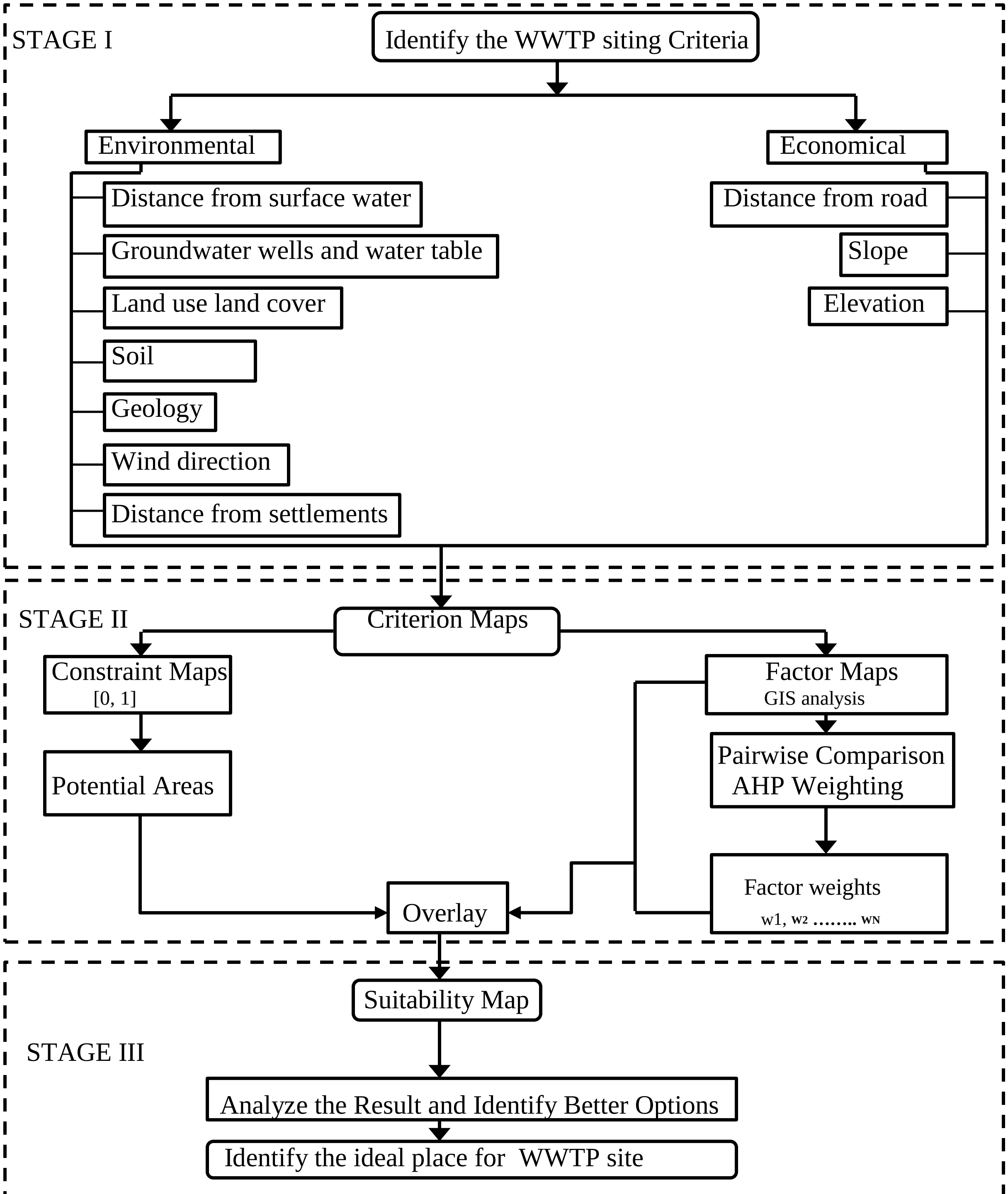


Fig. 3.8. Flow chart of the methodology

3.5. Remote sensing data processing

3.5.1. Image processing

The downloaded Landsat 8 images contain eleven bands and out of these seven bands were used. In order to use these images for the required analysis, they were processed. The first operation was stacking the images. Stacking involves joining the different Landsat image bands to produce one image containing the seven bands. To do this in ERDAS Imagine, the layer stack function was used. After the stacking, there was a need to subset the image which involved the cropping out of a portion of an image for further processing that is the area of study.

3.5.2. Image classification map

Image classification was carried out on the Landsat image to determine the land use of the study area. This was done in ERDAS Imagine by using the classifier function. Image classification was carried out using the manual supervised image classification was used to classify the land use. In a supervised classification, the analyst identifies in the imagery homogeneous representative samples of the different surface cover types (information classes) of interest. The selection of appropriate training areas with the help of visual interpretation elements and the different reflection characteristics of the features in the Landsat 8 image of 2015 and Google earth map and their knowledge of the actual surface cover types present in the image. The image would appear is a common band combination used to evaluate land use. In this image, green (band 3), red (band 4), and near infra-red (5) band are represented by blue, green, and red, respectively. The study area has been classified into six major land use and land cover classes, namely, water body, Agricultural land, built up areas, Barren/grass land, cultivated land and vegetation as shown in fig.3.9.

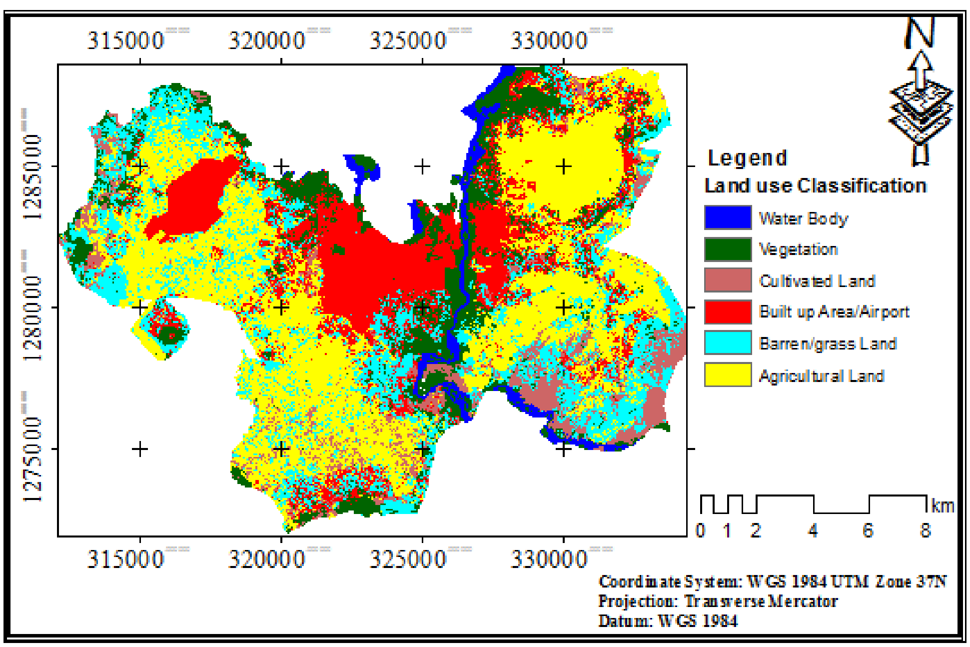


Fig. 3.9. Land use land cover classes Map of Bahir Dar town

3.6. Data analysis

3.6.1. Criteria determination

Locating the optimum location for the wastewater treatment plant site different criteria was determined. For selecting the evaluation criteria the general rule is that they should be recognized with respect to the problem situation (Malczewski, 1999). No universal techniques are available for considering a set of criteria although the desirable properties of objectives can yield guidelines for selecting a set of evaluation criteria (Malczewski, 1999). For a particular decision making problem, the set of evaluation criteria may be developed through an examination of the relevant literature, analytical study and opinions (Malczewski, 1999).

In this research, for locating the optimum wastewater treatment plant site, the constraint and factor criteria were identified according to the international practices, as well as from suitable literature related to the study area, and then based on the evaluation of the major considered sub criteria belongs to the main criteria of environmental and economical issues are shown in table 3.8.

Table 3.8. Criteria considered in this research

Main Criteria	Sub criteria	Way of influence
Environmental	Distance from surface water (river/streams and lake)	Constraint and factor
	Groundwater wells	Constraint and factor
	Groundwater tables	Constraint and factor
	Land use land cover	Constraint and factor
	Distance from settlements (urban residential and rural areas)	Constraint and factor
	Soil texture	factor
	Geology type	factor
	Wind direction	factor
Economical	Distance from road networks	Constraint and factor
	Slope	Constraint and factor
	Elevation	Constraint and factor

3.6.2. Constraint maps criteria setting

Constraint take the form logical maps which contain only the values of either one or zero. The values, corresponding to the condition of the study, represent the suitability or unsuitability of a certain place for the work. The unsuitability areas are locations where due to environmental concerns or public health is rejected for the purpose of wastewater site. To determine these areas, one should enter the collected data into the GIS environment and use geo-processing techniques like buffering, interpolation etc. According to different literatures constraint criterion maps were created for all the nine criteria. Table 3.9 shows the suitable and unsuitable descriptions for different type of constraint data sets in this research work.

Table 3.9. Constraint maps in this research work

Type of Constraint data	0: unsuitable; 1: suitable	References
Surface water	Less than 500m buffer: 0; Greater than 500m buffer: 1	Shahmoradi B, Isalou AA., (2013), Kontos et al., (2005)
Groundwater wells	Less than 500m buffer: 0; Greater than 500m buffer : 1	Gizachew K. & K.V.Suryabhagavan, (2012), Shahmoradi B, Isalou AA., (2013)
Groundwater tables	Less than 5m buffer: 0; Greater than 5m buffer: 1	V.R. Sumathi et al., (2007), EPA (2006)
Main road networks	Between 500m– 5000m buffer: 1; <500m & >5000m buffer: 0	Mansouri et al., (2013), Shahmoradi B, Isalou AA., (2013)
Land use	Built-up area, water bodies: 0;	Ahmad A. et al., (2011), EPA (2006)
Slope	Between 0^0– 20^0 : 1; greater than 20^0: 0	Di Zhao, (2015), Lin & Kao, (2005), Akbari et al., (2008)
Elevation	Between 1705m – 1975m: 1; greater than 1975m buffer: 0	Based on Bahir Dar town DEM data
Urban residential area	Between 1000m – 6000m buffer:1; <1000m & >6000m buffer: 0	Mansouri et al., (2013), Ahmad A. et al., (2011), Isalou et al., (2012)
Rural settlements area	Less than 500m buffer: 0; Greater than 500m buffer : 1	Zorica Srdjevic et al., (2012), Mansouri et al., (2013)

The first step in this analysis is applying the constraint criteria to create a map of the excluded areas. Areas which are excluded from consideration are assigned a value of 0 (unsuitable), while those open for further consideration are assigned a value of 1 (suitable). There were nine criteria identified under this category:

3.6.2.1. Slope constraint map

Too steep of a slope would make it difficult to construct and maintain, while too flat of a slope would affect the runoff drainage. With higher runoff rate and decreased infiltration, contaminants are able to travel greater distances from the containment area. Usually the wastewater treatment plants are needed to be built in a flat area, but this is wastewater treatment plant, it needs a little bit slope for drainage. In this study, 0-20 degrees is the potential slope range for constructing wastewater treatment plant site, as shown in fig. 3.10.

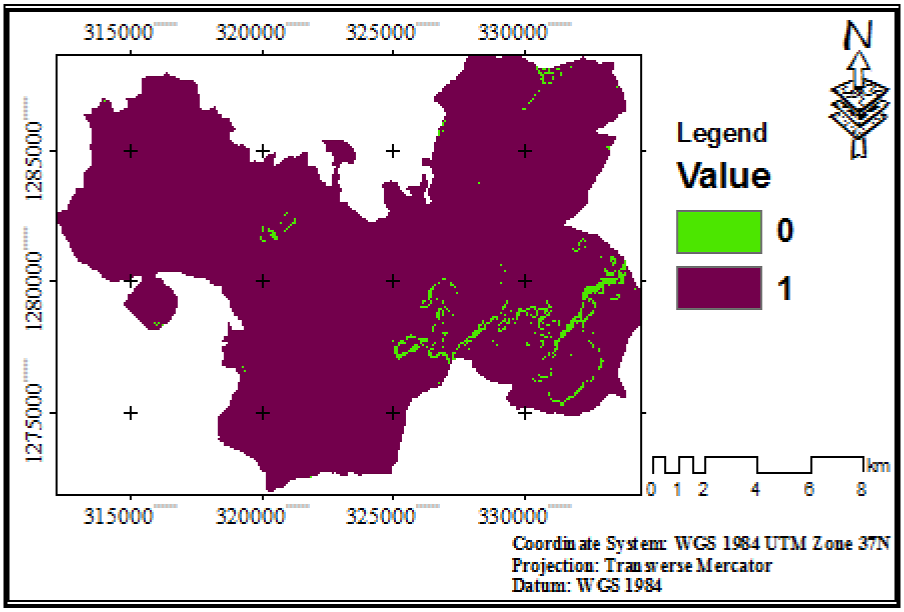
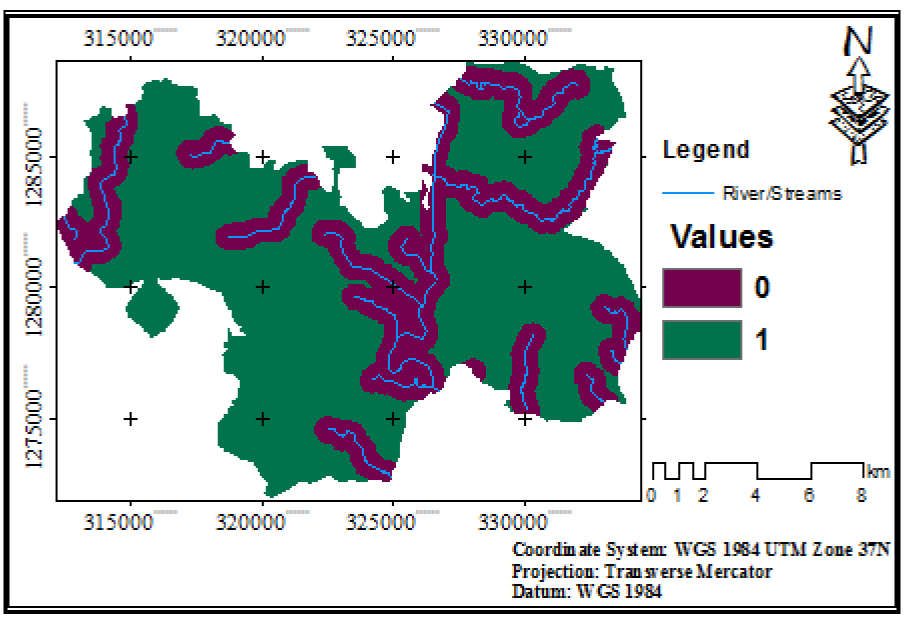


Fig. 3.10. Slope constraint Map

3.6.2.2. Surface water constraint maps

Water pollution is certainly one of the most important issues today and must be addressed accordingly in optimal wastewater treatment plant site selection processes. Pollution of surface water resources by leachate is a principle concern in relation to wastewater treatment plant location. Leachate generated by water passes through waste materials and becomes exposed a range of contaminants. Therefore, locate 500m away from the river/streams and Lake Tana for safety was chosen, as shown in fig. 3.11.

(a)



(b)

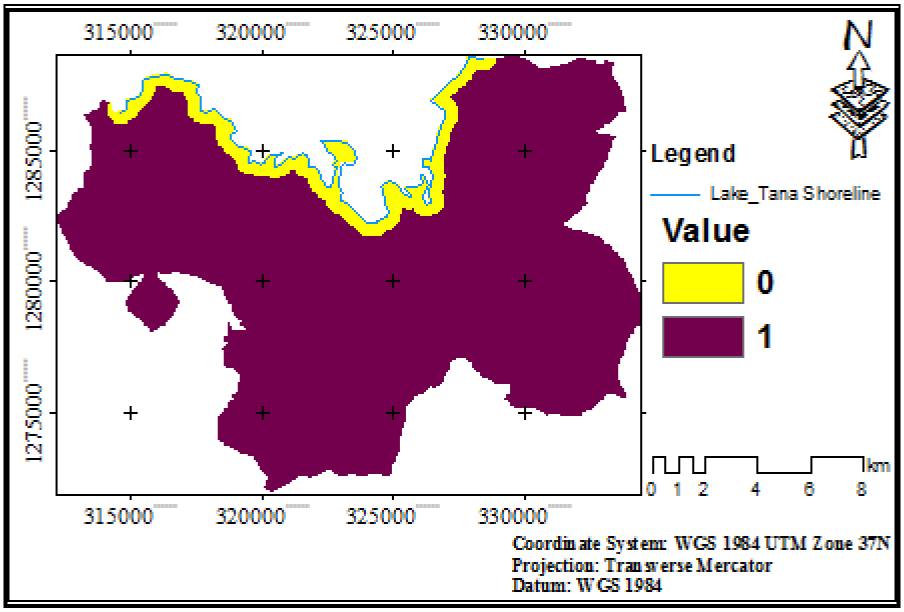
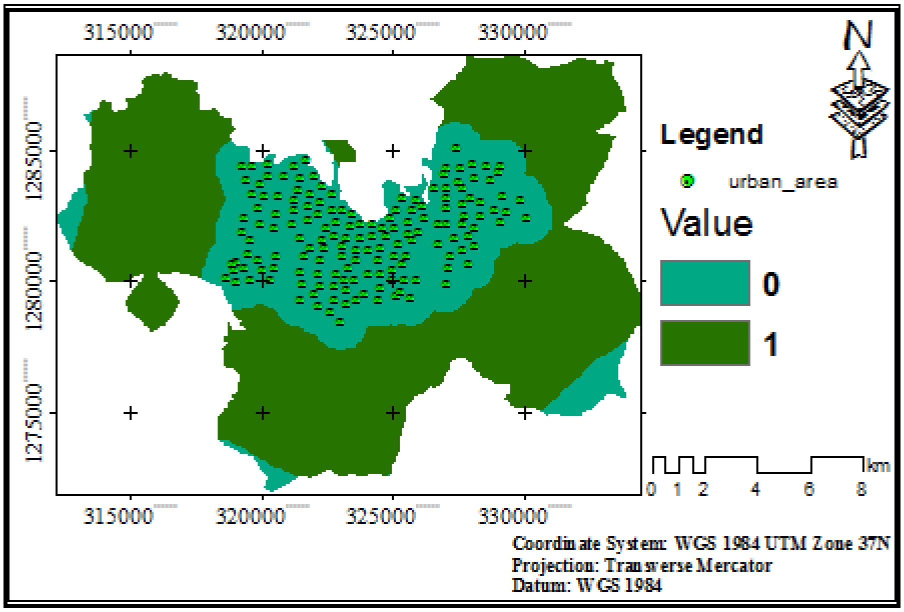


Fig. 3.11. (a) River/streams and (b) Lake Tana surface water constraint Maps

3.6.2.3. Settlements constraint maps

The wastewater treatment plant sites located close to the settlement area cause numerous environmental problems. The establishment of wastewater treatment plant within towns or villages is not suitable due to the unfavorable odor and noise; wastewater discharge areas must not be in the vicinity of the populated urban or rural areas. In the same time, it should not be located too far to avoid extra cost of wastewater treatment plant construction and maintenance. For this criterion proximity distance between 1000m – 6000m for urban settlements area and greater than proximity distance 500m for rural settlements area were chosen, as shown in fig. 3.12.

(a)



(b)

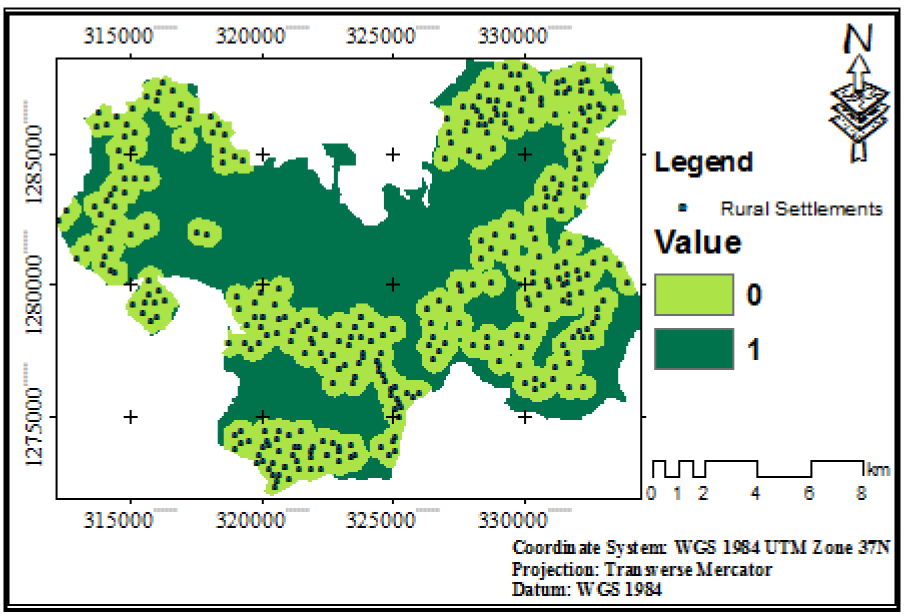


Fig. 3.12. (a) Urban and (b) rural settlements constraint Maps

3.6.2.4. Road networks constraint map

The wastewater treatment plant site should not be placed too far away from existed road networks, to avoid the expensive cost of wastewater treatment plant construction and maintenance; however, the presence of the wastewater treatment plant close to the roads for safety and pollution reasons. For this criterion a proximity distance between 500m – 5000m was chosen, as shown in fig. 3.13.

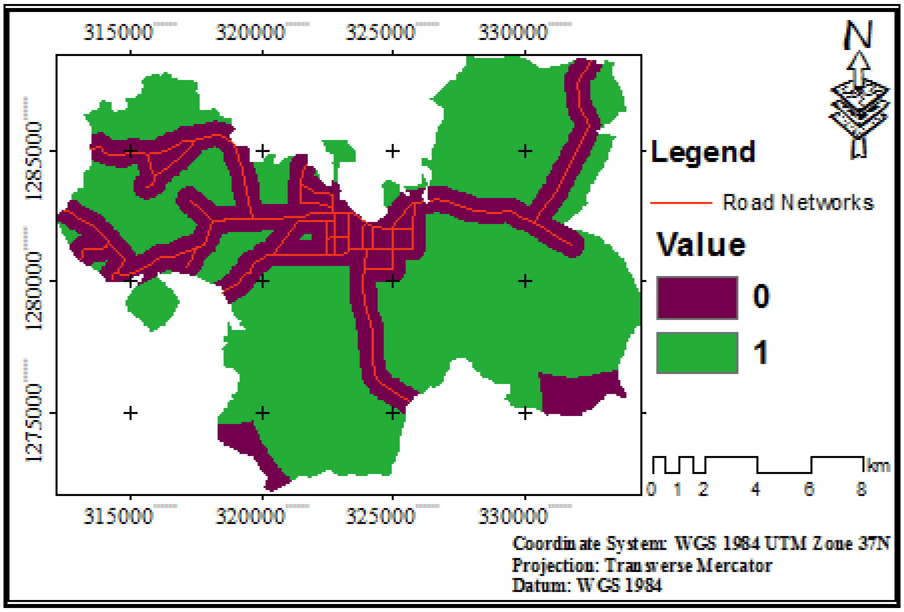


Fig. 3.13. Road networks constraint Map

3.6.2.6. Groundwater wells constraint map

To avoid groundwater wells pollution, the distance of groundwater well was taken into account as an exclusion criterion. As groundwater wells get contaminated from wastewater from water wells, the minimum its effect on the wells; a distance of 500m far from the groundwater wells was considered as unsuitable buffer zone (Gizachew K. and K.V.Suryabhagavan, 2012). In this study, a distance of 500m was considered unsuitable zone for wastewater treatment plant site, as shown in fig. 3.14.

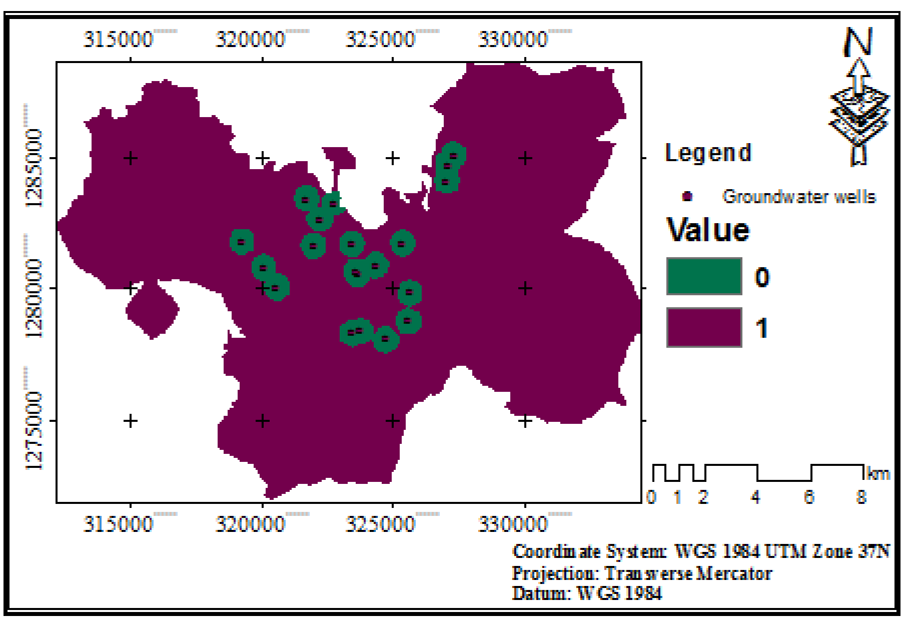


Fig. 3.14. Groundwater wells constraint Map

3.6.2.7. Depth to water tables constraint map

The depth of the groundwater tables plays an important role in determining the contamination risk of groundwater. Considering underground water contamination, depth of water table must be taken in to consideration as a highly effective criterion. According to (V.R. Sumathi et al., 2007), wastewater sites are prohibited in areas with a groundwater depth less than 5 meters. In this study, the depth less than 5m from ground surface is unsuitable (restricted) for constructing wastewater treatment plant site, as shown in fig. 3.15.

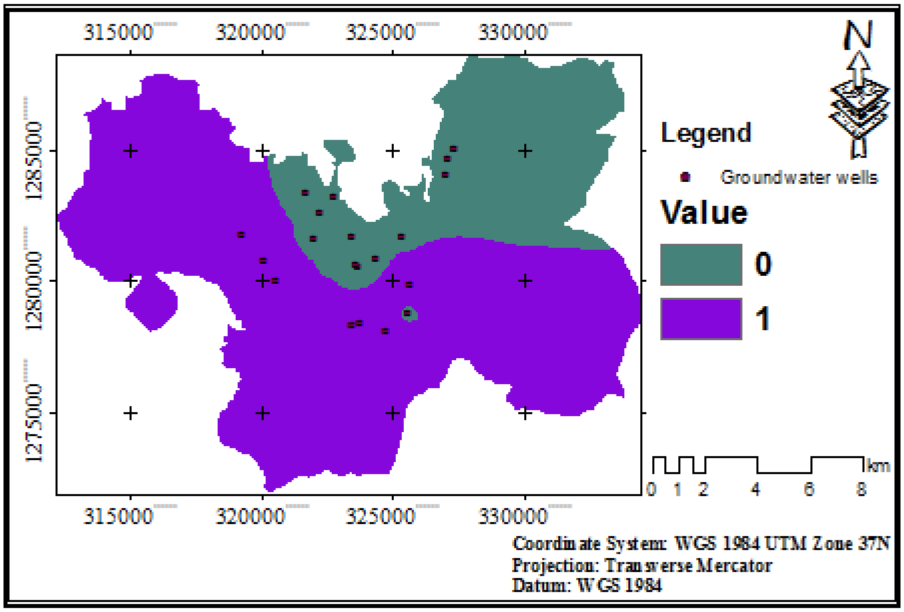


Fig. 3.15. Groundwater tables constraint Map

3.6.2.8. Elevation constraint map

The altitude of study area is between 1705m – 2017m, the wastewater treatment plant site should not be too high becouse its difficult to extract the sewage from the town pipe network. Therefore, the elevation of the site should be lower than that of the lowest parts of the town. In this study, was considered the altitude range between 1705m- 1975m for constructing a wastewater treatment plant site, as shown in fig. 3.16.

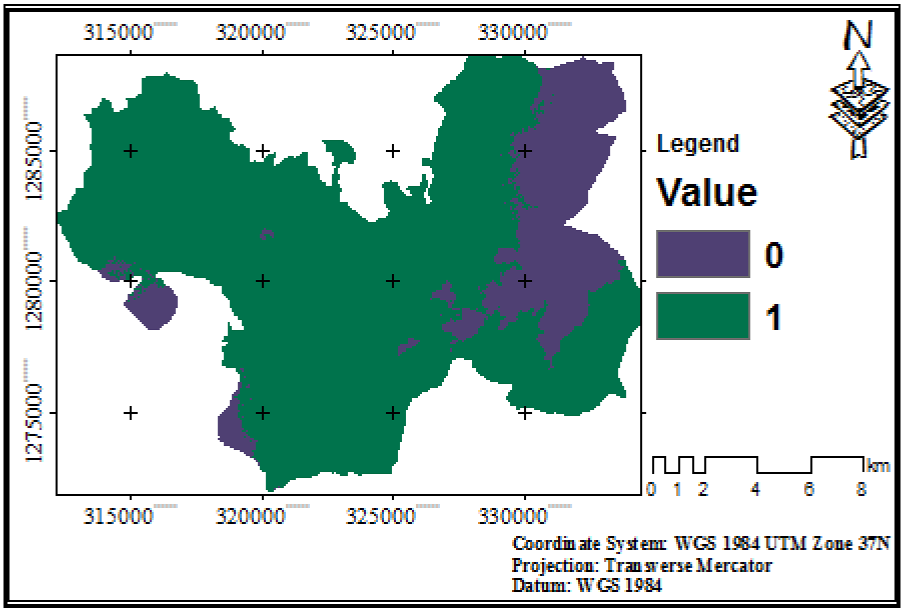


Fig. 3.16. Elevation constraint Map

3.6.3. Factor maps criteria setting

At this stage, factor criteria were used to further evaluate these sites according to their suitability in order to indicate the most preferable site for locating wastewater treatment plant. This is done through two steps of weighting process. In the first step, each factor was internally weighted based on the minimum and maximum distances and/or requirement. In the second step, each factor was externally weighted based on how critical and important the factor is to the wastewater site problem. The suitability for locating the optimal wastewater treatment plant site, the factor should be classified into classes unsuitable for wastewater treatment plant siting to high suitable for wastewater treatment plant siting (as shown in table 3.10). The suitability of each factor maps was both internally weighted based on their direct distance to features and environmental judgment and externally weighted using AHP, based on the relative importance of the criterion.

3.6.3.1. Determination of internal weight

In this part, each factor is studied individually. The locations of each factor can take a weight between zero and nine, based on their direct distance to the features, implementation as related to literatures based. As an example, considering the road networks, the locations are weighted based on their distance from the existing road networks. The distance should not be so far that to avoid extra cost of wastewater treatment plant construction and maintenance becomes a problem and close to the roads affects the public health. Hence, the locations that are close to the roads and far away from the roads have a higher weight than too close and too far away from the road networks. Similarly, from the geological and soil aspects, the highest weight is given to low permeability. For the surface water (river/ streams and lake), groundwater wells and groundwater tables, for example, the locations which are far from them have higher weight and vice versa.

For settlements, the locations are weighted based on their distance to the centers. The distance should not be so far that to avoid extra cost of wastewater treatment plant construction and maintenance becomes a problem and not so close that it provides an unpleasant appearance to the sightseeing, parks, and recreational facilities, which are mostly in the vicinity of towns. For urban and rural centers, the highest weight is given to locations that are far from the settlements than too close the settlements. In respect of slope, the highest weight is given to the slopes between 0^0 and 10^0 and the lowest weight is given to the slope greater than 20^0. Because due to the fact that difficulty to construct and maintain with slopes over 20^0. Table 3.10 shows the class and buffer zone were assigned to any sub criterion based on the relevant international literatures.

Table 3.10. Summary of main criteria, sub criteria, class/buffer zone, weights and their level of suitability used in selection of wastewater treatment plant site

Main criteria	Sub Criteria	Class/ buffer zone	Ranking	Level of suitability
Environmental	Land use land cover	Water bodies, Airport, Built up area	1	Unsuitable
		Agriculture & cultivated land	2	Very low suitable
		Vegetation	4	Moderate suitable
		Barren/grass land	5	High suitable
	Distance from river/streams	0-500m	1	Unsuitable
		500-1000m	2	Very low suitable
		1000-1500m	3	Low suitable
		1500-2000m	4	Moderate suitable
		>2000m	5	High suitable
	Distance from Lake Tana	0-500m	1	Unsuitable
		500-1000m	2	Very low suitable
		1000-1500m	3	Low suitable
		1500-2000m	4	Moderate suitable
		>2000m	5	High suitable
	Distance from Groundwater wells	0-500m	1	Unsuitable
		500-1000m	2	Very low suitable
		1000-1500m	3	Low suitable
		1500-2000m	4	Moderate suitable
		>2000m	5	High suitable

Table 3.10. Continued

	Groundwater tables	0-5m	1	Unsuitable
		5-8m	2	Very low suitable
		8-12m	3	Low suitable
		12-15m	4	Moderate suitable
		>15m	5	High suitable
	Distance from Urban areas	0-1000m & >6000m	1	Unsuitable
		1000-2000m	2	Very low suitable
		2000-3000m	3	Low suitable
		3000-4000m	4	Moderate suitable
		4000-6000m	5	High suitable
	Distance from rural areas	0-500m	1	Unsuitable
		500-1000m	2	Very low suitable
		1000-1500m	3	Low suitable
		1500-2000m	4	Moderate suitable
		>2000m	5	High suitable
	Aspect	N, NE, flat	2	Very low suitable
		NW, E	3	Low suitable
		W, SE	4	Moderate suitable
		S, SW	5	High suitable
	Geology type	Alluvium	2	Very low suitable
		Tarmaber Basalt	3	Low suitable
		Volcanic	4	Moderate suitable
		Ashangi Basalt	5	High suitable
	Soil type	Lithic & Euric leptosols	2	Very low suitable
		Euric Regosols	3	Low suitable
		Chromic & Haplic luvisols	4	Moderate suitable
		Eutric vertisols	5	High suitable
Economical	Distance from Road networks	0-500m & >5000m	1	Unsuitable
		500-1000m	5	High suitable
		1000-1500m	4	Moderate suitable
		1500-3000m	3	Low suitable
		3000-5000m	2	Very low suitable
	Slope	0^0 - 10^0	5	High suitable
		10^0 - 15^0	4	Moderate suitable
		15^0 - 20^0	3	Low suitable
		>20^0	1	Unsuitable
	Elevation	1705-1750m	2	Very low suitable
		1750-1850m	5	High suitable
		1850-1900m	4	Moderate suitable
		1900-1975m	3	Low suitable
		1975-2017m	1	Unsuitable

3.6.3.2. Determination of weight using AHP method

In the previous subsection the locations are weighted within each factor internally. However, it is obvious that the factors themselves do not have equal weight for the problem in hand. To obtain the external weights, the method described by analytical hierarchy process (AHP) (Saaty, 1980) was used. In this step, all identified factors were compared against each other in a pair wise comparison matrix which is a measure of relative importance among the factors as numerical values. The scale for comparison consists of values ranging from 1 to 9 which describe the intensity of importance, by which a value of 1 expresses equal importance and a value of 9 is given to those factors having an extreme importance over another factor as shown in table 3.11.

Table 3.11. Pair-wise comparison values for AHP (*Adopted* from Saaty, 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4,6,8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity I has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

A table 3.13, 3.14 and 3.15 shows the pair wise comparison matrix of environmental and economical main criteria, environmental sub criteria and economical sub criteria respectively. After sub criteria accounting in each two environmental and economical groups, their final weight are computed via multiplying obtained sub criteria weight by the related criteria weight, as shown in table 3.16.

Table 3.13. Main criteria pairwise comparison matrix

Criteria	Environmental	Economical	Weights
Environmental	1	3	0.75
Economical	1/3	1	0.25

Table 3.14. Economical criteria pairwise comparison matrix

Criteria	1	2	3	Weights
(1) Road Networks	1	1/3	1/5	0.109
(2) Elevation	3	1	½	0.309
(3) Slope	5	2	1	0.582

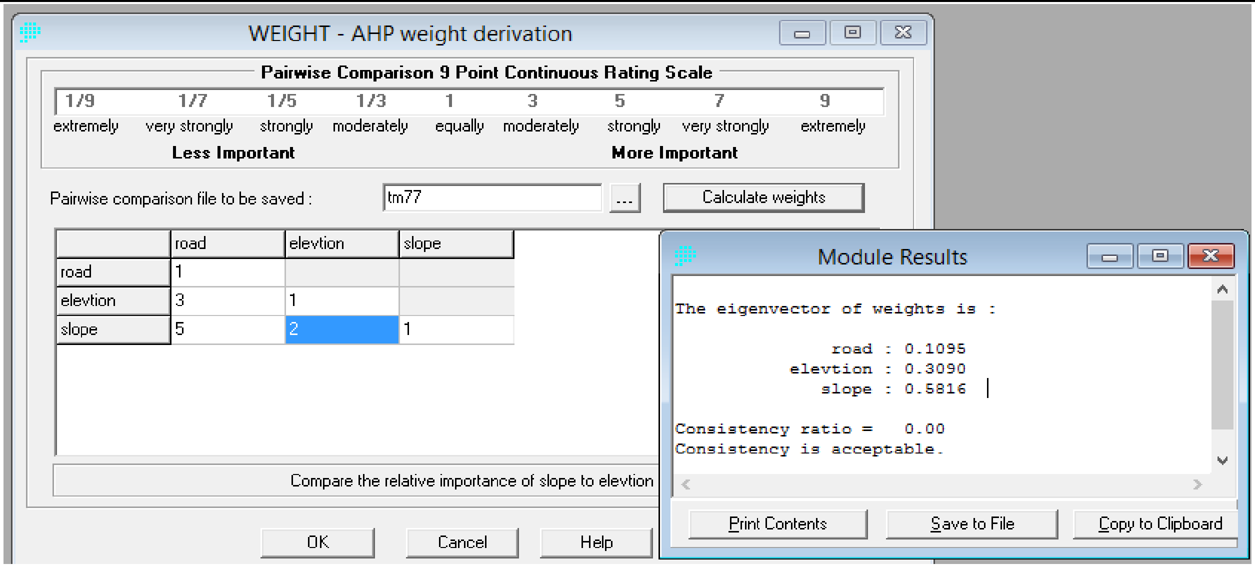
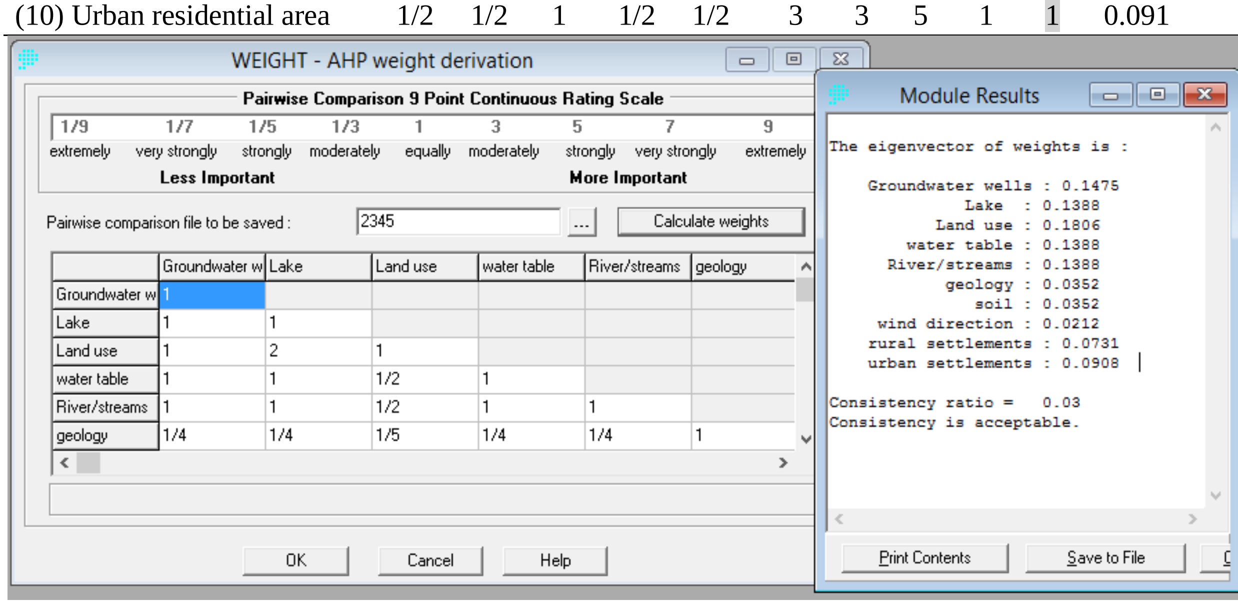


Table 3.15. Environmental criteria pairwise comparison matrix

Criteria	1	2	3	4	5	6	7	8	9	10	Weights
(1) Ground water wells	1	1	1/2	1	1	4	4	5	3	2	0.138
(2) Lake	1	1	1/2	1	1	4	4	5	3	2	0.138
(3) Land use land cover	2	2	1	2	2	5	5	6	2	1	0.193
(4) Ground water table	1	1	1/2	1	1	4	4	5	3	2	0.138
(5) River/streams	1	1	1/2	1	1	4	4	5	3	2	0.138
(6) Geology type	1/4	1/4	1/5	1/4	1/4	1	1	3	1/3	1/3	0.035
(7) Soil texture	1/4	1/4	1/5	1/4	1/4	1	1	3	1/3	1/3	0.035
(8) Wind direction	1/5	1/5	1/6	1/5	1/5	1/3	1/3	1	1/5	1/5	0.021
(9) Rural settlement area	1/3	1/3	1/2	1/3	1/3	3	3	5	1	1	0.073
(10) Urban residential area	1/2	1/2	1	1/2	1/2	3	3	5	1	1	0.091



According to the AHP calculations, the weight of the environmental criteria was 0.75, and the weight of the economic criteria was 0.25, suggesting that environmental criteria were more influential than to economical criteria for wastewater treatment plant site selection. Table 3.14 shows the highest weight was assigned to the slope criterion in the economic criteria because the finding of the study focuses on to economical suitable, as obstacles related to slope can be overcome with cost of excavation, fill and the maintenances. Table 3.15, shows the highest weight was assigned to the land use land cover criterion in the environmental because the finding of the study focuses on to environmental suitable, as it is considering future urban development and to protect human being from environmental hazards for the area. All of considered main and their sub criteria weight were summarized in table 3.16.

Table 3.16. Final weights of main criteria and sub criteria used in treatment plant site selection

Objective	Main criteria	weight	sub criteria	weight	CR	∑Weight
Suitability of WWTP site	Environmental	0.75	Land use land cover	0.193	0.03	0.14
			River/streams in (m)	0.138		0.10
			Lake Tana in (m)	0.138		0.10
			Groundwater wells in (m)	0.138		0.10
			Groundwater tables in (m)	0.138		0.10
			Urban residential area in (m)	0.091		0.07
			Rural settlement area in (m)	0.073		0.05
			Soil texture	0.035		0.03
			Geology type	0.035		0.03
			Wind direction	0.021		0.02
	Economical	0.25	Slope in (degree)	0.582	0.00	0.15
			Elevation in (m)	0.309		0.08
			Road networks in (m)	0.109		0.03

(Note: CR is consistency ratio)

3.7. GIS-based MCA model

In this study, the GIS-based MCA model builder can be includes three phase. Phase one is to combine the constraint maps to get a final constraint map. Phase two is to combine the weighted factor maps to get a final weighted factor map. The final result is a combination of final constraint map and final weighted factor map to get a suitability map of wastewater treatment plant. As for the final weighted factor map is a weighted linear combination of factor maps, an equation (1) as following:

$S = \Sigma\, wi\, xi$ where, S = suitability, wi = weight of factor i and xi = factor map i. (1)

As for the Boolean overlay operations, the equation for generating the final constraint map is shown as equation (2) below:

$$C = \Pi\, cj \quad \text{where, } cj = \text{constraint map } j,\ \Pi = \text{product} \tag{2}$$

The suitability map is derived by multiplying the overall weighted factor map and overall constraint map, as follows equation (3).

$$S = \sum_{i=1}^{N} wixi \text{ x } \Pi cj \tag{3}$$

Where, S is the suitability to the wastewater treatment plant location, xi is the factor map i, wi is the weights assigned to each factor and N is the number of factors. After the final factor map and final constraint map are generated, the GIS-based MCA process can produce the final suitability map by overlay final constraint map with final weighted factor map. Fig. 3.17 shows GIS-based MCA model, which C_map means constraint map and F_map means factor map.

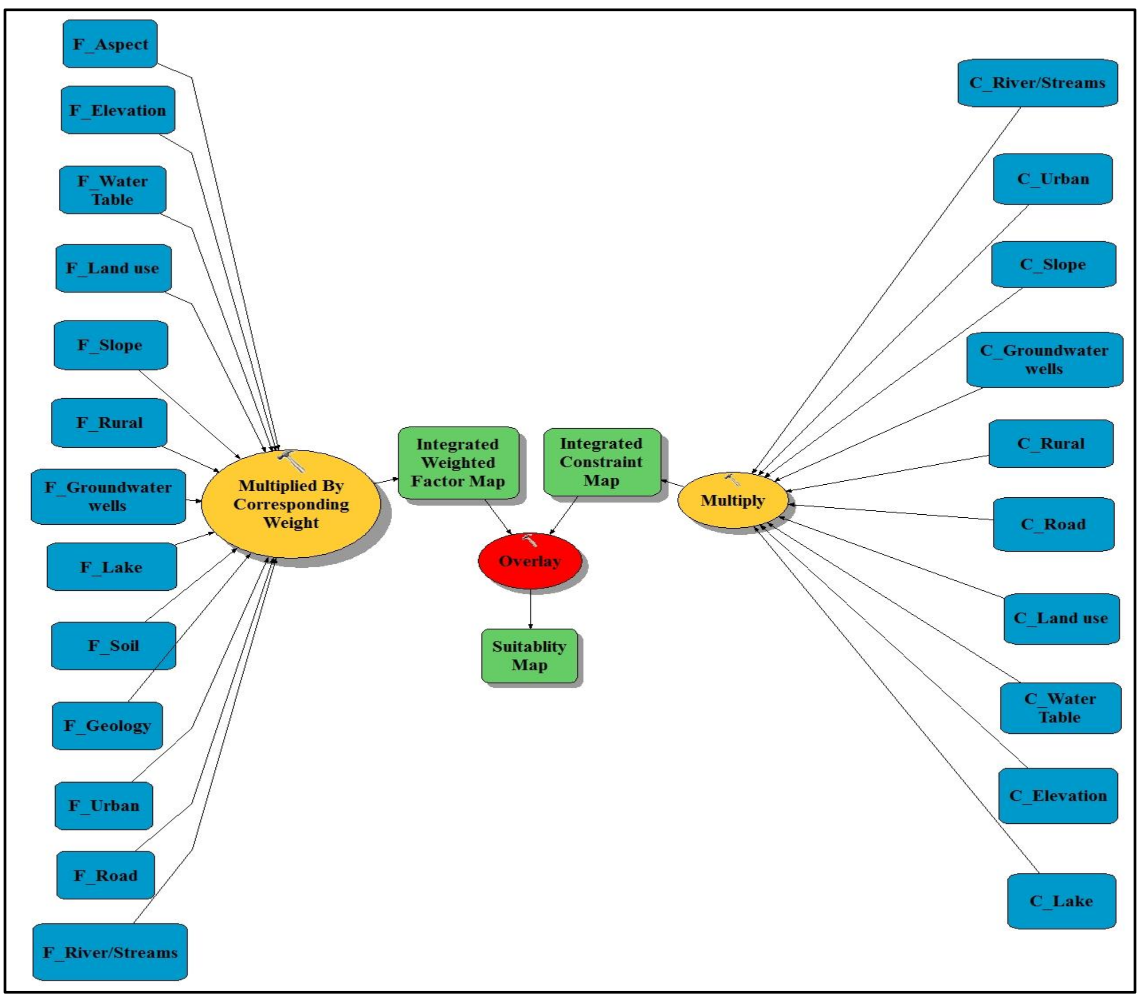


Fig.3.17. Flow chart of wastewater treatment plant GIS –based MCA model builder

4. RESULTS AND DISCUSSION

4.1. Suitability determination

This section presents and discusses the results of findings suitability determination for factor maps required as criteria for wastewater treatment plant site suitability analysis. In this study, thirteen factors were considered as environmental and economical criteria. These factors suitability determination have been selected according to their international standards extracted from various related literatures. Each factor is explained in detail below. These explanations include how each was evaluated, mapped, and weighted. The criterion was weighted by AHP and mapped using GIS techniques.

4.1.1. Environmental criteria suitability analysis

In this study, consider the environmental criteria land use land cover, surface water (river/streams & lake), groundwater wells, groundwater table, settlements (urban and rural), geology type, soil texture and wind direction.

4.1.1.1. Land use land cover map

The land use is considered an environmental factor in construction of wastewater treatment plant site. In the present study land use/land cover was analyzed from Landsat 8 image data for the wastewater treatment plant site selection. In the study area, there are six major land uses such as water body, built-up area and airport, agricultural land area, cultivated land, vegetation and barren/grass land areas. By reviewing different literature, it was advisable to select land, which was occupied by bare and grass lands suitable for wastewater treatment plant site. Land use types were grouped and ranked according to their suitability for wastewater treatment plant site as unsuitable, very low suitable, moderate suitable and high suitable for wastewater treatment plant site location by assigned a ranking values of 1, 2, 4 and 5 respectively, (see table 3.10 and fig. 4.1). A weighting value of 0.14 was computed by AHP method this factor.

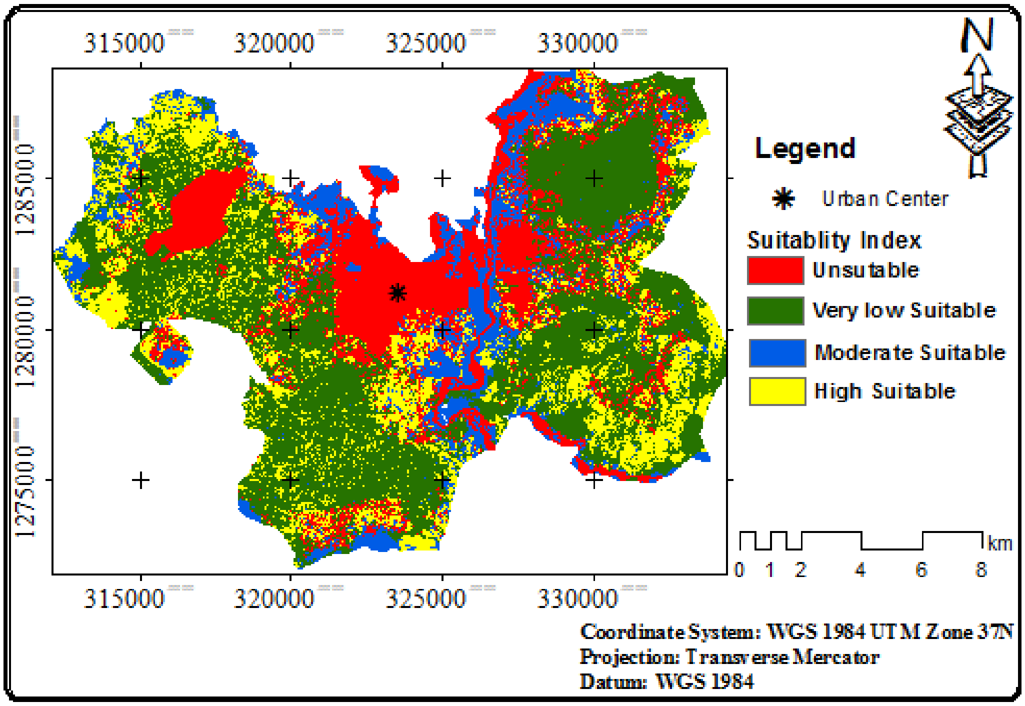
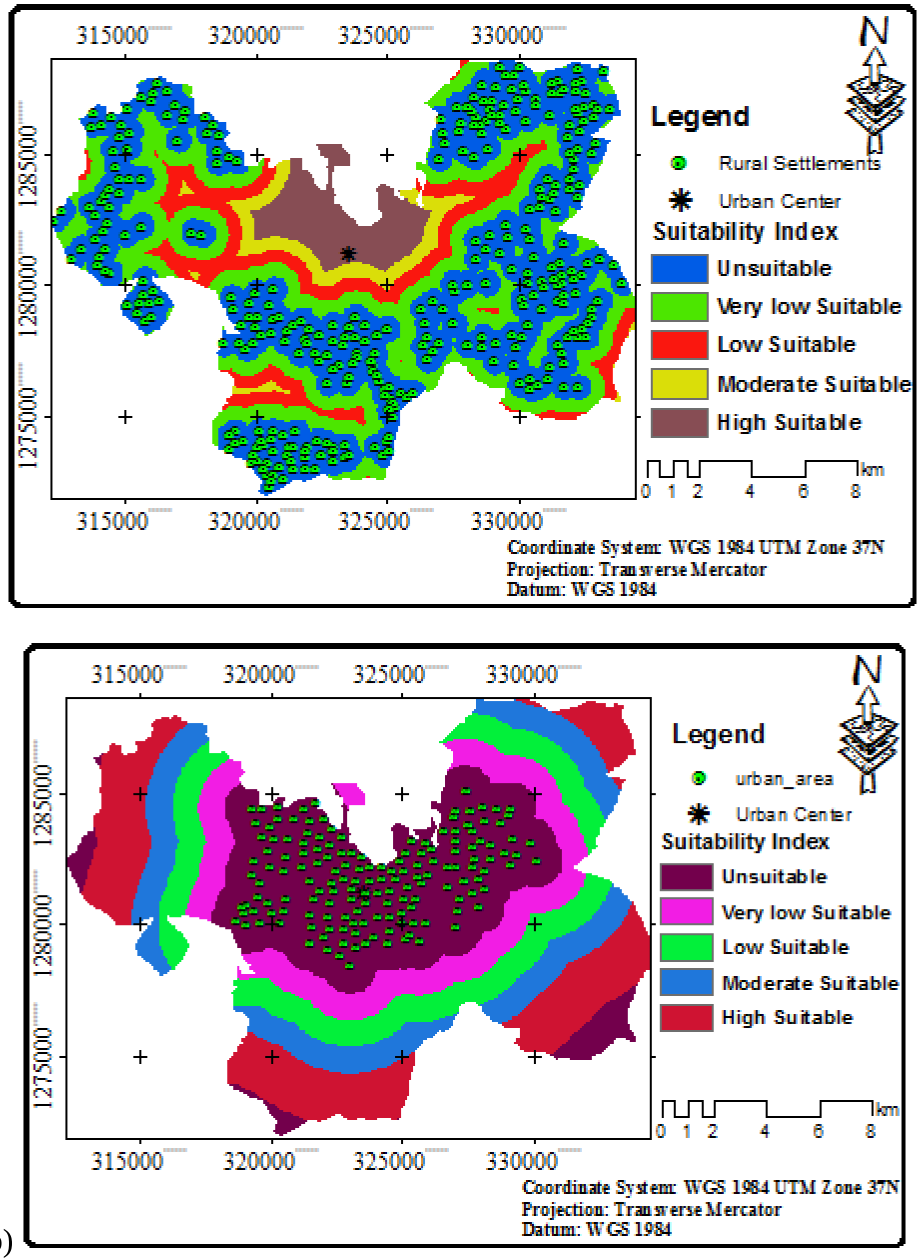


Fig. 4.1. Land use land cover factor Map

4.1.1.2. Distance from settlements

Wastewater treatment plants should not be located very close to urban residential and rural areas in order to protect the public from the nuisance and health impacts due to the potential hazards from wastewater. In the same time, it should not be located too far to avoid extra cost of wastewater treatment plant construction and maintenance. According to international literatures (Ahmad A. et al., (2011); Isalou et al., (2012); Sehnaz S. et al., (2011)), wastewater site at a distance less than 1000m from urban area are not allowed. In this study, the safe distances from settlements are determined as 6000m for urban centers and 2000m for rural villages. Like other criteria, settlement areas were classified according to their suitability. The study considered the reclassified distances as unsuitable from 0 to 1000m and greater than 6000m, very low suitable between 1000 and 2000m, low suitable from 2000 to 3000m, moderate suitable between 3000 and 4000m and high suitable from 4000 to 6000m for the urban areas. And for rural settlement according to Zorica Srdjevic et al., (2012), 2000m were put as criteria around the rural settlement. This distance was reclassified as unsuitable, 0 to 500m, very low suitable, 500-1000m, low suitable from 1000 to 1500m, moderate suitable from 1500-2000m and a high suitable area greater than from 2000m for wastewater treatment plant site (see table 3.10 and fig. 4.2). A weighting value of 0.07 and 0.05 were computed by AHP method for urban and rural settlements criteria respectively.

(a)



(b)

Fig. 4.2. (a) rural and (b) urban settlements factor Maps

4.1.1.3. Distance from groundwater wells

A total of 21 points ground water wells, data were obtained from Amhara Water Well Drilling Enterprise Office (AWWDEO), Bahir Dar. Proximity of wastewater treatment plant site to a groundwater well is one of the most important environmental criteria in the wastewater treatment plant suitability site selection. It helps in protecting groundwater wells from contamination of wastewater. There is no specific criterion of what is the best distance to locate the wastewater treatment plant site away from groundwater wells. For example (Shahmoradi B. and Isalou AA., 2013) suggested that the wastewater treatment plant sites should be located 500m far from the groundwater wells. In this study, reclassified distance less than 500m from groundwater wells are unsuitable, distance from 500m to 1000m, distance from 1000m to 1500m and distance from 1500m to 2000m are very low suitable, low suitable and moderately suitable respectively and distance more than 2000m is highly suitable for wastewater treatment plant site in the study area (see table 3.10 and fig. 4.3). This factor a weighting value of 0.10 was computed by AHP method to increase its importance of protecting the Groundwater from pollution.

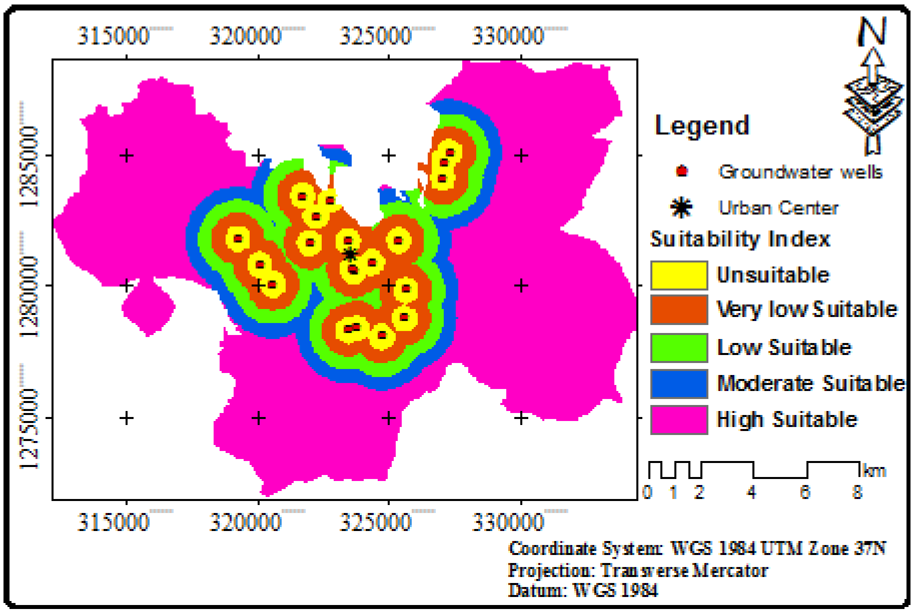


Fig. 4.3. Groundwater wells factor Map

4.1.1.4. Distance from surface water

Generally, wastewater discharge areas must not be sited near rivers, lakes, streams, ponds or swamps. According to Amhara National Regional State has established the Regional Hygiene and Environmental Executive Committee which has issued regional environmental sanitation regulations (No.16/2000), it is clearly states that not discharge wastewater to any water surface be it river, stream, lake and the like is forbidden. In the study area, Abbay River and Lake Tana are the main surface water. Researchers have suggested a distance up to 500m away from surface water (Kontos et al., 2005). The present study, Distance less than 500m from river/streams and lake are unsuitable, distance from 500m to 1000m, distance from 1000m to 1500m and distance from 1500m to 2000m are very low suitable, low suitable and moderately suitable respectively and distance more than 2000m is highly suitable for wastewater treatment plant site in the study area (see table 3.10 and fig. 4.4). A weighting value of 0.10 was computed by AHP method both river/streams and lake factors.

(a)

(b)

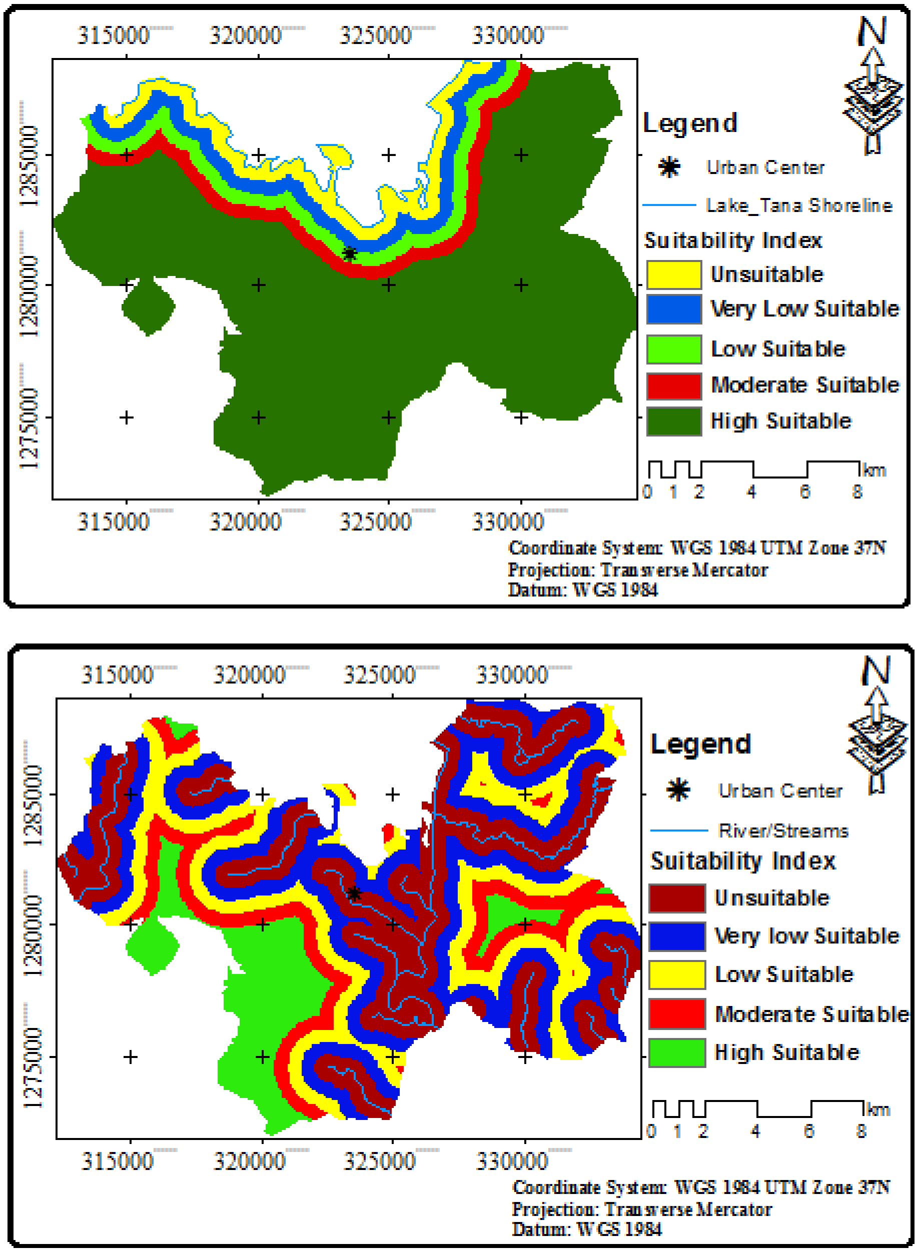


Fig. 4.4. (a) Lake Tana and (b) River/streams surface water factor Maps

4.1.1.5. Depth to water table

The water level data, which obtained from existing wells in the study area provided by the Amhara Water Well Drilling Enterprise office, Bahir Dar, as conducted and the interpolation was performed. The depth to water table was determined using the inverse distance weighting (IDW) interpolation of the water level data, to distinguish deep water table areas from shallow water tables areas. The depth of groundwater table is a significant parameter in determining the contamination risk of groundwater in order to limit potential contamination. The precipitation, site topography and soil type affects the rate of infiltration into the water table (Udomporn et al., 2009). In the study area, Most of the available water table data depths less than 5m. Areas with groundwater depth less than 5m from the ground surface were considered unsuitable for siting wastewater treatment plant. Based on the analysis, By increasing groundwater depth from 5 to 15 m, the suitability increases and the areas with depths of more than 15 m were considered high suitable. This means the travel time of wastewater leachate is very long in order to reach the water table. In this study, interpolation depth of <5m from the ground surface, was assigned a ranking value of 1, to prevent contamination from wastewater leachates, whereas a ranking value of 5 was assigned to depth of >15 m (see table 3.10 and fig. 4.5). This factor a weighting value of 0.10 was computed by AHP method.

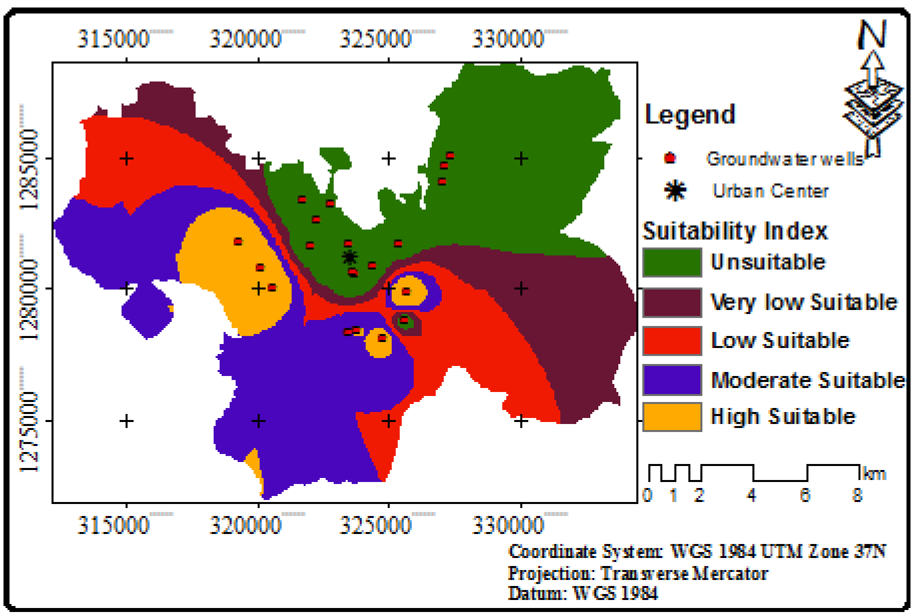


Fig. 4.5. Groundwater tables factor Map

4.1.1.6. Soil texture

There were six type of soils texture in the study area based on FAO (2000) method such as eutric vertisols, chromic luvisols, haplic luvisols, eutric regosols, lithic Leptosols and eutric leposols. Soil should be of sufficiently low permeability to significantly slow the passage of leachate from the site. Soil characteristics of textures were considered. Clay textured soil was most preferred for wastewater treatment plant as it is impermeable to leachate. Thus, sites in clay-rich environments are most preferable. The higher the permeability of the textured unit, the lower is the site suitability for wastewater treatment plant practices and the higher is its vulnerability. In the present study, soil texture was classified into four zones according to the texture unit of permeability characteristics; soils having high rate of permeability zone (lithic Leptosols and eutric leposols) are considered very low suitable for being used as wastewater treatment plant, while soils having medium rate of permeability zone (eutric regosols), low permeability rate of zone (chromic luvisols and haplic luvisols) and very low permeability rate of zone (eutric vertisols) were considered low, moderate and high suitable respectively (see table 3.10 and fig. 4.6). A weighting value of 0.03 was computed by AHP method for this factor.

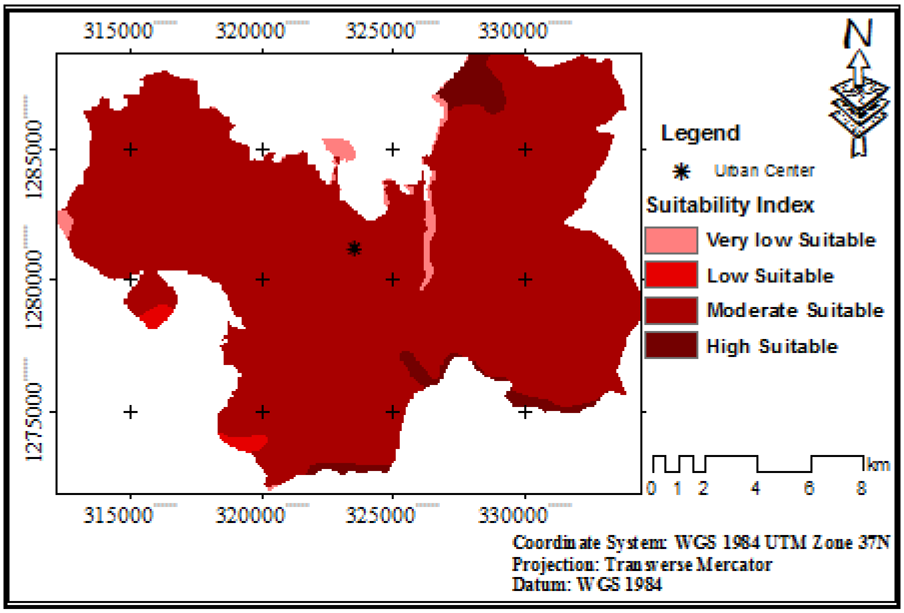


Fig. 4.6. Soil factor Map

4.1.1.7. Geology type

The geological map of the study area was extracted from geology map using ArcGIS software and the vector format of the soil data converted to raster format. On incorporating the nature of rocks, degree of weathering, permeability and extent of fractures the town area was reclassified into four wastewater treatments plant suitability classes area consisting of Alluvium, Tarmaber basalts, Basalts related to volcanic center (2) and (3) and Ashangi basalts. Alluvium deposit has high potential for water adsorption and is a very low suitable for wastewater treatment plant site. Tarmaber basalts are high permeability are thus the low suitable lithological units for wastewater treatment plant site. Basalts related to volcanic center (2) and (3) are low permeability and has limited water adsorption potential. Ashangi basalts are a very low permeability and are thus the high suitable lithologic units for wastewater treatment plant site (see table 3.10 and fig. 4.7). A weighting value of 0.03 was computed by AHP method for this factor.

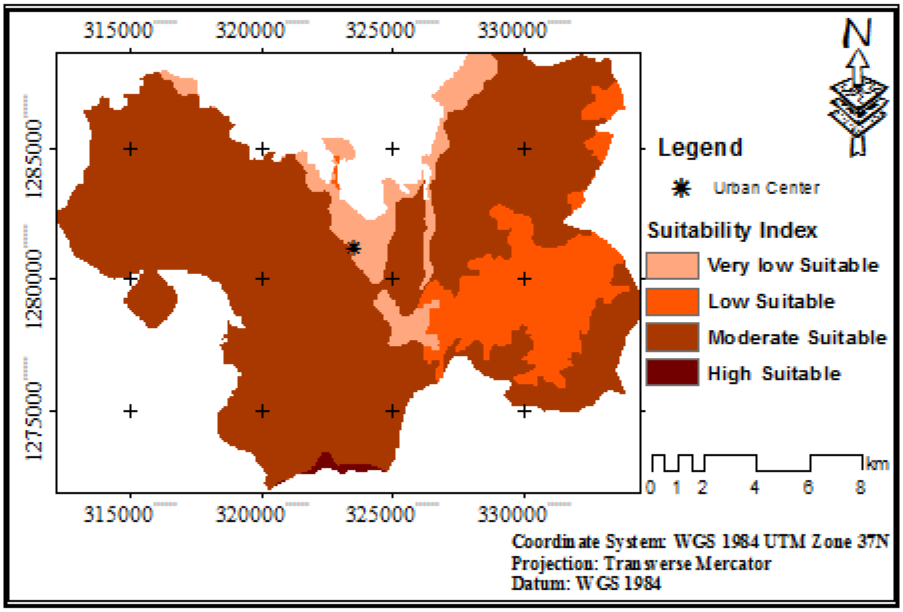


Fig. 4.7. Geology factor Map

4.1.1.8. Wind direction map

The wind direction is not known to be subject to any legal restrictions. But based on the premise that wastewater treatment plant site should not be in the direction of the wind. It is also an established fact that the direction of winds vary with altitude, slope and terrain roughness. To evaluate the wind direction of the study area, an aspect map was prepared using a digital elevation model with a 30x30m resolution. The site wind direction frequency of the study area was taking into consideration. The wind frequency percentages data were obtained from the National Meteorological Agency of Ethiopia (2014), the least frequently encountered winds in Bahir Dar town were the S and SW winds. But from the records Meteorological Agency, the N and NE wind is the dominant wind in the study area. Hence, the locations of N and NE areas are unsuitable, because they are more exposed to the wind and also the flat areas unsuitable, because these areas are susceptible to wind from all directions (see table 3.10 and fig. 4.8). A weighting value of 0.02 was computed by AHP method for this factor.

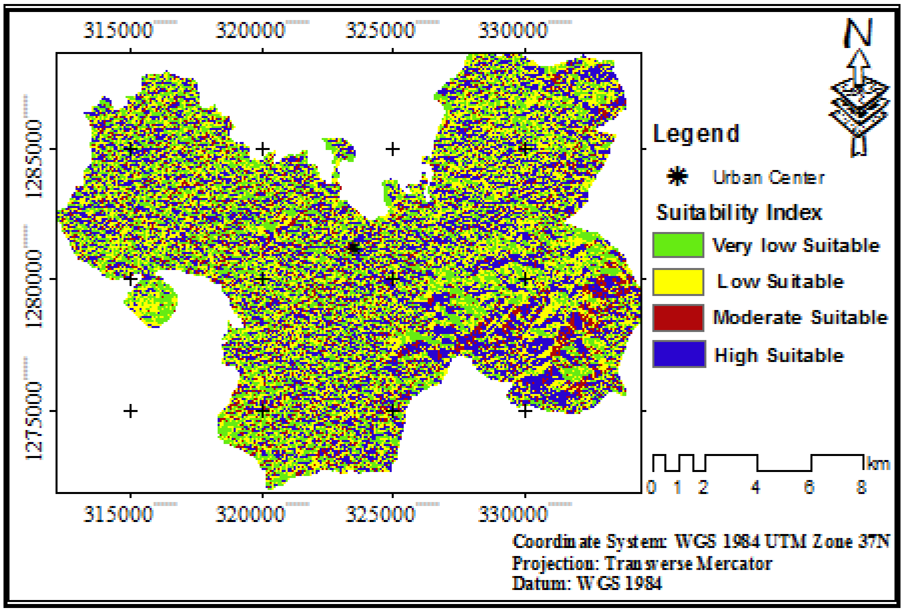


Fig. 4.8. Wind directions factor Map

4.1.2. Economical criteria suitability analysis

In this study, consider the economical criteria distance from road networks, slope and elevation.

4.1.2.1. Distance from road network

This criterion is concerned with the distance from the road network. The road network in the town consists of major roads and others. The road network layer of the study area was digitized from the study area of Topographical map. There is no specific rule of what should be the best distance to place the wastewater treatment plant site. Most studies suggested that the wastewater treatment plant site should be located within a 500m buffer from the roads (Mansouri et al., 2013; Shahmoradi and Isalou, 2013). However, planners may prefer to give an aesthetic concern when deciding a location of wastewater treatment plant site. Also, the wastewater treatment plant site should not be placed too far from the existed road networks, to avoid the expensive cost of wastewater treatment plant construction and maintenance; however, the presence of the wastewater treatment plant close to the roads affects the public health. In this study, distance classified less than 500m and more than 5000m from road networks are unsuitable, distance from 500m to 1000m, distance from 1000m to 1500m and distance from 1500m to 3000m are high suitable, moderately suitable and low suitable respectively and distance from 3000 to 5000m is very low suitable for wastewater treatment plant site location (see table 3.10 and fig. 4.9). A weighting value of 0.03 was computed by AHP method for this factor.

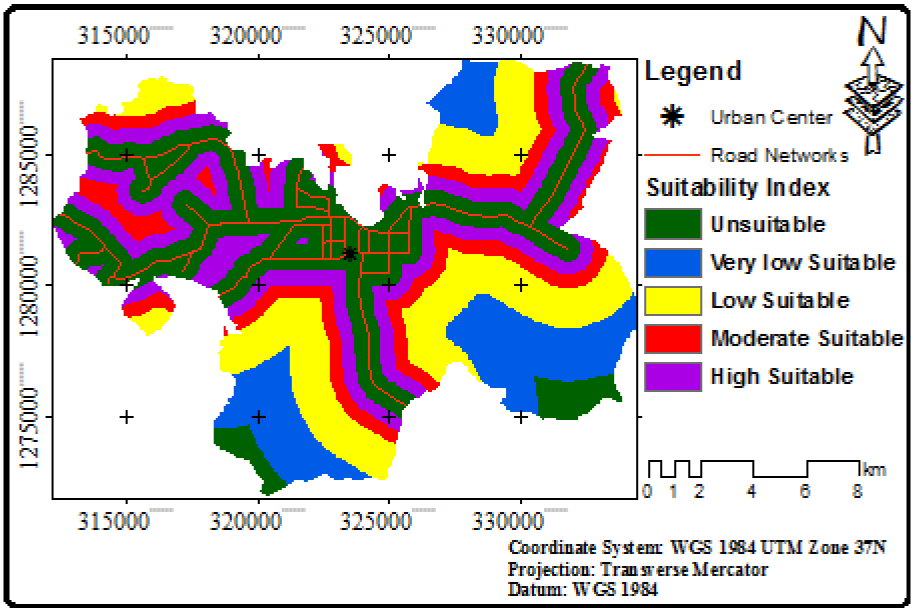


Fig. 4.9. Road network factor Map

4.1.2.2. Slope map

The slope map was generated from the ASTER GDEM data. Slope refers to the measures of the rate of change of elevation at a surface location and normally expressed in percent or degree slope. Construction of wastewater treatment plant in too steep slope sites will increase the cost of excavation and embankment. (Lin & Kao, 2005) have suggested that the appropriate slope for constructing wastewater treatment plant is about 8^0-12^0 because too steep of a slope would make it difficult to construct and maintain, while too flat of a slope would affect the runoff drainage. Thus, it is considered that in this study, the area greater than 20^0 slope, area within 0^0 to 10^0 slope, area within 10^0 to 15^0 and area with 15^0 to 20^0 slope were taken as unsuitable, high suitable, moderately suitable and low suitable respectively for wastewater treatment plant site selection (see table 3.10 and fig. 4.10). A weighting value of 0.15 was computed by AHP method for this factor.

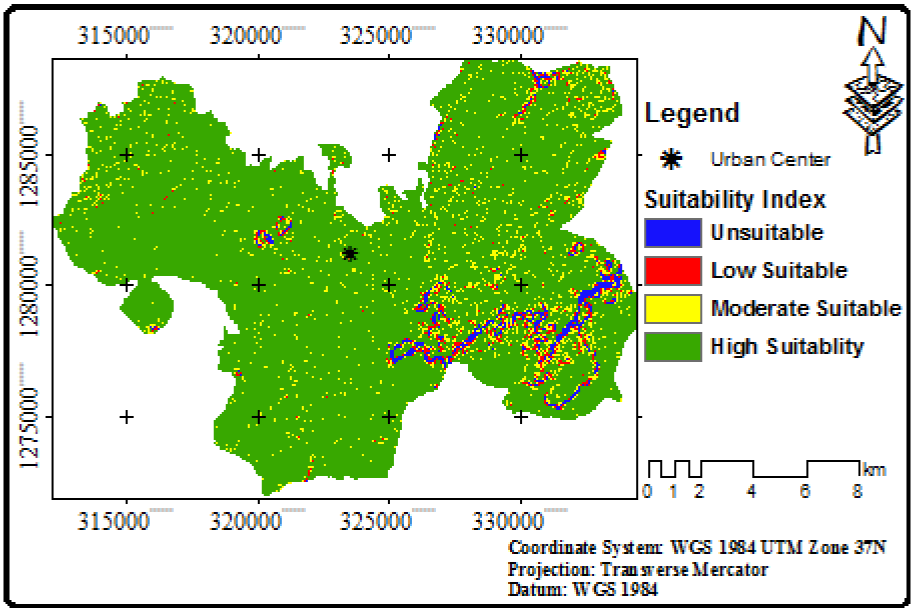


Fig. 4.10. Slope factor Map

4.1.2.3. Elevation map

Elevation map was generated from the ASTER GDEM data. The elevation of the study area generally ranges between 1705 and 2017meters. Elevation is a basic parameter for the construction of wastewater treatment plant site. Areas with too high elevation are not suitable wastewater treatment plant site. Because of it is difficulty to permit gravity flow. The best places for wastewater treatment plant should be located at a low elevation in order to permit gravity flow. Thus, it is considered that in this study, area within 1705-1750m altitude, area within 1750-1850m altitude, area within 1850-1900m altitude, area within 1900-1975m altitude and area within 1975-2017m altitude, were taken as a very low suitable, high suitable, moderately suitable, low suitable and unsuitable, respectively for wastewater treatment plant site location (see table 3.10 and fig. 4.11). A weighting value of 0.08 was computed by AHP method for this factor.

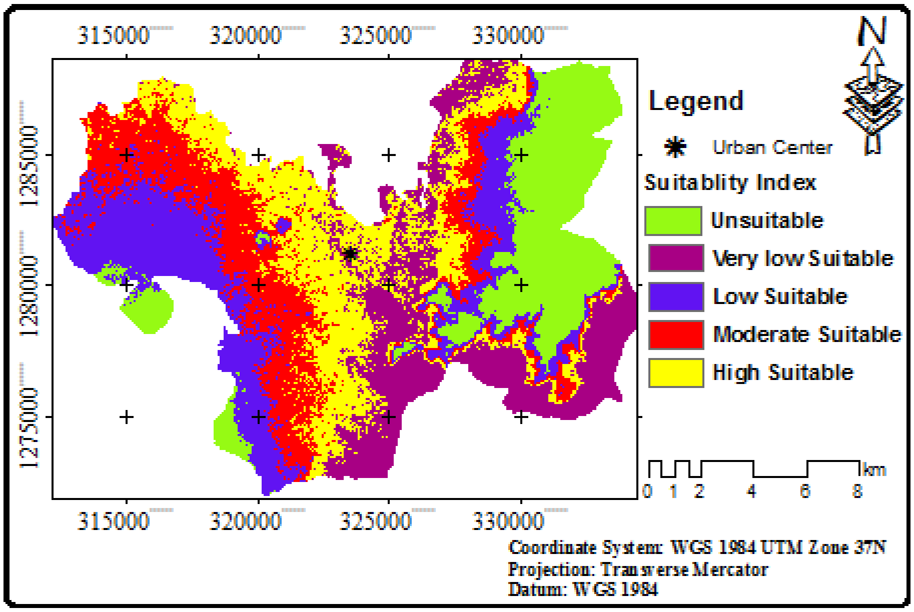


Fig. 4.11. Elevation factor Map

4.3. Overlay analysis and identifying suitable areas

To determine the suitable areas for wastewater treatment plant sites, there are thirteen factors, different siting criteria, various referenced materials and sources are used, both environmental and economical criterion such as proximity to surface water (river/streams and lake), settlements, road networks and groundwater wells, interpolation groundwater table, geology types, soil texture, land use land cover, slope, elevation and wind directions were considered to determining wastewater treatment plant sites. Each criteria thematic map was prepared using ArcGIS Spatial Analyst tools, and prepared maps were converted into raster format. The overlay analyses of the final constraint map with final weighted factor map were integrated and produced the final suitable wastewater treatment plant site map was prepared using ArcGIS software by the following principle:

Suitability WWTP Map = Σ [Criteria map * weight]*constraint map................................ (4)

Suitability index = ([surface water map] * 0.1+[groundwater wells map] * 0.1+[ground water table map]*0.1+[land use map]*0.14+[slope map]*0.15+[elevation map]*0.08 +[urban area map]*0.07+[rural area map]*0.05+[soil map]*0.03+[geology map]*0.03+[road map]*0.03 + [wind direction map]*0.02) * constraint map of (surface water * slope * elevation * urban area* road * rural area * land use * groundwater wells * groundwater table).

The results from the integration of weighted factor map and constraint map in the ArcGIS software reveals four suitability indices for the municipal wastewater treatment plant site of

Bahir Dar town. These are unsuitable (restricted), low suitable, moderately suitable and highly suitable site as shown in (Fig. 4.12).

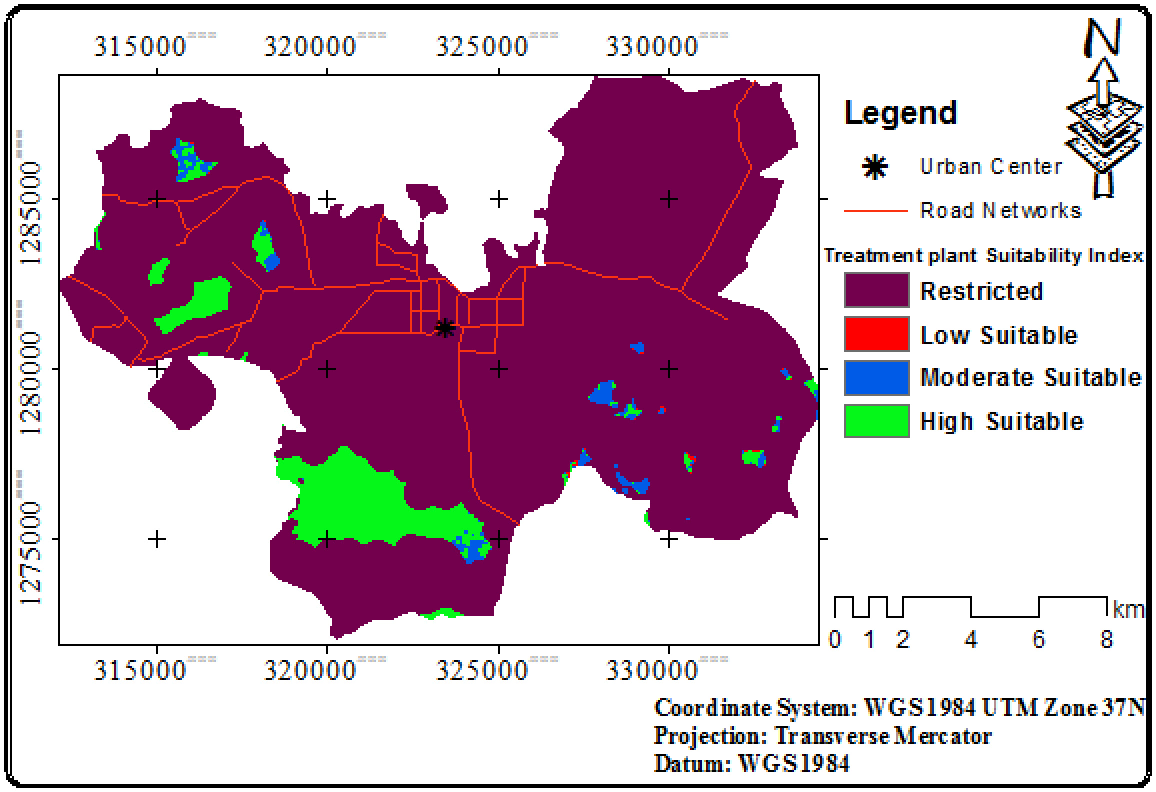


Fig. 4.12. Wastewater treatment plant sites suitability Map of Bahir Dar town

The area coverage of each suitability index of the sites was calculated in ArcGIS environment showed that 195.22 km^2 (91.48%) of the study area is unsuitable (restricted) for wastewater treatment plant site as the areas are environmentally unfavorable and economically impracticable to be proposed as wastewater treatment plant site. This unsuitable (restricted) area include close to surface water (river, streams, lake) (area with a 500m buffer zone), groundwater wells (area with a 500m buffer zone), groundwater table (area with a 5m depth), settlements (area with a 500m buffer zone for rural, with a 1000m buffer zone for urban area), areas with steep slope (>20^0), areas with higher elevation (>1975m), areas with built-up area, airport, water bodies and areas with close to road networks and far from road networks (with a 500m & >5000m buffer zone), respectively. The main advantage of these areas restriction was to minimize their negative effects of on environment and public health as well as to minimize the cost of construction and maintenance of the wastewater treatment plant site. However, 1.30km^2 (0.61%) of the area was low suitable for wastewater treatment plant site and the area of 3.91km^2 (1.83%) moderately suitable. Out of the remaining area, 12.98 km^2 (6.08%) of the area was high suitable, these areas are preferable for wastewater treatment plant, because of their minimum effect on environment, public health and cost effective than other parts of the study area, shown in (table 4.1), with different suitability indices.

Table 4.1. Statistical analysis for the wastewater treatment plant site suitability map

Suitability index	Area (km^2)	Area (%)
Unsuitable (Restricted)	195.22	91.48
Low Suitable	1.30	0.61
Moderate Suitable	3.91	1.83
High Suitable	12.98	6.08
Total	**213.41**	**100**

Most of the highly suitable wastewater treatment plant sites are located in the southern and western part of the study area in (fig. 4.12). The south eastern part of the town having high altitude and close to rural settlement was excluded from the selection of high suitable wastewater treatment plant sites. Accordingly, five candidate wastewater treatment plant sites each with an area greater than $0.2km^2$ were identified as the high suitable areas based on the size of the candidate sites for wastewater treatment plant site selection. In fact, because of the high structure construction, maintenance and operation expenses of wastewater treatment plant, it is preferred that the wastewater treatment plant establishment site responds to the next 15 and above years needs of the town. By considering wastewater production rate, number of population rate and cover matter amount in the wastewater treatment plant site there is a need of at least $0.2km^2$ land for the requirements of 15 years of the areas. Therefore, the areas with the extent of lower than $0.2km^2$ for wastewater treatment plant site selection were rejected and five candidate wastewater treatment plant sites from the study area were considered high suitable for wastewater treatment plant sites as shown in Fig. 4.13.

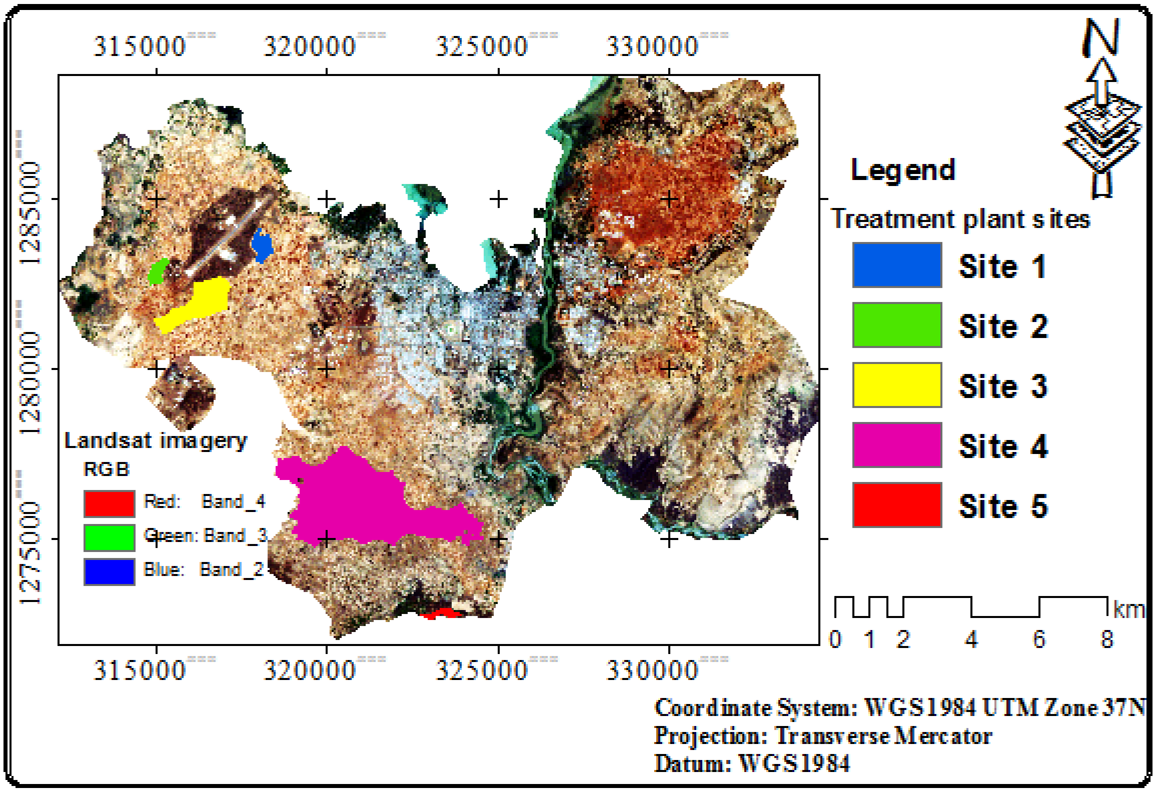


Fig. 4.13. Candidate wastewater treatment plant sites Map

4.4. Optimal suitable site selection

Areas recognized as the highly suitable for wastewater treatment plant site are reevaluated as environmental and economical criteria. The main purpose of reevaluated the environmental and economical criteria to propose the optimal site out of candidate highly suitable wastewater treatment plant sites, a minimum effect of environmental and public health. For evaluating best candidate highly suitable wastewater treatment plant site, proximity to surface water, groundwater wells, road networks and settlements and slope, topography, depth to water table, wind direction and land use land cover.

In order to solve the decision problem by consider all the five candidate sites simultaneously comparison through analytic hierarchy process (AHP) from different criteria. According to the results from in Appendix Table A3, it has been concluded that from proximity to river/streams point of view, site 4 was the high suitable (weight: 0.41), whereas site 2 and site 5 were the lower suitable (weight: 0.09). Moreover, with regard to proximity to road networks, site 1 was the high suitable (Weight: 0.35), while site 5 with weight 0.07 was the lower suitable. It is observed that all the candidate sites are having equal relative weight (weight: 0.20) with respect to wind directions and slope. This shows that these sites are contributing equal significance with respect to wind directions and slope.

In the pair-wise comparison with respect to geology and soil, it is seen that, site 1, 2, 3 and 4 are contributing identical relative weight (0.17) with respect to geology and soil showing that the priorities of these sites are equally important with respect to geology and soil. Whereas site 5 was the high suitable site (weight: 0.33). In terms of elevation, site 4 was the high suitable (weight: 0.40), while site 5 was the lower suitable (weight: 0.08). Moreover, with respect to proximity to Lake Tana and Groundwater wells site 3, site 4, and site 5 were the high suitable (weight: 0.22), while site 1 with weight 0.11 was the lower suitable.

According to relative weights of candidate site with respect to Proximity to urban settlement, site 2 and site 5 were found to have high suitable relative weight as 0.30 that shows site 2 and site 5 are most prior candidate site followed by other. While site 1 was the lower suitable (weight: 0.09) with respect to proximity urban settlement. On the other hand with respect to proximity to rural settlement, site 1 was the high suitable (weight: 0.33), while site 2 was the lower suitable (weight: 0.14). In the pair-wise comparison with respect to land use land cover, it is seen that, site 1, site 2, site 3 and site 4 are contributing identical relative weight (0.16) with respect to land use land cover showing that the priorities of these sites are equally important. Relative weights with respect to land use land cover, site 5 is resulting into highest weight as 0.33 thus considered as most dominant candidate site. In terms of proximity to groundwater table, site 3, site 4 and site 5 with a weight of 0.25 was recognized as high suitable, while site 1 with a weight of 0.11 was the lower suitable.

At this stage, scores were assigned to all the 5 sites for arriving at a final choice. The scores of all sites were determined by multiplying criteria weight by candidate site weight that was derived previously concerning the same criteria and then the summation of the corresponding products as shown in table 4.2.

Table 4.2. Calculation of scores of candidate wastewater treatment plant sites

Criteria	Site 1	Site 2	Site3	Site 4	Site 5
Road networks	0.03x0.36	0.03x0.19	0.03x0.19	0.03x0.19	0.03x0.07
River/streams	0.10x0.15	0.10x0.09	0.10x0.26	0.10x0.41	0.10x0.09
Land use land cover	0.14x0.17	0.14x0.17	0.14x0.17	0.14x0.17	0.14x0.32
Ground water tables	0.10x0.11	0.10x0.14	0.10x0.25	0.10x0.25	0.10x0.25
Ground water wells	0.10x0.12	0.10x0.22	0.10x0.22	0.10x0.22	0.10x0.22
Soil texture	0.03x0.17	0.03x0.17	0.03x0.17	0.03x0.17	0.03x0.32
Geology type	0.03x0.17	0.03x0.17	0.03x0.17	0.03x0.17	0.03x0.32
Slope	0.15x0.20	0.15x0.20	0.15x0.20	0.15x0.20	0.15x0.20
Elevation	0.08x0.24	0.08x0.14	0.08x0.14	0.08x0.40	0.08x0.08
Lake Tana	0.10x0.12	0.10x0.22	0.10x0.22	0.10x0.22	0.10x0.22
Wind direction	0.02x0.20	0.02x0.20	0.02x0.20	0.02x0.20	0.02x0.20
Rural settlement area	0.05x0.33	0.05x0.14	0.05x0.19	0.05x0.17	0.05x0.17
Urban residential area	0.07x0.09	0.07x0.30	0.07x0.16	0.07x0.16	0.07x0.29
Score of	**0.171**	**0.180**	**0.201**	**0.235**	**0.213**

Table 4.2 indicates that in comparison to the candidate sites, candidate wastewater treatment plant site 4 was the highest in score (0.235). This means that this site satisfies most of the environmentally and economically criteria set in this study. Site 4 is located the southern part of Bahir Dar town. The area of high suitable class for wastewater treatment plant within site (4) cover a large area, it can be used this site for a long period and also it is a safe distance 5.5km away from urban center shown in (table 4.3). The groundwater table is deep from the surface, which happens to be the deep in the district. Thus, it is argued that if selected wastewater site, it will cause minimal deterioration in the quality of the groundwater. Also, along with this advantage, there is no surface water body available nearby. Thus, Site 4 was proposed as the optimal suitable site for the study area in terms of a minimum influence environmental risk and public health. On the other hand, candidate site (1) was the minimum satisfies in which the score calculated for this site was the least in (0.171) mainly due to near urban settlements, groundwater wells and water tables. Site 1, 2 and 3 were checked on the satellite image 2015. Hence, revaluation site 1, 2 and 3 are near to Bahir Dar Airport. By the case of this, site 1, 2 and 3 are rejected just because Birds may transfer pathogens to drinking water collection or storage areas it is difficult to for passenger. So it is essential to consider suitable distance from wastewater treatment plant site according to airport. Therefore, site 1, 2 and 3 are not appropriate for suitable wastewater treatment plant by the case of airfield. However, site 1, 2 and 3 are located at a reasonable distance from rural settlements and are equally access road networks

connectivity. As shown in table 4.3, the candidate sites were ranked on the basis of score availability.

Table 4.3. Identified candidate sites for wastewater treatment plant

Site no.	Rank	score	Area (km^2)	Location Distance
1	5	0.171	0.430	6km or more away from the urban center
2	4	0.180	0.296	8km or more away from the urban center
3	3	0.201	1.614	7km or more away from the urban center
4	1	0.235	9.554	5.5km or more away from the urban center
5	2	0.213	0.212	8.5km or more away from the urban center

Site no. 5 is located the southern part of Bahir Dar town and the area also located within the high suitable class for wastewater treatment plant site, and it is located near to the study area boundary. On the other hand, site 5 is relatively from geology type, soil texture and land use a highly suitable. The main problem with this site is that it might not be used for a long period, because it covers a small area among the other sites. And also it is poor accessible road networks connectivity and approximately 8.5km far from urban areas. However, site five is recommended to the second wastewater treatment plant location.

5. CONCULUSION AND RECOMMNDATIONS

5.1. Conclusion

This research shows how to use GIS-based multi-criteria analysis (MCA) to select the optimal site for wastewater treatment plant. The suitable site selecton of wastewater treatment plant site in Bahir Dar town, the weight of main and sub criteria were evaluated by AHP method according to their importance. According to the AHP calculations, the weight of the environmental criteria was 0.75, and the weight of the economic criteria was 0.25, suggesting that environmental criteria were more important than to economical criteria for wastewater treatment plant site selection for this study. Each criteria map was mapped by using GIS spatial analysis tools. The overlay analysis of the given weighted factor maps and constraint maps were integrated and produced the final suitable wastewater treatment plant site map was prepared by using ArcGIS tools. The suitability indices the overall score for the alternative, which valid between 0.26 and 4.76. Pixels with 0.26 were considered as unsuitable. On the other hand, pixel with values 4.76 are likely to be high suitable. The study area was classified into four groups of high, moderate, low and unsuitable, which covered 6.08%, 1.83%, 0.61%, and 91.48% of the study area, respectively. Among the highly suitable treatment plant areas, five candidate sites having an extent more than $0.2km^2$ were selected and revaluated in terms of road networks, river/streams, lake, geology, soil, slope, elevation, wind direction, groundwater wells, groundwater table, rural and urban settlements and land use land cover to identify the optimal suitable site. The outcome showed that the area of proposed site 4 is about $9.5km^2$ and located 5.5km in the southern part of the town is the optimal suitable wastewater treatment plant site will minimize public concerns over health and environmental impacts and will be economical suitable.

5.2. Recommendations

Depending on the findings of the study the following recommendations were suggested.

- Site 4 is recommended to the first optimal wastewater treatment plant site in Bahir Dar town based on the GIS based multi-criteria analysis. But, in terms of urban planning and public opinions there might have different views, which might need further investigations, taking into consideration accurate environmental study needs more field work such as performing accurate geological soil tests and hydrogeological studies.

- The stakeholders should be included in suitability site selection decision-making process. That will lead to incorporation of preferences of several stakeholders (like ministry of agricultural land, urban planners and community among others) should participate in the selection process of wastewater treatment plant site to avoid any opposition in the future.
- The present study more factors were considered for a suitable wastewater treatment plant site selection. However, other factors such as drainage pipe networks and transmission lines are not included criteria determination. Because the limitation of data source. Therefore, further study should fill this research gap by including these factors.

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APPENDIX

Table A1. Existing groundwater wells data

No.	Location	Coordinates	Wells depth	Water level

		East	North	Elv. (m)	(m)	(m)
1	Near Michael Church	322746	1283247	1808	73.5	2.1
2	Kebele 08	325369	1281723	1815	90	3.1
3	Ehud gebya	320552	1280070	1814	104.35	14
4	Near old airport	323430	1281696	1808	56	1.5
5	Plastic factory	324708	1278095	1795	125	17
6	Moenco	320051	1280804	1823	120	14
7	At Tana Secondary School	322194	1282655	1813	80	4.5
8	Bahir Dar university	325626	1279842	1800	105	10
9	Near EELPA substation	323444	1278347	1819	81	9.6
10	Kebele-14	323650	1280580	1817	56	1.8
11	Near SOS K-13	321705	1283422	1810	73	0.5
12	Kebele-11	327043	1284102	1820	80	2.2
13	Yibab	319214	1281781	1805	150	16
14	Near Saint Gebrieal Church	323766	1278440	1810	86	10.2
15	Peda	327291	1285069	1793	93	1.5
16	At Ewketi Fana School	324337	1280884	1804	72	3.40
17	Feres woga	324164	1257048	2099	61	10
18	At Cherchera	327084	1284731	1821	76	2.6
19	Bahir Dar stadium	323592	1280649	1794	134	1.4
20	Near Kuliqual meda School	321958	1281632	1802	50	1.8
21	Bahir Dar university peda	325583	1278794	1789	123	3.25

Source: Amhara Water Well Drilling Enterprise office, Bahir Dar, (2015).

Table A2. Incorporated data spatial reference

Coordinate System	WGS 1984 UTM Zone 37N
Projection	Transverse Mercator
Datum	WGS 1984
Unit	Meter

Table A3. Comparison and weights of each site with regard to different criteria

	Land use land cover						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1	1	1	1/2	0.167	0.00
Site 2	1	1	1	1	1/2	0.167	
Site 3	1	1	1	1	1/2	0.167	
Site 4	1	1	1	1	1/2	0.167	
Site 5	2	2	2	2	1	0.333	

	Proximity to surface water						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	2	1/2	1/3	2	0.1529	0.01
Site 2	1/2	1	1/3	1/4	1	0.0876	
Site 3	2	3	1	1/2	3	0.2573	
Site 4	3	4	2	1	4	0.4147	
Site 5	1/2	1	1/3	1/4	1	0.0876	

	Proximity to lake shoreline						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1/2	1/2	1/2	1/2	0.111	0.00
Site 2	2	1	1	1	1	0.222	
Site 3	2	1	1	1	1	0.222	
Site 4	2	1	1	1	1	0.222	
Site 5	2	1	1	1	1	0.222	

	Proximity to Ground water wells						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1/2	1/2	1/2	1/2	0.111	0.00
Site 2	2	1	1	1	1	0.222	
Site 3	2	1	1	1	1	0.222	
Site 4	2	1	1	1	1	0.222	
Site 5	2	1	1	1	1	0.222	

	Ground water depth						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1	1/2	1/2	1/2	0.1097	0.01
Site 2	1	1	1/2	1/2	1/2	0.1458	
Site 3	2	2	1	1	1	0.2482	
Site 4	2	2	1	1	1	0.2482	
Site 5	2	2	1	1	1	0.2482	

	Geology type						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1	1	1	1/2	0.1667	0.00
Site 2	1	1	1	1	1/2	0.1667	
Site 3	1	1	1	1	1/2	0.1667	
Site 4	1	1	1	1	1/2	0.1667	
Site 5	2	2	2	2	1	0.3333	

	Soil texture						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1	1	1	1/2	0.1667	0.00
Site 2	1	1	1	1	1/2	0.1667	
Site 3	1	1	1	1	1/2	0.1667	
Site 4	1	1	1	1	1/2	0.1667	
Site 5	2	2	2	2	1	0.3333	

	Wind direction						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1	1	1	1	0.20	0.00
Site 2	1	1	1	1	1	0.20	
Site 3	1	1	1	1	1	0.20	
Site 4	1	1	1	1	1	0.20	
Site 5	1	1	1	1	1	0.20	

	Proximity to road networks						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	2	2	2	4	0.3554	0.00
Site 2	1/2	1	1	1	3	0.1916	
Site 3	1/2	1	1	1	3	0.1916	
Site 4	1/2	1	1	1	3	0.1916	
Site 5	1/4	1/3	1/3	1/3	1	0.0698	

	Proximity to urban settlements						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1/3	1/2	1/2	1/3	0.0888	0.00
Site 2	3	1	2	2	1	0.2978	
Site 3	2	1/2	1	1	1/2	0.1578	
Site 4	2	1/2	1	1	1/2	0.1578	
Site 5	3	1	2	2	1	0.2978	

	Proximity to rural settlements						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	2	2	2	2	0.3301	0.01
Site 2	1/2	1	1/2	1	1	0.1459	
Site 3	1/2	2	1	1	1	0.1939	
Site 4	1/2	1	1	1	1	0.1651	
Site 5	1/2	1	1	1	1	0.1651	

	Slope						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	1	1	1	1	0.20	0.00
Site 2	1	1	1	1	1	0.20	
Site 3	1	1	1	1	1	0.20	
Site 4	1	1	1	1	1	0.20	
Site 5	1	1	1	1	1	0.20	

	Elevation						
	Site 1	Site 2	Site 3	Site 4	Site 5	Weight	CR
Site 1	1	2	2	1/2	3	0.2444	0.01
Site 2	1/2	1	1	1/3	2	0.1367	
Site 3	1/2	1	1	1/3	2	0.1367	
Site 4	2	3	3	1	4	0.4030	
Site 5	1/3	1/2	1/2	1/4	1	0.0791	

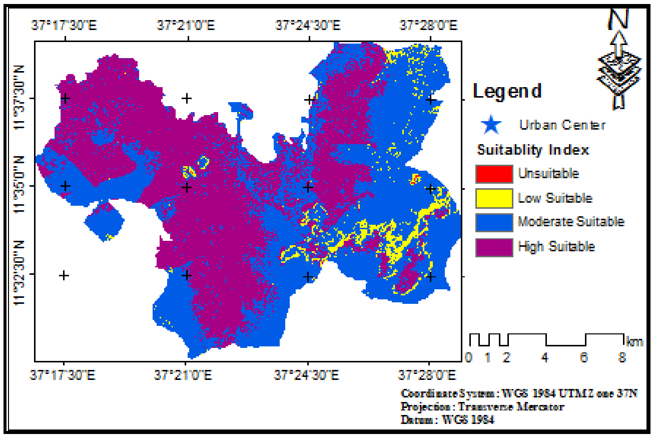

Fig. A1. Suitable Map based on economic criterion

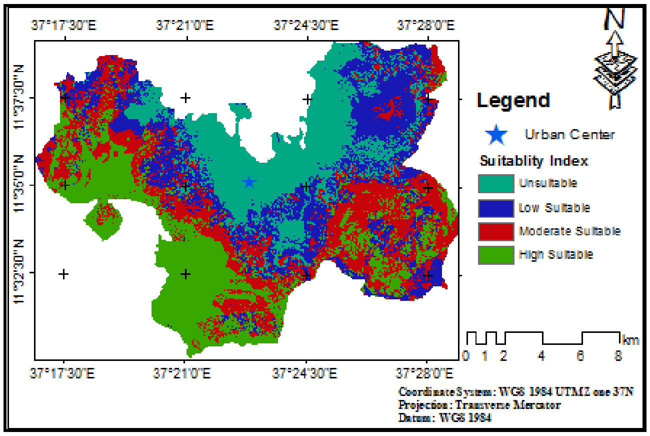

Fig. A2. Suitable Map based on environmental criterion

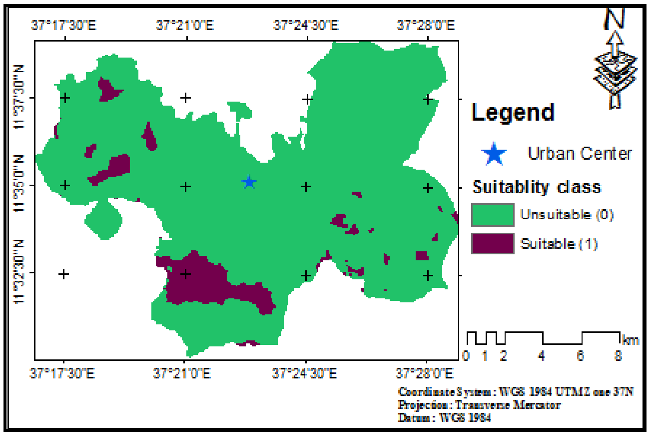

Fig. A3. Final result of constraint Map