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GEOSPATIAL WEIGHTED OVERLAY ANALYSIS FOR SUITABLE SITE SELECTION OF WASTEWATER TREATMENT PLANT IN LANDHI INDUSTRIAL AREA, KARACHI

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ABSTRACT:
Industrial wastewater management remained a big challenge for developing countries. Industries directly discharged their effluents into the natural drains, sewer system, internal septic tank, and nearby fields. Recent urbanization and industrial activities have led to environmental deterioration, creating complex environmental conditions and health hazards. This study aims to propose a suitable site for the construction of a wastewater treatment plant (WWTP) in the Landhi Industrial Estate (LIE) of Karachi, using Weighted Overlay Analysis (WOA). Four selection criteria were considered in for this analysis: road network, a slope, surface water, and land use/land covers. Weights were assigned for each criterion to find a suitable site. The two suitable sites are selected according to the suitability criteria.
Keywords: GIS, Multi-criteria analysis (MCA); Site Selection, Wastewater, Wastewater treatment plant (WWTP);

Introduction

Water is essential for survival and basic need of life [1]. Pakistan is facing rapid urbanization, which also brought other environmental issues, including insufficient drainage capacities and poor treatment of grey and black water. Being a water-scarce country, adequate drainage and wastewater treatment systems remained one of the biggest challenges for the country.

Karachi is the biggest city in the country with three sewage treatment plants TP1 (SITE), TP2 (Mahmoodabad) and TP3 (Mauripur), having a combined capacity of 150MGD to treat wastewater. Since 2015 these treatment plants are not working and their current ability to treat sewage is zero. Now Karachi's 15 million population is

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illegally discharging their 100% raw sewage into the nearest coastal waters and for populations living in proximity serve as the cesspools of disease. Other mega cities of Pakistan are no different from Karachi. Major cities along the rivers are offenders for polluting these freshwater sources [2]. About 90% population of Sindh is dependent on underground water for drinking and other domestic use [3].

The textile processing industry requires a large volume of water to run various operations in different units and uses a variety of chemicals in these processes. The textile industry uses sequence of processing stages that require water, chemical, and energy and which also generate waste. The primary requirement of the textile and fashion industry is demand for significant variations in type, pattern, and color combination of fabric results in fluctuations in waste generation volume and load. The nature of the waste depends on the textile processing facility, such as the spinning and weaving processes, dying and knitting technologies, and the types of fibers and chemicals used in the processes [2].

Several small to medium industries are running in the informal sectors of Karachi but only a few have installed basic effluent treatment facilities, while the others discharging their effluent directly into the coastal areas without treatment [3]. Industrial water pollution remained uncontrolled due to little or no incentives for the industry to treat their effluents [4]. The sewage treatment issue is one of the main problems in many cities worldwide, and it getting worse recently in different regions. Building an efficient and practical sewage treatment plant is an excellent way to treat polluted water [5]. Suitable site selection is the most crucial stage of wastewater treatment, causing negligible environmental effects. Thus, site selection studies usually utilize many parameters, and a systematic methodology is highly needed to integrate the various information, which has been obtained from multidiscipline [6]

RS/GIS data and geospatial analysis techniques have been used for water and wastewater engineering facilities, particularly planning, designing, and controlling before construction and maintenance by integrating and analyzing data for environmental projects [7].

GIS based multi-criteria analysis is one of the best methods for decision makers to make a systematic and scientific decision after considering multiple geolocated factors [5][8]. The purpose of this study is to build a decision-making model to find the optimal site for a WWTP using weighted overlay MCA Decision building criteria were extracted from the satellite images and the digital elevation model. [9]

MATERIALS AND METHODS

Study Area

Landhi Industrial Area is one of the pioneer industrial states in Pakistan established in 1949 (Figure 1). Landhi Industrial Area consists of medium to large 300 industrial units of textile, steel, food, chemical, Pharmaceutical, Automobile, Chemical, Engineering & Flour Mills. The total covered area is 44.515 km^2 approximately. The total number of plots is 1200, with an average of 10 acres [10].

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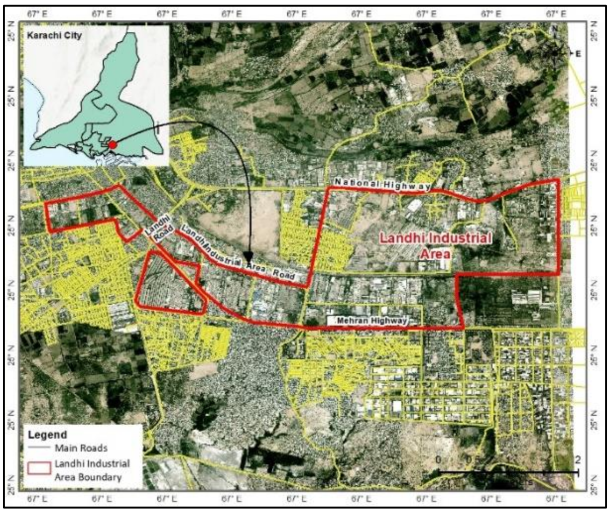

Figure 1: Study Area Map of LIA

Data

Different data sources have been utilized in this study, and the following data have been used in this study.

i. Landsat 8 Operational Land Imager (OLI) for December 2021 were used to delineate LULCs.

ii. Shuttle Radar Topographic Mission's (SRTM) Digital Elevation Model (DEM) calculate slope of the area.

iii. Road network of the study area was acquired from DIVA-GIS, portal for free GIS data.

Criteria for Site Selection

To avoid the negative/cumulative and synergistic impacts of the textile and other industries effluents on the environment, it is important to select the site considering all environmental aspects [11]. The site for WWTP should satisfy the following criteria [7];

i. Slope less than 15% (5% in our study area)

ii. Site should be away from the thickly habituated areas

iii. It should be 200 meters away from the main roads and stream/water bodies

Wind speed and directions are also essential factors for selecting a suitable WWTP site. In this study suitable site is selected for a closed treatment system that will not be causing odor problems; thus, these criteria are not included in this study.

Weighted Overlay Analysis (WOA)

For WOA, different weights are assigned to all the criteria according to their importance for a suitable site. If LULC is the most important criterion, give it to higher weights (out of 100). In each criterion, there are various subclasses, like in LULC, there are urban area, open area/soil, water, and vegetation. In this case, subclasses

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in LULCs assigned ranks according to their suitability for constructing a new site, which should be an open area. (The highest rank in all four classes is 4, and the areas less or not suitable, assigned with lowest rank 1). These ranks of subclasses multiply by the weight of criterion and get the total weight for each subclass.

Table 1: Creation table for site suitability analysis [11]

S.No	Criteria	Classes	Rank	Weight	Total Weight
1	Slope	< 5	3	25	75
		5 –15	2		50
		> 15	1		25
2	LULC	Soil/Open area	3	35	105
		Agriculture land	2		70
		Urban	1		35
		Water bodies	1		35
3	Streams	0 – 100	1	30	30
		100 – 200	2		60
		> 200	3		90
4	Roads	0 – 100	1	10	10
		100 – 200	2		20
		> 200	3		30

Slope

In this study, the main objective of the site selection is to reduce the energy needed for pumping by selecting sites having natural slopes. LATI is in the most urbanized area of Karachi city, and the surrounding area has a slope in between slope 0 - 13 percent. LATI area has a gradual slope towards the Arabian Sea, and slope decreases along the bank of Malir River. An area with a low slope will be suitable for the WWTP site because the waste collection pipes will follow the gradient towards the Southwest (Figure 1). The slope is classified into three categories 0 – 5 (Highly Suitable) and 6–15 (Moderately suitable) and >15 (Not suitable).

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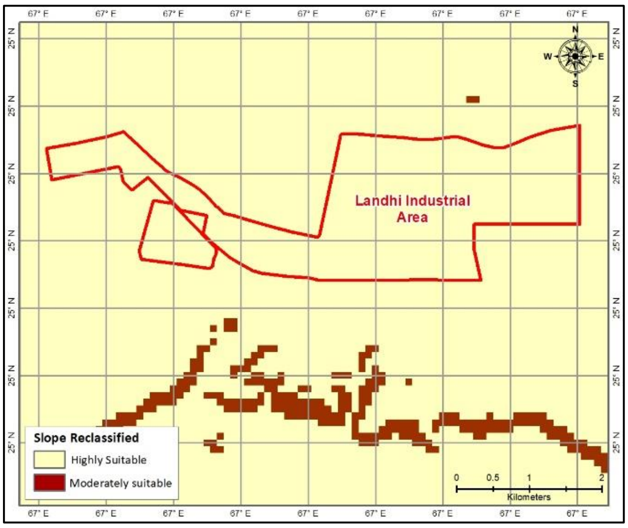

Figure 2: Slope Ranks (Reclassification values)

Distance Stream Network

DEM is used to delineate drainage network of the study area. Drainage density was Stream network is used to protect its nearest area and restrict it for any construction close to streams. LATI is located on the left bank of the Malir River basin, Sukan and Malir are two streams that needs to be considered while selecting the WWTP site. Area with higher drainage density excluded from the study by giving lowest weight/importance for site selection (Figure 3).

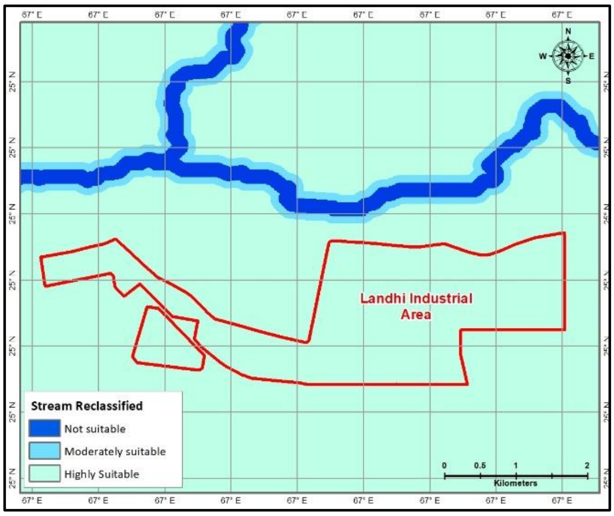

Figure 3: Drainage Ranks (Reclassification values)

Landuse/landcover (LULC)

Textile industries are also responsible for air emissions and water pollution, so the WWTP must be at a significant distance from water bodies and thickly populated areas. To map the major LULCs of the study area Landsat 8 satellite images (31st

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December 2018) is used to classify LULC with a maximum likelihood algorithm. Urban area, agriculture, river, soil/open area and other vegetation are the major LULC of the study area. (Figure 4).

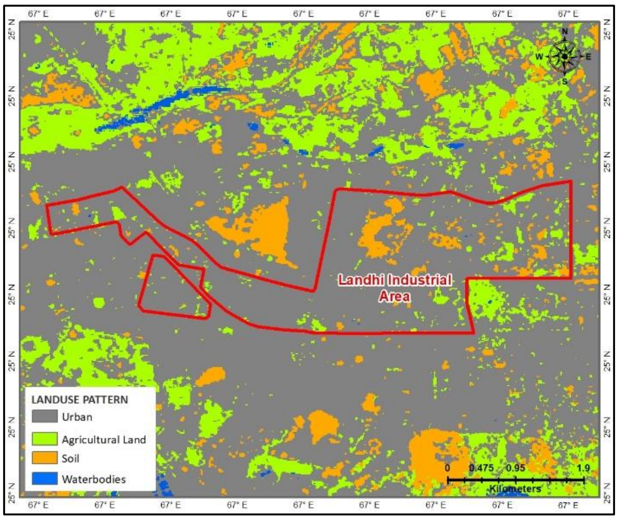

Figure 4: LULC of the Study Area

Roads

Road network for this study is acquired from open streets maps. A buffer of 200 meters is applied, and given the lowest rank for the WWTP site, WWTP should be located at least 200 m away from the roads. Buffer analysis from ArcGIS geoprocessing tools is used to create the buffer around primary roads (Figure 5).

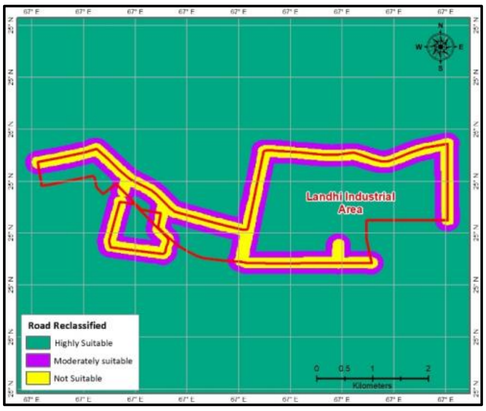

Figure 5: Road Ranks (Reclassification values)

Weighted Overlay Step by Step Process

Weighted overlay analysis is one method of modelling suitability in a GIS environment, and it involves the following process for analysis.

- Assigned weight to each criterion.
- All criteria values converted into a standard suitability scale.

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- Criteria layers overlaid by multiplying each criteria suitability rank value with its weight and totaling the values to derive a suitability value.
- The suitability values are registered to new raster in an output layer.
- The symbology in the output layer is based on these values.
- Assigning weights to all criteria in the weighted sum process allow to control the influence of different criteria in the suitability model.
- Multiplying each criterion layer's weight by each cell's/pixel's suitability value
- At the end all criteria are summed to get a suitability value.

Results

The results from WOA are categorized into three classes according to suitability, presented in Table 2 and Figure 6. Suitable areas were overlaid with LULC (Figure 7) to check if the suitable areas lie in open areas or agricultural areas; the summary is presented in Table 3. Two significant sites highlighted in figure 6 could be most suitable for WWTP. Site A is located inside the Landhi Industrial Estate, and site B is located adjacent to the Radio Pakistan Colony, both locations are suitable for collecting wastewater through pumping.

Table 2: Area of different suitability categories for WWTP

S.No	Suitability	Area (SqKm)
1	High	1.4
2	Moderate	32
3	Poor	107

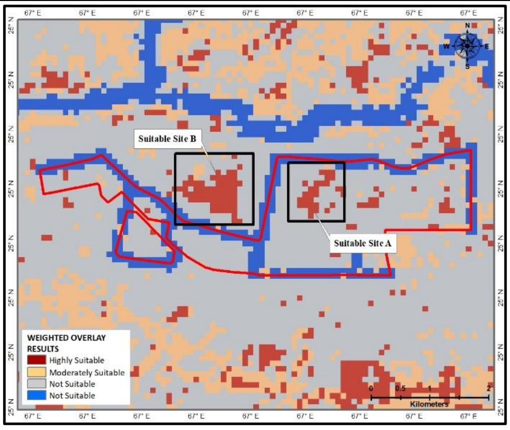

Figure 6: Suitable sites – weighted overlay analysis

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Table 3: Suitable Areas According to LULC

S.No	Suitability	LULC	Area (Sq.Km)
1	High	Soil/Open Area	1
2	Moderate	Agriculture	0.8
3	Poor	Urban	12
4	Poor	water	4.5

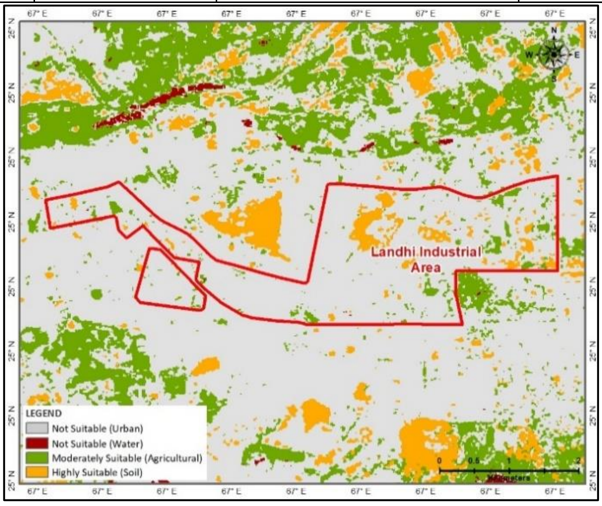

Figure 7: Suitable sites based on LULC

Discussion

The study deal with the importance of the WWTP in the progress of civilization and environmental protection. The methodology adopted in the study combined the techniques of remote sensing and GIS. Moreover, GIS enables us to integrate different layers and manage a large database, and it gives more accurate results when compared to conventional methods. Hence, GIS has proved to be a powerful tool in managing spatial and non-spatial data in suitability evaluation. WOA is widely used as a decision tool in selecting a suitable site for WWTP. Four criteria were selected, which are urban/residential, streams, roads, and ground slope. A paired comparison matrix was prepared for criteria classes, and individual class weights and map scores were worked out. These weights were applied in a linear summation equation to obtain a unified weight map containing due weights of all input variables.

The results revealed that two separated sites, A and B (Figure 6), could serve as sites for the WWTP. The area of site A approximately 80Acres (0.34sqkm) located inside the LATI and mainly consists of urban and open/soil land, but the construction cost will be much higher than site B for this site. The piping network will be passing through the urban area and need a lot of excavation work and permission from the different departments, and it will affect the surrounding area. Site B is located adjacent to the

Radio Pakistan Colony and approximately 2.5 km from the Malir River. This site also consists of urban and open land. This site is suitable for less construction work; piping work can be done along the Railway track and will follow the natural gradient. This site has an area of about 159 Acres (0.64 sqkm). The present study with using the RS and GIS methodology gives a glance clue of such problems. Such studies require high resolution remote sensing data and Geodatabase to get good results.

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