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GIS based Site Suitability Analysis for delineation of Wastewater Treatment Plant potential zones in Upper Ponnaiyar Watershed, South India

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Abstract. The management of water resources is a major challenge for most of the dry land areas, as the demand for water are increasing and the quality are being compromised due to a number of natural and economic factors. Rural, periurban and urban should focus in future for decentralised wastewater treatment systems. The cluster of decentralised treatment system provide best management of wastewater in summer and winter seasons. The investment, operation and maintenance of decentralised treatment plants will provide a higher level of environment. In the selected study area Upper Ponnaiyar, water pollution issue has gotten worse recently, in order to solve the water pollution issue, building a wastewater treatment plant is a good way to treat polluted water. If the proper location for the treatment plant is not selected, then it may lead to soil degradation and groundwater pollution. This study was conducted by using GIS techniques for selecting suitable wastewater treatment plant zonation.There are seven parameters considered in the analysis consists of land use/land cover, elevation, road proximity, a slope of the ground, drainage density, geology, and soil. The weighted index 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, 73.88 km^2 (6.90%), 359.55 km^2 (33.59%), 441.08 km^2 (41.21%), 180.71 km^2 (16.88%), 15.05 km2 (1.41%) of the total study area was found to be unsuitable, low suitable, moderate suitable, high suitable and very high suitable respectively. The area of very high suitable is preferable for wastewater treatment plant sites, because of their minimum effect on the 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.

Key words:
GIS, Weighted Overlay Analyses, Wastewater Treatment Plant.

Апстракт. Управљање водним ресурсима представља велики изазов за већину сувих подручја, јер потражња за водом расте, а квалитет је угрожен због бројних природних и економских фактора. Рурална, приградска и урбана подручја требало би да се у будућности фокусирају

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на децентрализоване системе за пречишћавање отпадних вода. Кластер децентрализованих система за пречишћавање обезбеђује најбоље управљање отпадним водама у летњој и зимској сезони. Инвестиције, рад и одржавање децентрализованих постројења за пречишћавање обезбедиће виши ниво заштите животне средине. У одабраном подручју истраживања, Горњем Понајару, проблем загађења воде се у последње време погоршао, а како би се решио проблем загађења воде, изградња постројења за пречишћавање отпадних вода је добар начин за третирање загађене воде. Уколико се не изабере одговарајућа локација за постројење за пречишћавање, то може довести до деградације земљишта и загађења подземних вода. Ова студија је спроведена коришћењем GIS техника за избор одговарајуће зонације постројења за пречишћавање отпадних вода. У анализи се разматра седам параметара: коришћење земљишта/покривеност земљишта, надморска висина, близина пута, нагиб терена, густина дренаже, геолошка грађа и земљиште. Анализе индексног преклапања финалне мапе са финалном мапом фактора су интегрисане и указале су на коначну одговарајућу локацију постројења за пречишћавање отпадних вода коришћењем алата ArcGIS (просторни аналитички алат). Као резултат, 73,88 km^2 (6,90%), 359,55 km^2 (33,59%), 441,08 km^2 (41,21%), 180,71 km^2 (16,88%), 15,05 km^2 (1,41%) укупног подручја истраживаног подручја утврђено је као непогодно, слабо погодно, умерено погодно, веома погодно и веома високо погодно, респективно. Подручје веома високе погодности је пожељније за локацију постројења за пречишћавање отпадних вода, због њиховог минималног утицаја на животну средину, јавно здравље и исплативије у односу на друге делове истраживаног подручја. Ово истраживање може помоћи надлежним органима да формулишу своје стратегије развоја у складу са одабраном погодном локацијом постројења за пречишћавање отпадних вода која је доступна у том подручју.

Кључне речи:
ГИС, Weighted Overlay Analyses, постројење за пречишћавање отпадних вода.

Introduction

Wastewater also knows as waste water is the water-carried waste both in solution or suspension that is intended to be disposed from a community. 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 (WRRC, 2008). Wastewater Treatment Plant is a facility designed to receive the waste from domestic, commercial and industrial sources and to remove materials that damage water quality and compromise public health and safety when discharged into water receiving systems (Smith et al. 1999; Hughes, 2004; Fraschetti et al. 2006; Milnes & Perrochet, 2007). The Remote Sensing and GIS applications give a simple way of integrating and analyzing this environmental data for efficient and successful implementation of an environmental project (Osman, 2013). Deepa et al. (2015) discussed a GIS based approach to select appropriate wastewater treatment technology, a case study of Shollinganallur Taluk Kanchipuram District, Tamil Nadu.

Zhou et al. (2022), explained the location selection method for wastewater treatment plants integrating dynamic change of water ecosystem and socio-cultural indicaors, a case study aof Phnom Penh. The results demonstrate that the selected locations are all highly suitable and outside zones where construction is forbiddan. The method proposed in the article provides a more comprehensive and scientific perspective for WWTP location selection. The geographical information system (GIS) can manage multiple sccources and large amounts of spatial data (Kao et al. 1996). The Location of WWTPs can be determined using GIS by analyzing various indicaors, including topography, wind direction, hydrology, land use type, and distance from water bodies, (Abdalla & Khidir, 2017; Hongbo, 2019; Nigusse et al. 2020).

Liu et al. (2022) developed A GIS-Based Method for Identification of Blindness in Former Site Selection of Sewage Treatment Plants and Exploration of Optimal Siting Areas: A Case Study in Liao River Basin. Wastewater treatment is a critical component of a sustainable and clean environment. Itvinvolves the process of eliminating pollutants and contaminants from wastewater to ensure it is safe for disposal or reuse (Yang et al. 2023). Abdelmagid et al. (2024) integrated FAHP and GIS in the assessment process enables decision-makers to consider various technical, economic, environmental, ecological, and management aspects, thereby providing a comprehensive framework for site selection that can be replicated in other regions with different conditions. This approach enhances the decision-making process in municipal management and promotes more informed and effective planning in the Tabuk region.

The sewage treatment plants tend to be regarded as disposal facilities in China, as the national reclamation rate is less than one-tenth of wastewater, and energy recovery is even less common, except for in key cities, such as Beijing (Smith et al. 2018). Hence, this research attempted the relevant database in a spatial framework to evolve a wastewater treatment plant site map for Upper Ponnaiyar River basin with the application of Remote Sensing and GIS techniques. 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.

Study area

The study area, Upper Ponnaiyar watershed, from part of Krishnagiri and Dharmapuri district of Tamil Nadu which has been selected for the study lies between 12°24’36.42” to 12°52’37.73”N latitude and 77°41’18.25”E to 78°12’54.13”E longitude (Fig. 1). It covers a geographical area of 1070.27 km^2 and fall in parts of survey of India toposheet Nos. 57 H and 57 L. The Ponnaiyar River originates in the Chikkaballapur district of Karnataka at an elevation of about 900 m above Mean Sea Level and then flows towards south east direction for a distance of 400 km through Karnataka and Tamil Nadu and finally emptying into Bay of Bengal. The district headquarters are well connected with other towns in the neighbouring districts, as well as with the towns in the neighbouring States of Andhra Pradesh & Karnataka. Bangalore to Chennai and Bangalore to Salem National Highways pass through the study area.

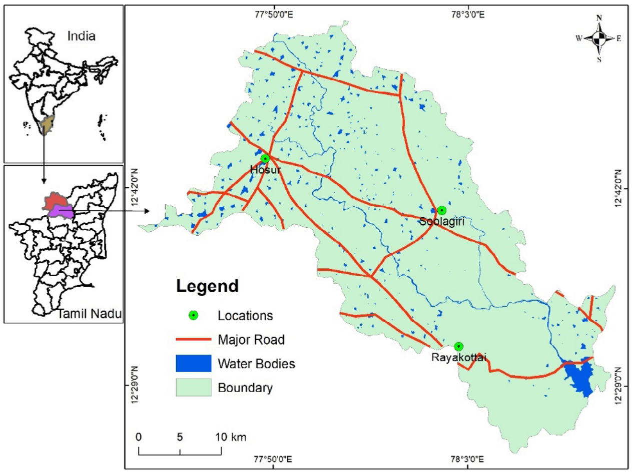

Fig. 1. Location map of the study area.

Methodology

In the present study, there are seven land suitability factors that have been chosen for site suitability assessment such as land use, geology, soil, drainage density, road proximity, elevation and slope. Thematic maps of the study area can beprepared by integrating survey of India toposheet of 1:50,000 scale, existing maps, IRS LISS III satellite image and SRTM image by using the software ArcGIS 10.8. These maps were verified in the field through extensive ground truth and necessary corrections were made wherever required (Table 1). The methodologies mainly based on GIS-based weighted index overlay analysis.The IRS LISS III image has utilized for preparation of land use/land cover patterns in the study area. From the SRTM

***Table 1.** Data used.*

Sl.No.	Parameters/Satellite data	Souce	Scale
1	IRS LISS III	NRSC	25 m resolution
2	Elevation	SRTM DEM	90 m resolution
3	Slope	SRTM DEM	90 m resolution
4	Land use/Land Cover	IRS LISS III	As per map
5	Drainage Density	Toposheet	1:50,000
6	Road Proximity	Toposheet	1:50,000
7	Geology	GSI	1:50,000
8	Soil	NBSS	1:50,000

DEM 90m resolution satellite data utilized for preparation of slope degrees and elevation map. Geological features have been prepared from the GIS published map and soil information gathered from the Soil Survey of India map. The drainage line digitized from Survey of India toposheet and drainage density was generated from ArcGIS tool. The road information was also gathered from toposheet and road proximity maps by using the buffer tool in GIS software.The ranks and weightages were assigned to all the thematic data depends on the importance of influence for locating the plant. The weightage assigned for different themes is shown in the Table 2. Then, all the thematic layers were integrated; the weightages of each parameter added and finally, the study area has been divided into very high suitable, high suitable, moderate suitable, low suitable and unsuitable for concluding the site suitability (Fig. 2).

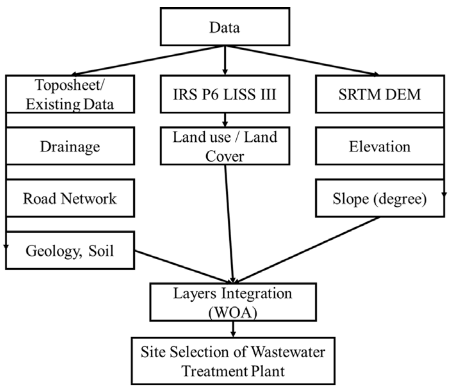

***Fig. 2.** Flow Chart Methdology for Selection of Site Suitable Wastewater Treatment Plant.*

***Table 2.** Effect of influencing factor, relative rates and score for each potential factor.*

S.No	Factor	Major effect (a)	Minor effect (b)	Proposed relative rates (a + b)	Proposed score of each influencing factor
1	Road Proximity	2	0	2	13
2	Land use and Land cover	2	1.5	3.5	22
3	Soil Order	4	0	4	25
4	Drainage Density	1	0.5	1.5	9
5	Slope (Degree)	2	0.5	2.5	16
6	Elevation	1	0.5	1.5	9
7	Geology	1	0.5	1	6
	Total			16	100

Calculation of Weighted Value

The weighted values were computed with the help of multi influence factor (MIF) method, with assigning the distinctive parameters, road proximity, land use and land cover (LULC), soil, drainage density, slope, elevation and geology (Fig. 3). The impact

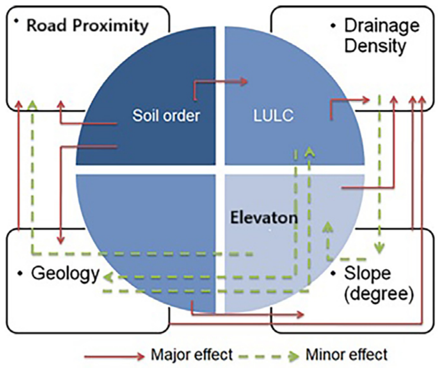

***Fig. 3.** Interrelationship between the multi-influencing factors concerning the land capability for waste water treatment*.

of each major and minor factor is assigned weightage values of 1.0 and 0.5 as shown in Table 2. The combined weighted of both major and minor impacts are considered for calculate the relative rates. This rate is additionally used to calculate the value of each impacting factor. The proposed score for each influencing variable is calculated by utilizing the formula;

$$Wt = \frac{(A+B)}{\sum(A+B)}\, x\, 100 \quad (1)$$

Where, A is the major interrelationship between two elements and B is the minor interrelationship between two variables. The concerned score for each affecting component was partitioned similarly and allocated to each reclassified factor.

Factors Influencing Land Capability

Elevation: The elevation is an important parameter in designing plants and wastewater networks. During the construction of Wastewater Treatment Plant (WWTP), the path of the main collector of the wastewater was considered. In optimum design, the wastewater flows to the treatment in an open channel using gravity. The elevation of the site WWTP should be lower than the lowest parts of the area (below the local datum). These features along with other parameters were determined for selecting the final sites.The elevation map was generated from the SRTM DEM with 90m resolution data and shown in Fig. 4. The elevation ranges from 468 to 1029 m, (above mean sea level – amsl) assigned to rank and weights.

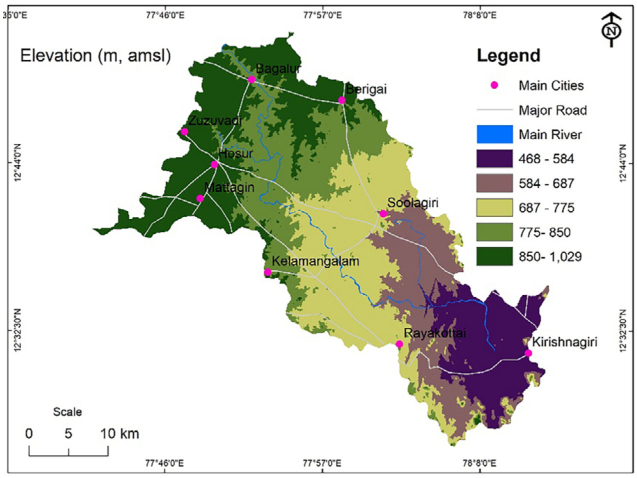

Fig. 4. Elevation of the study area.

Slope: In site selection studies, the slope is an important component, both environmentally and economically. Construction of WWTP on steep sites will increase the cost of excavation and embankment and also intensify the wastewater flow to surface and underground water resources (Omer & Sami 2017). Lin & Kao (1999) stated that slopes that are less than 12% steep prevent the runoff pollution. Slope layer was obtained from Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) 90 m-resolution (Fig. 5). The slope of the area is classified into five classes, and appropriate slope for the construction of WWTP is between 0–3°, which is placed in the very suitable class. The low angle of the slope may get good gradual flow of wastewater collection and to avoid over land flow during rainy seasons. Slopes that are more than 16° prevent the runoff, wastewater inappropriate way and are not suitable for civil construction.

Land use/Land Cover: Land use/land cover plays a vital role as it is used for identifying the

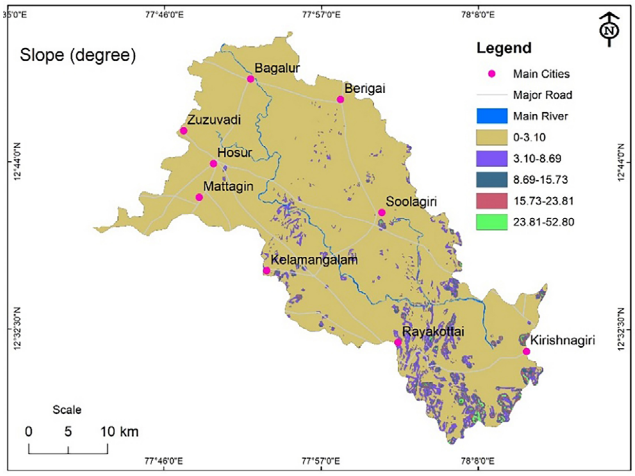

Fig. 5. Slope (degree) in the study area.

suitable site. The land use/land cover map was prepared from IRS LISS III satellite image using interpretation key elements and it is shown in Fig. 6. River and water bodies, built-up, agricultural land, forest land and barren land are major land use/land cover classes in the present study. In land use, ranks are assigned based on the importance of the feature. Rank 5 indicates the very highest priority; Rank 3 indicates medium priority and the Rank 1 indicate the low priority. Based on the feature importance the rank is assigned from 1 to 5 in land use classification.

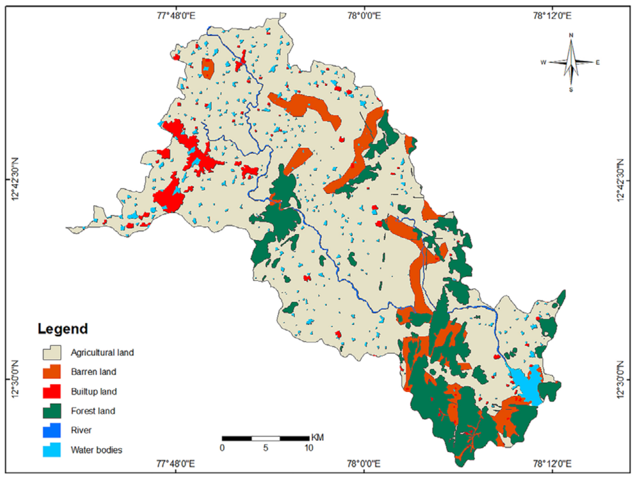

Fig. 6. Land use/land cover map of the study area.

Drainage Density: All the drainages were drawn from Survey of India topographical map of 1:50.000 scale. The drainage network consists of the major river – Upper Ponnaiyar as it cuts across the study area and the surrounding tributaries. The map was reclassified into five classes, viz; 0.25–1.5, 1.6–2.7, 2.8–3.9, 4.0–5.1, and 5.2–6.4 km/km^2 (Fig. 7). Similarly, ranks were assigned to drainage density; based on surface infiltration and runoff. The area near high drainage density is suitable for WWTP which is related to low permeability, which leads to low infiltration and increased runoff.

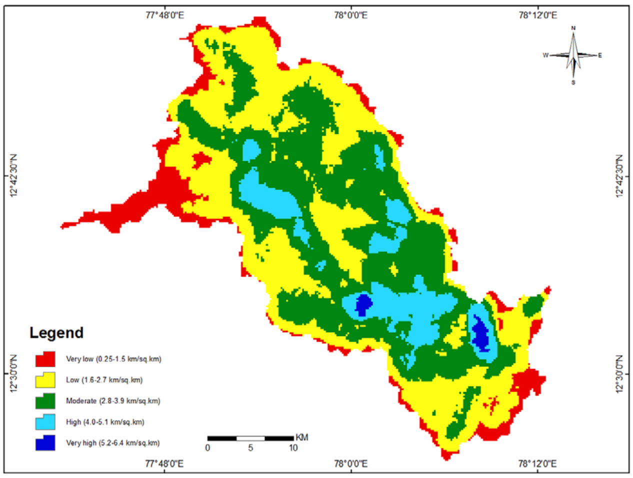

Fig. 7. *Drainage density in the study area.*

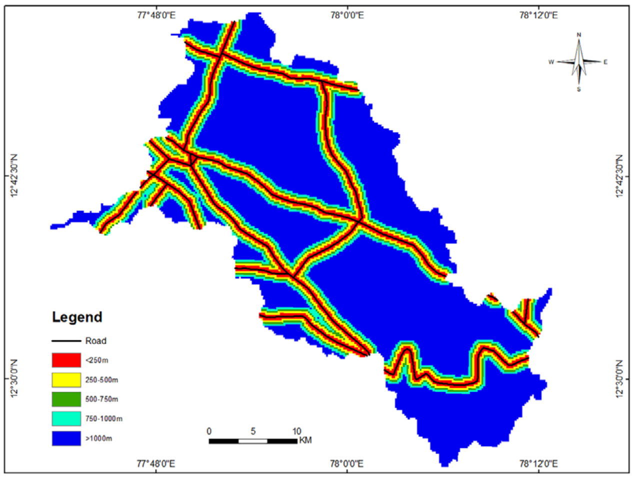

Fig. 8. *Distance from the road network in the sut.*

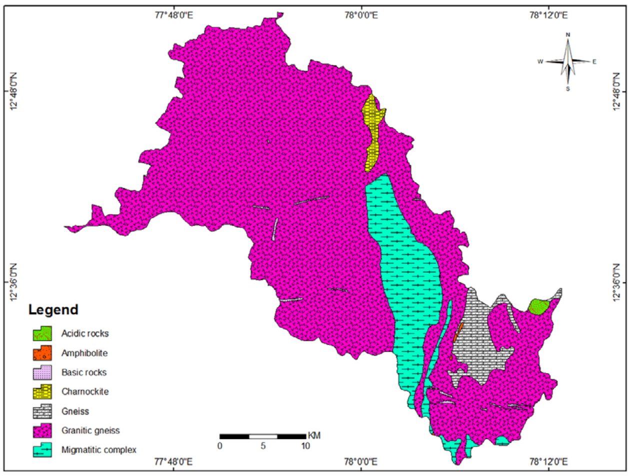

Fig. 9. *Geological settings of the study area.*

Road Proximity: The major road network is prepared from Survey of India toposheets and shown in Fig. 8. The national highways NH-7 and NH-207 passes in the study area. Ideally, the wastewater treatment plant should be away from major roads. Distance from the roads increases the cost of wastewater treatment plant construction and maintenance; however, the presence of the wastewater treatment plant close to the roads affects the landscape, climate, and the public health (Omer & Sami 2017). In this study four categories of buffer zones express the distances from the roads, these are: <250m, 250–500m, 500–750m, 750–100m and >1000m. In this case, higher rank was given to away from the main road and gradually low and very lowest ranks were assigned closer to the road networks.

Geology: The lithology play an important role in land suitability site selection. The rock complex in the study area were identified as granitic gneiss, migmatitic complex, gneiss, charnockite, basic rocks, amphibolites and acidic rocks (Fig. 9). The study area forms part of the polymetamorphic and multistructural Archaean Complex of Peninsular India and is underlain by crystalline formations. Therefore, the lowest ranks were assigned to the geological features in the study area.

Soil. Soil play an important role in the eventual removal of the waste. Soil texture controls the seepage of wastewater, absorption of pollutant, and surface water penetration into landfills (Thoso, 2007). The soil orders of the watershed are broadly grouped into alfisols, entisols, hill soil and inceptisols. The gravelly clay type of soil is found predominantly in the study area (Fig. 10). The clayey soil is found towards the north, northwest and central portion whereas the slightly unconsolidated soil like enthusiastic seen

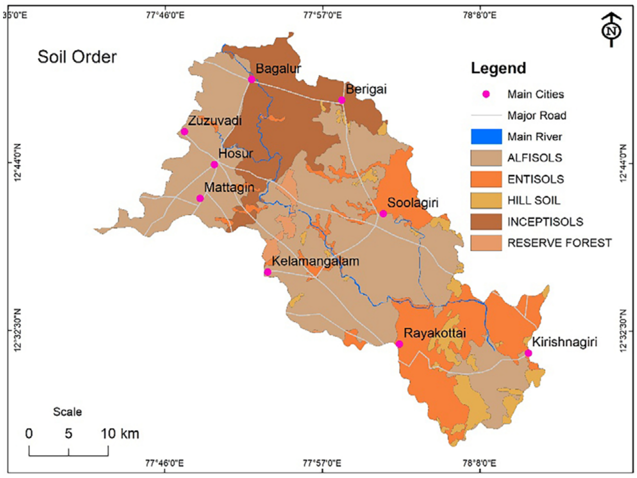

Fig. 10. *Soil order in the study area.*

distributing on the east and the southern portion of the study area. Based on the infiltration rate of the soil characteristics rank has been assigned from 1 to 5.

Composite Suitability Index (CSI)

Grouping of polygons of high ranks of all the thematic layers has helped in delineating the sites that are excellent for construction of water harvesting structures. Based upon the standard deviation, the polygons were grouped into classes suitable for construction of ground water recharge structures. A Composite Suitability Index (CSI) has been calculated for each composite unit by multiplying weights with the rank of each parameter and summing up the values of all the parameters. Categorization of the CSI is achieved by ranging the CSI into five classes.

Class 1 Maximum >		CSI ≥ 4σ
Class 2	4σ >	CSI ≥ 3σ
Class 3	3σ >	CSI ≥ 2σ
Class 4	2σ >	CSI ≥ 1σ
Class 5	1σ >	CSI ≥ Minimum

Where σ represent standard deviation.

The weighted index overlay was calculated using the formula sum (weights × ranks) for every factor (Table 3).

WIO = ∑ [(9×Elevation ranks) + (16×Slope ranks) + (9× Drainage density ranks) + (22×land use/land cover ranks) + (13×Road proximity ranks) + (6×Geology ranks) + (25×Soil ranks)]

Table 3. *Area coverage and identification of suitable areas.*

S.No.	Suitability	suitability classes (σ=45)
1	Unsuitable	130-175
2	Low	175-220
3	Moderate	220-265
4	High	265-310
5	Very high	310-355

Results and discussion

The weighted index overlay analysis was performed on a GIS platform to identify the suitable location for a land suitability site. The prepared various thematic maps such as land use/land cover, slope, elevation, road proximity, drainage density, geology, and soil were used for weighted overlay analysis. The selection of criteria for identifying the suitable land suitability site is based on the requirement in the particular region; it may not be a universal standard (Makan et al., 2012). Based upon the importance of the each feature weight has been assigned (Table 3). Weighting is used to express the relative importance of each factor to another (Subramani et al., 2014). The larger the weight, the more important is the factor in overall utility. In a weighted overlay analysis, GIS-based model was created to identify the suitable site for wastewater treatment plant that can be found out and classified as good, moderate and poor as shown in Fig. 11.

The area coverage of each suitability index of the sites was calculated in ArcGIS environment and has shown that 15.05 km^2 (1.41%) of the study area is very high (restricted) for wastewater treatment plant site as the areas are environmentally favourable and economically accepted to be proposed as wastewater treatment plant site. This unsuitable (restricted) site include, areas with steep slope (>16%), areas with higher elevation (>916 m), areas with close to road networks and far from road networks with a 250 m buffer zone. The main advantage of these areas restriction was to minimize their negative effects on environment and

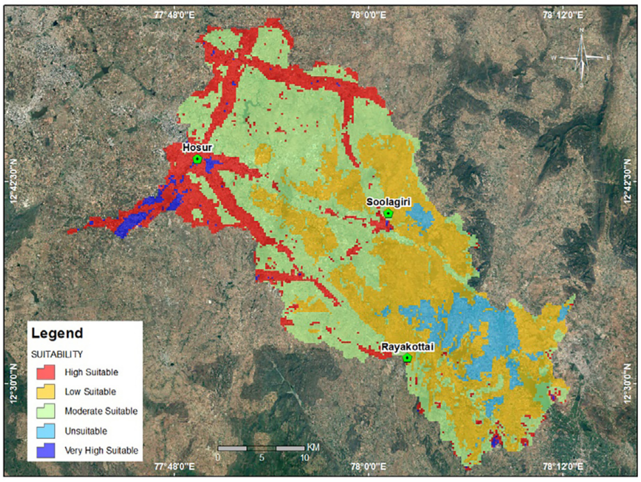

Fig. 11. Site suitability for Wastewater Treatment Plant (WTP).

public health as well as to minimize the cost of construction and maintenance of the wastewater treatment plant site. However, 180.71 km^2 (16.88%) of the area was high suitable for wastewater treatment plant site and the area of 441.08 km^2 (41.21%) moderately suitable. Out of the remaining area, 359.55 km^2 (33.59%) and 73.88 km^2 (6.90%) of the area was very low suitable and unsuitable, respectively, these areas are preferable for waste-water treatment plant, because of their minimum effect on environment, public health and cost effective than other parts of the study area, shown in with different suitability indices (Table 4).

***Table 4.** Features in each theme and weight factors.*

S.No.	Theme	Classes	Ranking	Weight	Level of site suitability
1	Elevation	468–584	5	9	Very high
		584–687	4		High
		687–775	3		Moderate
		775–850	2		Low
		850–1029	1		Unsuitable
2	Slope	0–3.10	5	16	Very high
		3.10–8.69	4		High
		8.69–15.73	3		Moderate
		15.73–23.81	2		Low
		23.81–52.80	1		Unsuitable
3	Drainage density	0.25–1.5	1	9	Unsuitable
		1.6–2.7	2		Low
		2.8–3.9	3		Moderate
		4.0–5.1	4		High
		5.2–6.4	5		Very high
4	Land use/land cover	Barren land	4	22	High
		Forest land	3		Moderate
		Agricultural land	3		Moderate
		Builtup land	2		Low
		Water Bodies	1		Unsuitable
		River	1		Unsuitable
5	Road proximity	<250	1	13	Unsuitable
		250–500	2		Low
		500–750	3		Moderate
		750–1000	4		High
		>1000	5		Very high
6	Soil	Entisols	4	25	High
		Reserve forest	3		Moderate
		Hill soil	3		Moderate
		Inceptisols	2		Low
		Alfisols	2		Low
7	Geology	Gneiss	2	6	Low
		Granitic gneiss	2		Low
		Basic Rocks	2		Low
		Amphibolite	2		Low
		Charnockite	1		Unsuitable
		Migmatitic complex	1		Unsuitable
		Acidic rocks	1		Unsuitable

Conclusions

Wastewater treatment plant is great in demand due to the increasing population, urbanization and industrialization. The methodology employed in this study described the GIS and weighted index process techniques for the selection of suitable sites for the wastewater treatment plants in the Upper Ponnaiyar watershed. The result of this study indicated that, out of the total area, 73.88 km^2 (6.90%) and 359.55 km^2 (33.59%) of the area was very highly suitable and highly suitable, respectively. It has been identified the location in the Southeast part of the study area which fullfill all the criteria for a wastewater treatment suitability site. These areas are preferable for wastewater treatment plant, because of their minimum effect on the environment, public health and cost effective than other parts of the study area, with different suitability indices. With the increasing acknowledgement of the significance of site selection, more research will be conducted in this field. In order to enrich the framework of site selection models, this study developed a combined multi-criteria site selection model with GIS, and Remote Sensing (RS) technologies, revealing blindness in former site selections of sewage treatment plants and exploring optimal siting areas. Hosur Town has the largest optimal siting areas because of its gentle terrain and acceptable soil types. This town can be considered as a pilot site for the construction of wastewater treatment plants.

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Резиме

Анализа погодности локације заснована на ГИС-у за разграничење потенцијалних зона постројења за пречишћавање отпадних вода у сливу Горњег Понајара, Јужна Индија

Постројења за пречишћавање отпадних вода су веома важна због растуће популације, урбанизације и индустријализације. Методологија која је коришћена у овој студији заснована је на ГИС техникама за избор погодних локација за постројења за пречишћавање отпадних вода у сливу Горњег Понајара. Резултат ове студије је показао да је од укупне површине 73,88 km2 (6,90%) и 359,55 km2 (33,59%) подручја веома високо погодно и високо погодно, респективно. Идентификована је локација у југоисточном делу подручја истраживања која испуњава све критеријуме у погледу погодности локације за пречишћавање отпадних вода због минималног утицаја на животну средину, јавно здравље и исплативости у односу на друге делове подручја истраживања, са различитим индексима погодности. Са све већим значајем избора локације, спровешће се више истраживања у овој области. Да би се обогатио оквир модела за избор локације, ова студија је развила комбиновани вишекритеријумски модел избора локације са ГИС техникама и даљинском детекцијом указујући на оптимална подручја за локацију. Град Хосур поседује највећа оптимална подручја за локацију постројења за пречишћавање отпадних вода због свог терена са малим нагибом и прихватљивих типова земљишта. Овај град се може сматрати „пилот локацијом“ за изградњу постројења за пречишћавање отпадних вода.

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