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Geospatial Based Optimum Site Selection for Wastewater Treatment Plant: The Case of Debre Berhan Town, Amhara Regional State, Ethiopia

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Abstract Wastewater treatment plant is one of the most serious problems the world facing, the problem gets more serious in developing countries. The city of Debre Berhan is currently generating wastewater simply discharging on the road, open fields and waterway sites that has not been selected by scientific study which is environmentally sound and socio-economically acceptable. Hence, it is found necessary to study and select new wastewater treatment plant site for the city that is environmentally, socially acceptable and economically feasible. This study was conducted by using Geographic Information System technique for selecting suitable wastewater treatment plant sites. Factors such as slope, elevation (altitude), proximity from ground water table, depth of ground water well, soil types, wind direction, geological types, land use/ land cover, proximity from roads and proximity from water bodies were used for selecting suitable wastewater treatment plant within the study area. The factor maps were reclassified and standardized in ArcGIS environment followed by preparation of their suitability maps. The weighted overlay analyses of the final map with final weighted factor map were integrated and produced the final suitable wastewater treatment plant site map using ArcGIS Spatial Analyst tools. As a result, 0.41km^2 (0.72%), 10.24km^2 (18.09%), 22.21km^2 (47.91%), 18.35km^2 (32.37%) and 0.9km^2 (0.91%) of the total study area was found to be very highly suitable, highly suitable, moderately suitable, lowly suitable and unsuitable for wastewater treatment plant siting, respectively. The area of very high suitable are preferable for wastewater treatment plant sites, because of their minimum effect on environment, public health and cost effective than other parts of the study area. Therefore, the study will help the concerned authorities to formulate their development strategies according to the selected suitable wastewater treatment plant site available to the area.

Keywords: *wastewater treatment plant, GIS, Debre Berhan Town*

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1. Introduction

Wastewater are materials that include refuse from households, non-hazardous waste from industrial, commercial and institutional establishments (including hospitals, schools and government and non-government organizations), market waste, yard waste, street sweepings as well as construction debris [1]. The generation of Municipal wastewater is one of the considerable factors that are creating a threat to environmental health [1,2]. wastewater management is referred to as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and recovery, and final wastewater treatment plant in a manner that is in accordance with the best principles of public health, economics, engineering, urban and regional planning, conservation, aesthetics, and other environmental considerations which are also responsive to public attitudes [2].

The problem of wastewater management is widely seen in economically developing countries because of their only intension of industrial development and it is causing them effects on environmental and public health problems in the later times [2]. According to [3]. Africa is suffering from the weak management of wastewater due to inappropriate planning, lack of good governance, poor technology, weak economy and lack of awareness and promotion to environmentally sustainable development. In Africa the most common waste water treatment plant site is the use of open sites without any ecologically and hydrologically vulnerable areas [4,5]. Cities in Africa are facing critical environmental problems occurred due to improper management of wastewater leading to the pollution of water, land and air causing problems to the urban environment and the health of the population [6].

In Debre Berhan town, there are problems of wastewater treatment plant sites [7]. Most of households in Debre Berhan discharge wastewater into streets and flood water drainages [8]. They also discharge wastewater

into Beressa 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. As the population of Debre Berhan Town is dramatically increasing due to both natural birth and immigration of people mostly from the nearby rural areas, the town has more than 165,000 inhabitants and in parallel as the living standard of the dwellers of the Town is growing, the generation of household, industrial and construction wastewater is increasing significantly [9].

Since, GIS is the best assemblage of computer equipment and a set of computer programs for the entry and editing, storage, query and retrieval, transformation, analysis, and display (soft copy) and printing (maps) of the factors (spatial data) wastewater treatment plant site [10]. Therefore, this research attempted the relevant database in a spatial framework to evolve a Wastewater treatment plant site map for Debre Berhan Town with the application of technique in GIS environment. This Wastewater treatment plant site map based on administrative units is particularly handy for the planners and administrators for formulating remedial strategy and implementation of the adopted wastewater management strategy [11].

1.1. Objectives of the Study

The main objective of this research is to find the optimal location of wastewater treatment plant by using the GIS-based analysis approaches in Debre Berhan town, which are environmentally and economically suitable.

In order to achieve the main research objective, ***the specific objectives of the study are to:***

- To identify and examine environmental and economic factors for selecting highly suitable wastewater treatment plant sites, and prepare thematic map for each.
- 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 Debre Berhan town.

2. Materials and Methods

2.1. Data Organization Methods

Preconditions of data analysis such as adjustments for errors, irregularities and absence, until they are ready for the main processing or analysis are vital for good findings. Preprocessing activities are done and therefore, data editions like corrections, modifications, deletions, substitutions etc. were made deeply during data preprocessing.

2.2. Data Analysis Methods

The data analysis process of wastewater siting involves numerous factors with complicated correlations [12]. These factors are Distance from main road, Slope, Elevation, Distance from surface water, Groundwater wells, Groundwater tables, Land use land cover, Soil texture, Geology type and Wind direction. Therefore, GIS based multi criteria spatial analysis techniques and AHP approach has been used to address the proposed study [13]. The assessment procedure for wastewater treatment plant siting is presented as the following in Figure 1. Multi Criteria Evaluation analyzes suitability based on standardized factors and weighted overlay [13,14]. Factors define areas or alternatives according to a continuous measure of suitability. Factor weights were determined by the Analytical Hierarchy Process.

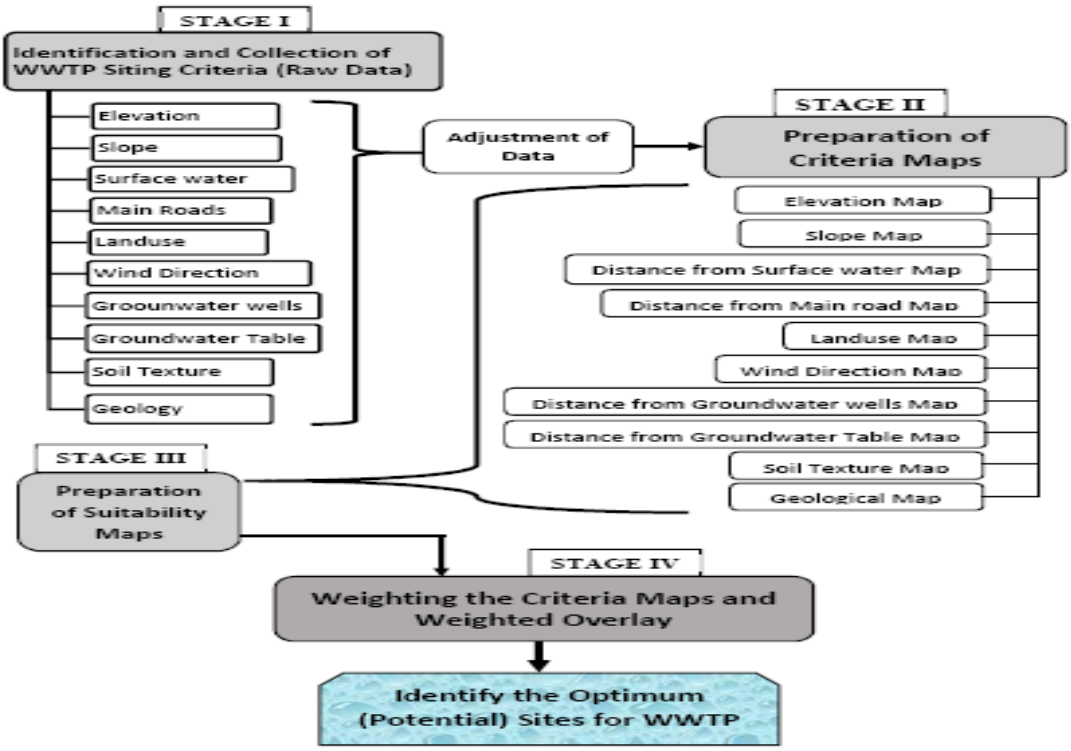

Figure 1. Technological scheme of the research work

2.3. The Criteria for Waste Water Treatment Plant

Multiple criteria are considered as factors controlling the site selection for the treatment plant [15,16]. All this are either from the economical aspect (related with human activities such as distance from road, distance from settlement, and distance from water wells or from environmental aspect such as distance from surface water, slope, soil texture, geology, wind direction and elevation.

3. Results and Discussion

3.1. Results

To determine the suitable areas for wastewater treatment plant sites, there are ten factors, different siting criteria, various referenced materials and sources are used, both environmental and economical criterion. 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 map with final weighted factor map were integrated and produced the final suitable wastewater treatment plant site map.

The procedure which was used in the study is known as weighted linear combination (WLC) where continuous criteria (factors) were standardized to a common data model that was raster layer with a resolution of 30 m cell size, and then combined by means of a weighted overlay. Weighting is used to express the relative importance of each factor to other [15]. The larger the weight, the more important is the factor in overall utility.

The relative comparisons between the ten data layers were performed by asking experts comprising of hydrologists, engineers, end-users and reviewing of literature to give the assessments and judgments regarding the variables related to WWTP and their significances in terms of weights. The comparison conducted indicated that highest weighting for the elevation data layer followed by the slope, surface, road, land use, groundwater table, groundwater well, wind direction, geology, and soil data layer.

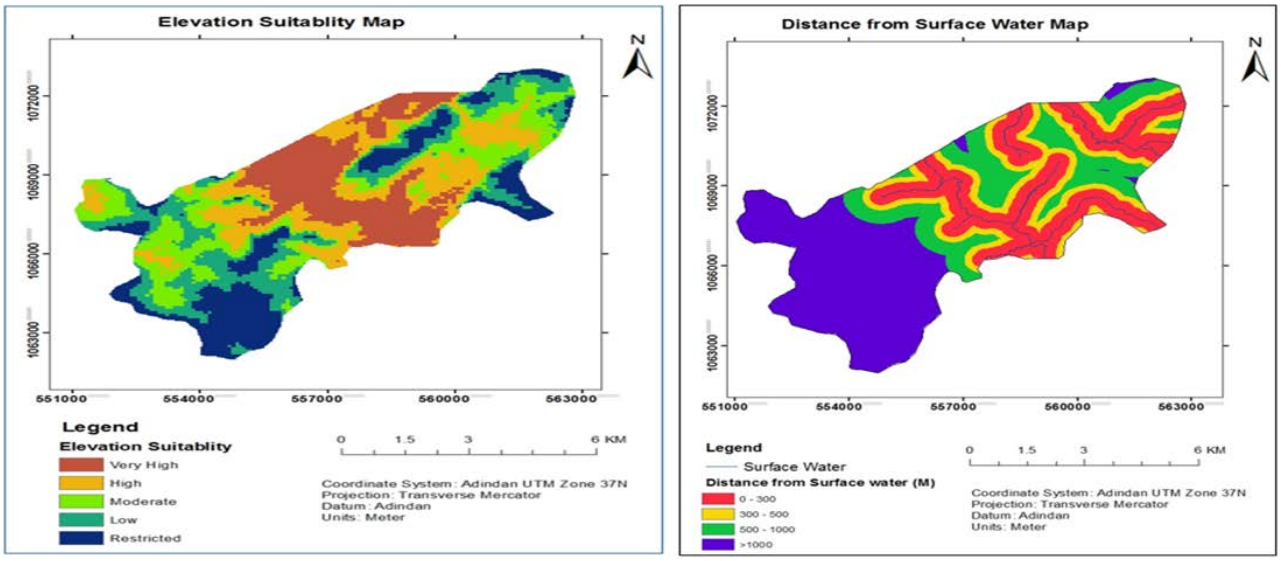

Figure 2. Elevation and distance from surface water suitability map

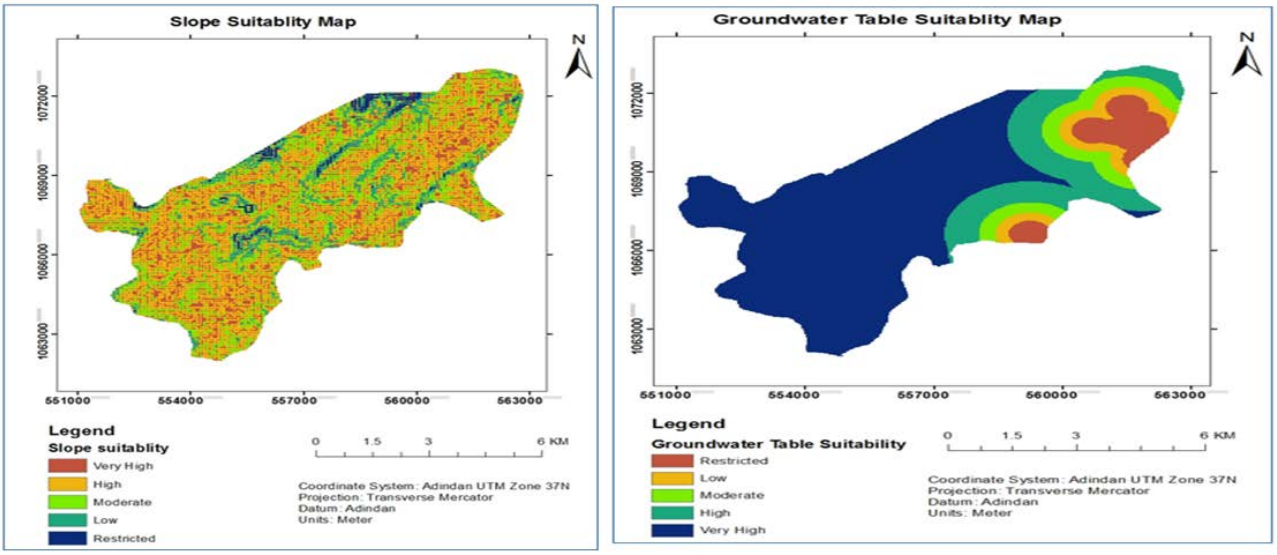

Figure 3. Slope and groundwater table suitability map

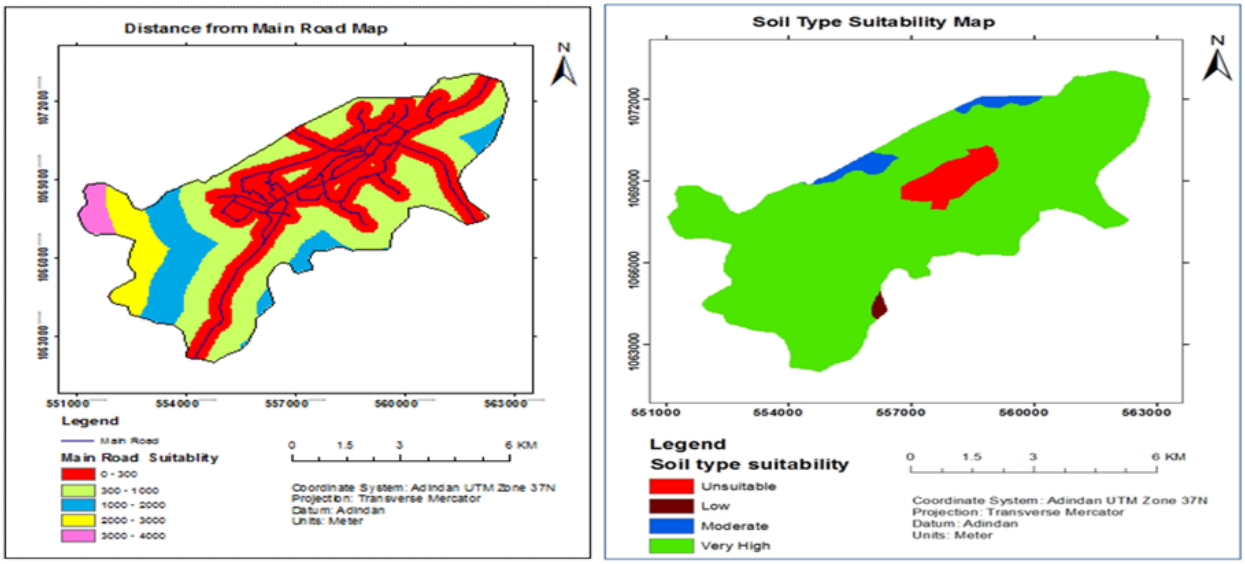

Figure 4. Soil type and distance from main road suitability map

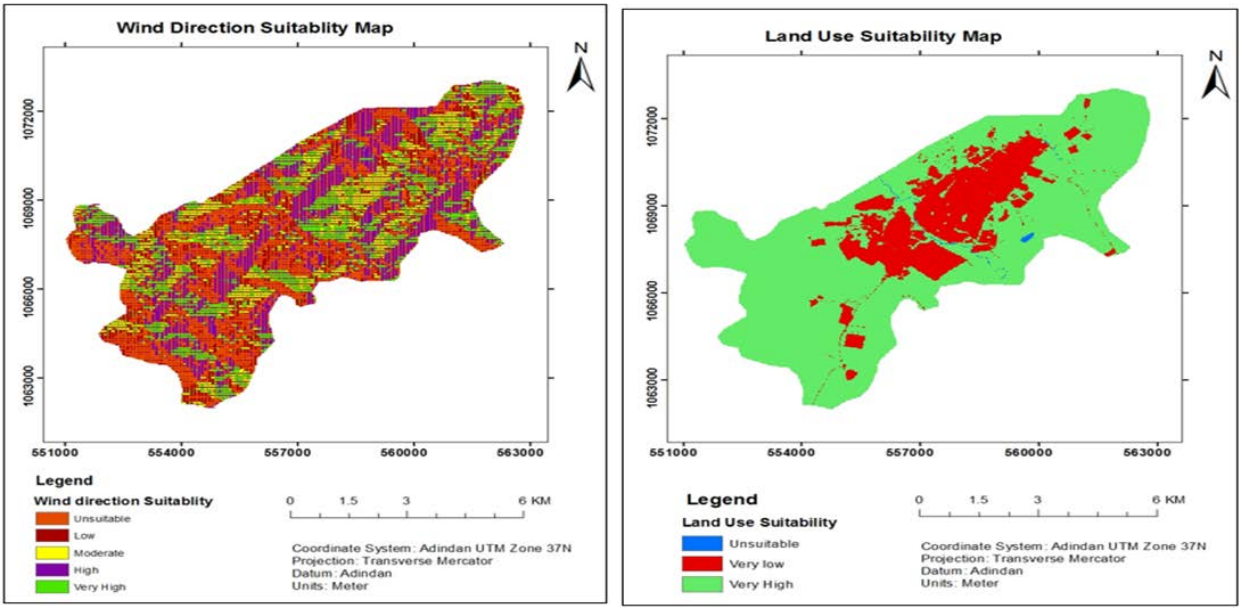

Figure 5. Wind direction and land use suitability map

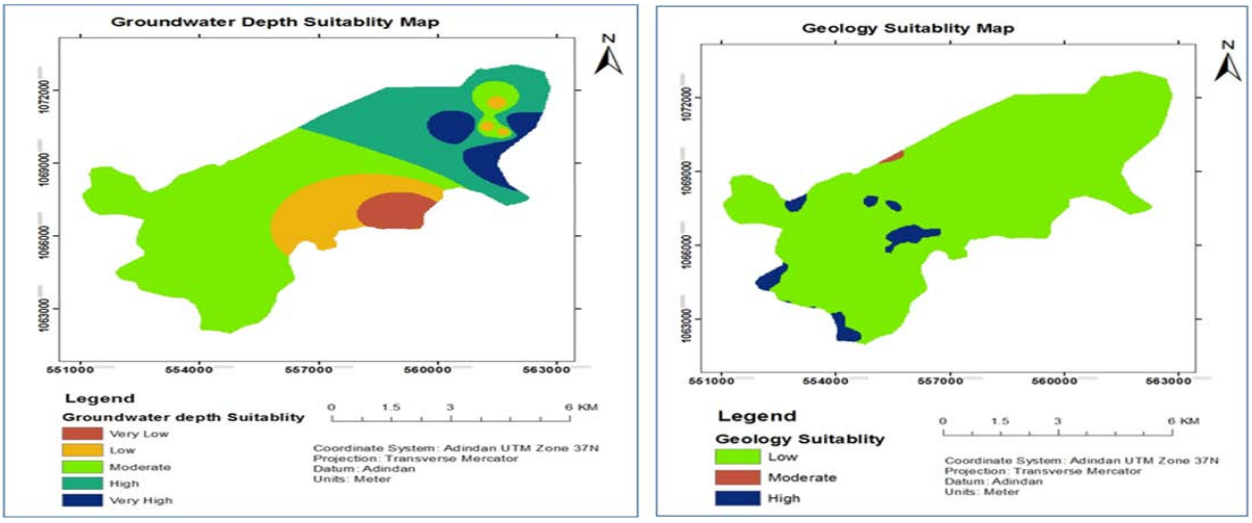

Figure 6. Groundwater depth and geology suitability map

Table 1. Weighted, classes and rankings of factors for Wastewater Treatment Plant analysis of study area

Factors	Weight	Classes	Ranking	Level of Suitability
Elevation (Meter)	0.30	2618 – 2727	5	Very high
		2727 – 2769	4	High
		2769 – 2791	3	Moderate
		2791 – 2815	2	Low
		2812 - 2870	1	Very low
Slope (Percent)	0.20	0 - 2	5	Very high
		2 – 9	4	High
		9 – 15	3	Moderate
		15 – 30	2	Low
		> 30	1	Unsuitable
Surface Water (Proximity)	0.15	0 - 300	1	Unsuitable
		300 –500	5	Very high
		500 - 1000	4	High
		1000 – 5500	3	Low
Main Road (Proximity)	0.10	0 - 300	1	Unsuitable
		300 – 1000	5	Very High
		1000 – 2000	4	High
		2000 – 3000	3	Moderate
		3000 - 4000	2	Low
Landuse (based on their sensitivity to Wastewater Treatment Plant)	0.05	Water bodies	1	Unsuitable
		Built up	2	Low
		Open space	4	Very High
Ground Water Table (Proximity)	0.05	0 - 500	1	Unsuitable
		500 – 800	2	Low
		800 – 1200	3	Moderate
		1200 – 2000	4	High
		> 2000	5	Very high
Ground Water Well (Related to depth)	0.05	22.789 – 67.174	1	Very Low
		67.174 – 76.673	2	Low
		76.673 – 83.779	3	Moderate
		83.779 – 92.287	4	High
		92.287 – 120.181	5	Very High
		Flat, N, NE	1	Unsuitable
		E	2	Low
		SE	3	Moderate
		W, NW	4	High
		S, SW	5	Very high
Geology (Related to permeability)	0.03	Amba Aiba Basalts	1	Low
		Amba Alaji	2	Moderate
		Rhyolite Tarmaber basalts	4	High
Soil type (Related to water absorption)	0.03	Eutric Cambisols	1	Low
		Eutric Leptosols	2	Moderate
		Eutric Vertisols	4	High
		Urban Area	5	Unsuitable

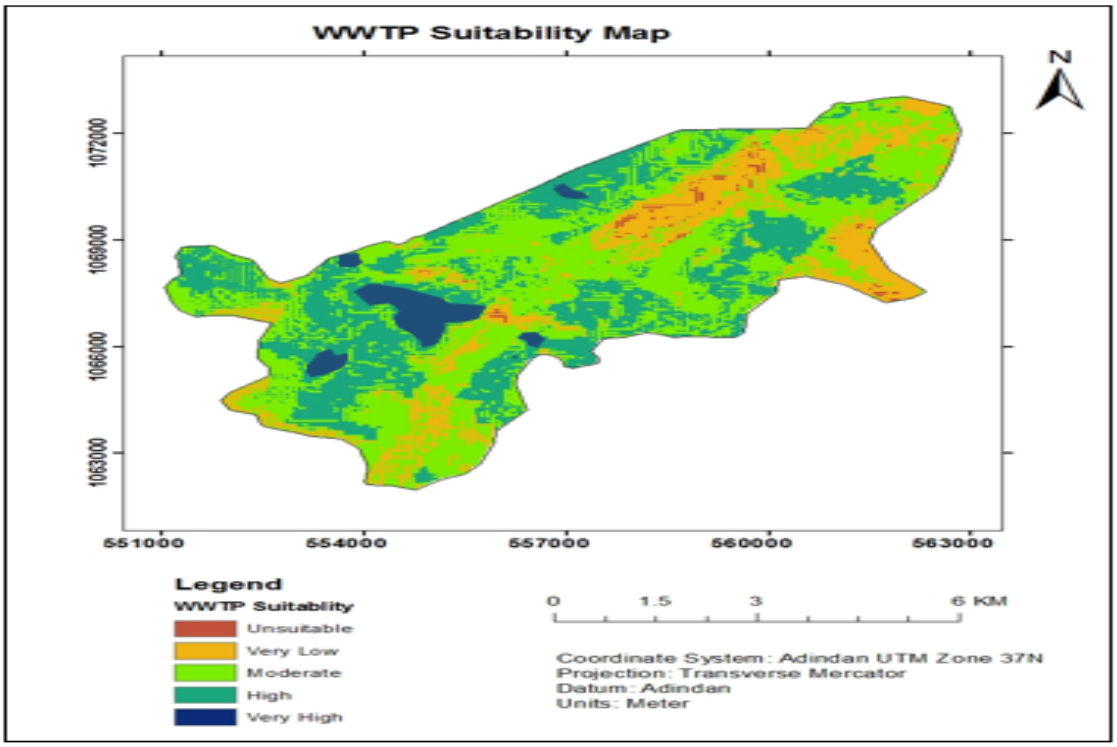

Figure 7. Wastewater Treatment Plant Suitability Map of Study Area

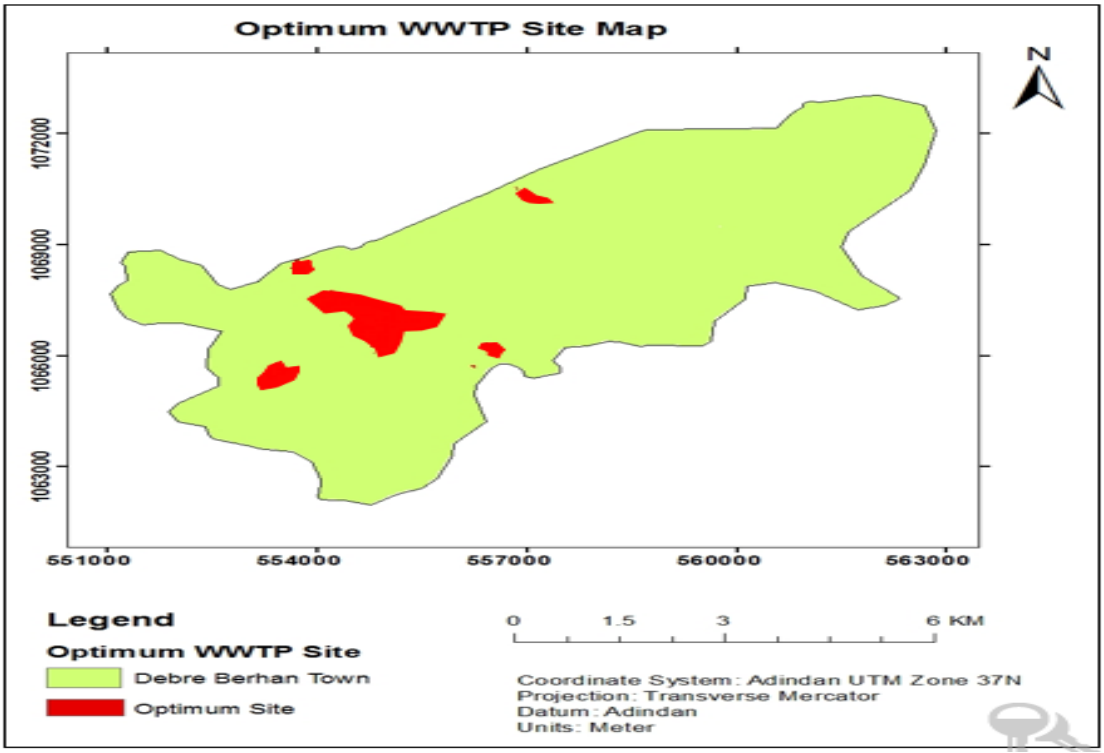

Figure 8. Optimum Wastewater Treatment Plant Site Map of Study Area

3.2. Discussions

3.2.1. Area Coverage and Identification of Suitable Areas

The area coverage of each suitability index of the sites was calculated in ArcGIS environment showed that 0.90 km^2 (0.91%) 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 300m buffer zone), groundwater wells (area with a 22m depth), groundwater table (area with a 500m buffer zone), areas with steep slope (>30%), areas with higher elevation (>2812m), areas with close to road networks and far from road networks with a 300m buffer zone. 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, 18.35km^2 (32.37%) of the area was low suitable for wastewater

treatment plant site and the area of 27.21km^2 (32.37%) moderately suitable. Out of the remaining area, 0.41 km^2 (0.72%) and 10.24 km^2 (18.09%) of the area was very high suitable and high suitable, respectively, 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 1), with different suitability indices.

Table 2. Area Coverage and identification of suitable areas

NO.	Suitability	Area(km^2)	Area (%)
1	Very High	0.41	0.72
2	High	10.24	18.09
3	Moderate	27.21	47.91
4	Low	18.35	32.37
5	Unsuitable	0.9	0.91
Total		**57.11**	**100.00**

3.2.2. Selected Sites in Terms of Governing Factors

Due to the dynamic ups and down topography of Debre Berhan City, it is very challenging and not comfortable to site specific and all over controlling location for the treatment. From the result of weighted overlay analysis in Figure 8 above, different factors have been developed and combined and as result of this combination the possible suitable sites for constructing Wastewater Treatment Plants are selected and shown in western and south western regions of the City. In comparison with the altitude factor of the city which spans from 2618 to 2870 as seen from Figure 2 and Table 1, the selected potential sites are found approximately at lower altitudes (2770 - 2790) and this intern implies they are suitable because lowland areas are better to introduce treatment plants than higher ones. Slope is one of the highly affecting factors for locating the sites and in this regard the selected sites are at preferable slope levels from 0 to 11% because areas at flat and gentle slopes are preferable for potential sites. Surface water is the next high rank given controlling factor in suitable site assessment and due to this, the selected treatment site when compared to the surface water proximity is good, but some streams are there that are draining water only during the summer season. In the City, another factor that has been taken into consideration was the road network. Even though the spatial data of land use that is obtained from the City's Municipal is not up to date, difficulties have been come across to clearly identify and demarcate the type, standard and level of service of the existing and planned roads.

However bearing in mind the current and future advancement of Debre Berhan towards expansion, the researchers have tried to identify mainly important roads that influence location of the treatment plant site. The next and very important factor that should be considered is the factor showing the direction of wind. As to the evidence obtained from the National Meteorological Agency (NMA) of Ethiopia, the direction of wind Debre Berhan City mostly experience is in the North and North East direction. Thus due to the unpleasant smell from sewage treatment through wind, it is not appropriate to construct the treatment plant at City side where the wind is believed to come from. Based on that reason places at the northern and north eastern sides of the city are considered unsuitable while the reverse i.e. Southern and South Eastern sides are high potentials of establishing the plant. Therefore in this analysis result most of the selected sites lie in the south and south west region of the City. Depth of ground water wells and distance from ground water table are also considerable for introduction of Wastewater Treatment Plant P for that particular area. Thus places where Ground water wells are at depth of less than 20m and ground water table at minimum distance of less than 500m are attempted to be avoided based on the information of Debre Berhan City Water Supply and Sanitation Office. According to the Land Use map from the City's Municipal Office, the land cover classes are categorized into three major categories as Built up, Open Spaces and Water bodies from which open spaces have got very high suitability chance. From the land use aspect of the city therefore the possible sites that currently selected are fortunately found in the open spaces of the south west region where no construction projects are implemented. The soil texture types wrapping the whole area of the City which are known in their scientific names as Eutric Cambisols, Eutric leptosols, Eutric Vertisols except the urbanized area among which Eutric vertisols dominantly occupied more than 90% of the City's area coverage. Selected sites therefore lie in the area of eutric vertisols soil type which very comfortable for Wastewater Treatment Plant construction. Lastly from the information of the Geological Survey of Ethiopia (GSE), the geological factor of the area is tried to be seen and found has rare effect on the selection of suitable sites.

3.2.3. Debre Berhan in the Past and Current in Relation with Wastewater Treatment Plant

Ten years before Debre Berhan City become the host for Beverage Industries Such as Dashen and Habesha Beer Factories, Tanning Factory, Large settlements where peoples live in high rise buildings called Condominiums, different standard Hotels, different large State and Federal Government Institutions, higher Educational institution Debre Berhan University and etc, Municipal waste was easily controlled using different mechanisms such as such as on-site sanitation system, Latrines and Truck Supported disposal system (Ministry of Water, Irrigation and Electric (MoWIE) of Ethiopia, 2015). According to the MoWIE, such means are effective when little or no piped waste water is available. Apart from this Debre Berhan is recently becoming amongst the cities rapidly being surrounded by developing factories and Industry Park of various purposes, waste management shall be the pre planed project of the City.

4. Conclusion

From the Integrated Geographic Information System (GIS) Spatial Analyst and Data Management tools, it could possibly enable to delineate or select the optimal sites for Wastewater Treatment Plant [15]. The selected sites as a result of these analyses are therefore found best and reliable information for any government and non-government bodies to introduce the treatment plant based on the research result either as a reference Benchmark partially or use as it is pre proposed.

Researchers, starting from their series of data gathering, preparation, factor development and Analysis stages have found that Wastewater Treatment Plant sites must be reserved and construction project of the treatment plant must be implemented at least at one point among the selected areas for Debre Berhan City.

Based on the comparing and contrasting of all the limiting factors (Altitude, Slope, Distance from surface water, Distance from main road network, Wind direction, Distance from ground water wells, Distance from ground water Tables, Soil texture and Geological conditions), the researchers strongly believe that the final selected sites are the most acceptable, reason based and exact places for Wastewater Treatment Plant construction.

The study indicated that, out of total area, 0.41 km^2 (0.72%) and 10.24 km^2 (18.09%) of the area was very high suitable and high suitable, respectively, 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, with different suitability indices.

A proclamation in No 200/2000 that has been declared by the Ethiopian Public Health says, “no person shall dispose solid, liquid or and other waste in a manner which contaminates the environment or affects the health of the society”. From this proclamation and the researchers photographic evidences exhibited in appendix part, due to the worst waste management in Debre Berhan City, the need for Wastewater Treatment Plant in is found extreme.

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