Final Project
(Report)

Title: Integration of GIS and MCDM for evaluation of Combined Cycle Power Plant Locality
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Project Repository: *https://github.com/Zain1443/GIS5571*
Google Drive Link:
Time Spent: 120 hours

Abstract

Site selection is a key phase of the sitting process of any thermal power plant and may significantly affect the capital and generation cost during its entire life cycle. This study introduces a GIS-based protocol to locate optimal sites for combined cycle power plant installation, selecting Sindh province, Pakistan, as a case study. This analysis is based on different economic, technical, and environmental criteria such as proximity to the gas source, national grid and water source, road accessibility, safe distance from urban settlements, land cover, and site elevation. Due to the unavailability of indigenous gas reserves in Pakistan to support future CCPPs, the current project will use the imported RLNG pipeline as a fuel source. Suitability scores for each criterion are assigned using information from published literature, subject matter expert opinion, criteria constraints, and exclusion zones. The results show that less than 1% of the studied region is very highly suitable for CCPP placement mainly due to the extended distance from the gas source in the east, low elevation in the south, and some bordering areas of the studied region. Additionally, the existing CCPPs were placed on the suitability map and it was found that only half of the existing six CCPPs are installed in high suitability zones. The project aims to streamline the site suitability process by making the model scalable and workflow transferable. It can be used for locating optimal sites for power generation plants in large study areas based on hydrocarbon or renewable energy.

Keywords: *Site Suitability Analysis, GIS, AHP, CCPP, Power generation planning*

Problem Statement

Pakistan has been going through severe energy crises for decades primarily due to inefficient use of energy resources and a lack of comprehensive long-term energy policies. There is a need for new and efficient power plants in the country, such as CCPP. A (CCPP is an assembly of thermodynamic cycles that work in tandem to convert heat energy from the same source to mechanical energy. The first challenge in designing and constructing a combined cycle power

plant is to identify and measure the merits of potential locations against the needs of CCPP. This study aims at conducting site suitability analysis research for a CCPP in Sindh province, Pakistan, based on economic, technical, and socio-environmental aspects by incorporating GIS with MCDA. Sindh is chosen as an area of interest because it has the coast and infrastructure to carry out RLNG transmission.

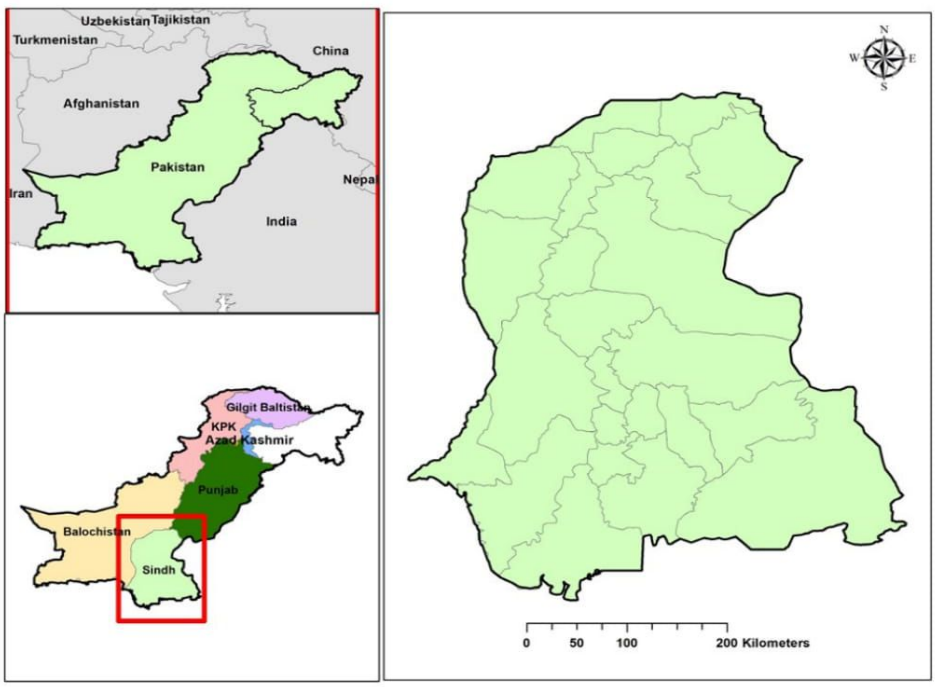


Figure 1: Location map of the proposed study.

Table 1. Required Data for this project.

#	Requirement	Defined As	(Spatial) Data	Attribute Data	Dataset	Preparation
1	Study Extent	Vector data to define the study's extent	Vector	Polygon	-	Yes
2	RLNG pipeline	Vector data to locate the RLNG pipeline in the study extent	Vector	Polylines	-	Yes
3	Electrical Grid	Vector data to locate the national grid	Vector	Polyline	-	Yes
4	Roads Network	Vector data to highlight all roads in the study extent	Vector	Polyline	-	Yes
5	Digital Elevation Model	Raster data to determine slope in the study extent.	Raster	Pixel/Cells	USGS/NASA Landsat	No

6	Land cover	Raster data to determine land use in the study extent.	Raster	Pixel/Cells	USGS/NASA Landsat	No
7	Urban Settlings	Vector data (point) to locate city centers in the study extent	Vector	Point	-	Yes
8	Streams	Vector data (polylines) to locate river streams in the study extent	Vector	Polyline	-	Yes
9	Slope	Raster data to show the slope of the land in the study extent	Raster	Pixel/Cells	-	No

Input Data

The input data for this project are from the Sui Southern Gas Company Ltd., Pakistan; National Transmission and Despatch Company, Pakistan; Landsat imagery courtesy of NASA Goddard Space Flight Center; the U.S. Geological Survey. Some of the vector layers are prepared after a lot of data wrangling, analysis of historical maps, image georeferencing, and digitization.

Table 2. Input Data for this project.

#	Title	Purpose in Analysis	Link to Source
1	Study Extent	For defining the study area	-
2	RLNG pipeline	Economic consideration: CCPP site should be close to the RLNG pipeline.	-
3	Electrical Grid	Economic consideration: CCPP site should be close to the National grid.	-
4	Roads Network	Economic consideration: CCPP site should has road accessibility.	-
5	Digital Elevation Model	Technical Consideration: CCPP site low elevation area is vulnerable to flooding and high elevation region's low air pressure could also adversely affect the operations of the mechanical equipment	USGS/NASA Landsat
6	Land cover	Study extent land covered by forests, wetlands, impervious surfaces, agriculture, and other land & water types.	USGS Landsat
7	Urban Settlings	Environmental Consideration: CCPP site should be farther away from streams.	-
8	Streams	Economic Consideration: CCPP site should be close to streams.	-
9	Slope	Technical Consideration: CCPP site should have a relatively low slope.	-

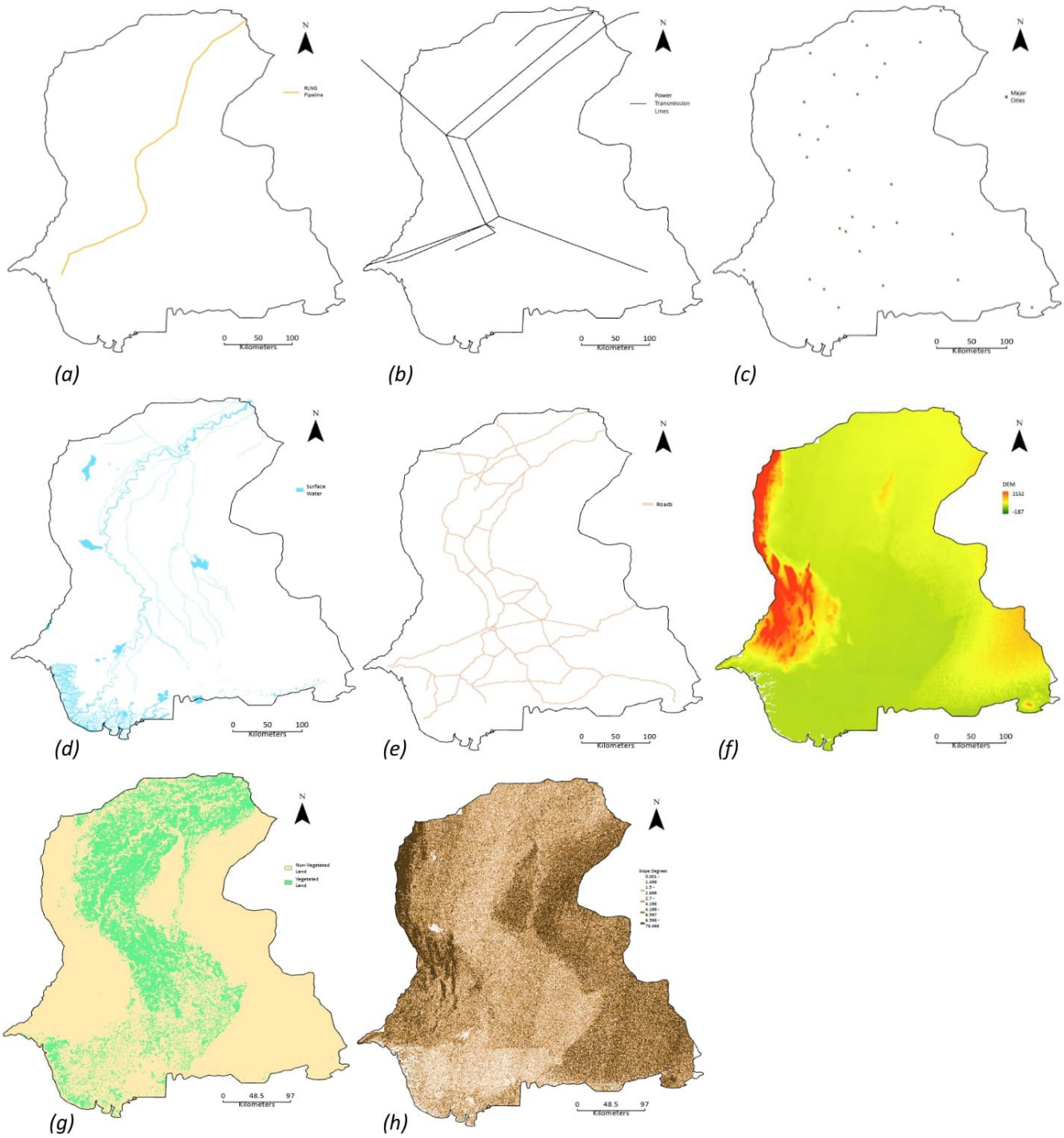


Fig. 1: Input datasets a) RLNG Pipeline, (b) Power Transmission Lines, (c) Major City Centers, (d) Surface Water Sources, (e) Road Network, (f) Site Elevation, (g) Vegetated Land, and (h) Slope

Methods

Site selection assessment for a CCPP is a complex and systematic mechanism, including establishing a selection criterion, determining criterion weights, performing data analysis, estimating scores of all candidate sites, and evaluating the suitability of all nominated sites. In this study, the integration of GIS and multi-criteria evaluation is used to assess land suitability. The methodology of the project is summarized in the flow chart, as shown in Figure 1.

Figure 2: Flow Diagram of the Project Methodology.

The criteria weights estimate the worth of selection inputs against each other, and their weights have a significant impact on the outcomes. The relative significance of each criterion compared to another is estimated using Analytical Hierarchy Process. A survey questionnaire was designed to acquire inputs from the experts working in the various relevant sectors. The opinions of subject matter experts were converted to numerical information using the linguistic scale provided in Table 1. The relative significance of one criterion compared to another is measured using a numerical scale of 1–9, with 1 and 9 indicating equal and extreme importance, respectively.

Table 3. Linguistic Terms scale for AHP method.

Linguistic Term	Numeric Scale	Explanation
Equal Importance	1	Two activities contribute equally to the objective
Moderate Importance	3	Experience and judgment slightly favor one activity over another activity
Strong Importance	5	Experience and judgment strongly favor one activity over another activity
Very Strong Importance	7	One activity is favored very strongly over another activity
Extreme Importance	9	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	1/3, 1/5, 1/7, 1/9	Inverse comparison

Subsequently, Pairwise Comparison and Normalizing matrices were created to determine criteria weight estimation. The consistency ratio was also calculated to make sure the reported scores were consistent. The CR value came out as 0.075, which is less than 0.10, as recommended in the literature. It implies that the reported feedback and decision-making process is consistent.

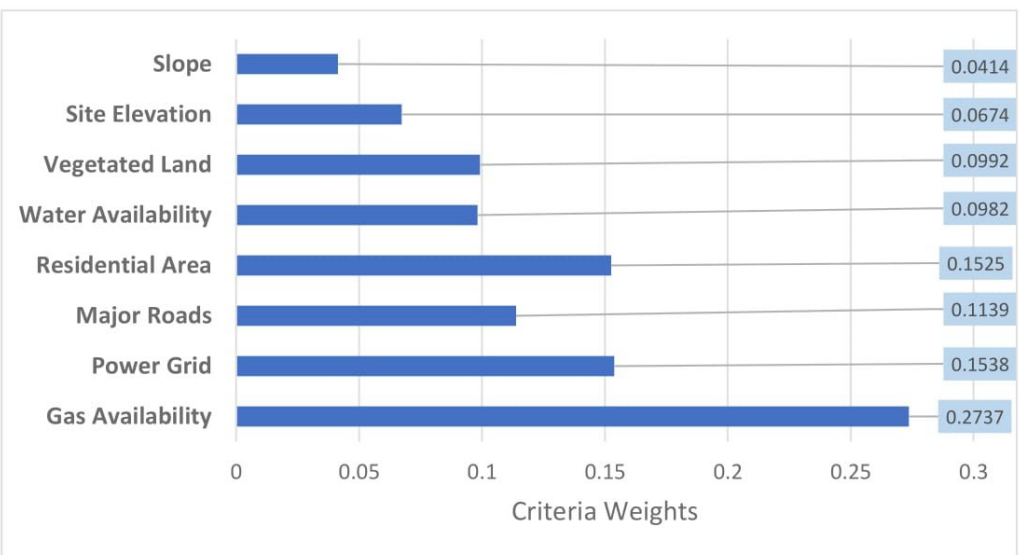


Figure 3: Flow Diagram of the Project Methodology.

Since the input criteria layers are in different numbering systems with different ranges and to combine them into a single weighted overlay analysis, each cell for each criterion was reclassified into a common preference scale, such as 1 to 9, with 9 being the most favorable. The multiple buffers set at a certain distance from each input criterion are summarized in Table 4.

These buffers are then given suitability importance scores based on literature review and inputs taken from professionals working at various thermal power plants across Pakistan. For instance, Ali et al. and Baseer et al. suggested allocating the highest priority to an area up to 12 km from any potential power plant site [1, 2]. Similarly, during the reclassification of the national grid layer, the regions within a 12 km distance from power transmission lines were assigned the highest scores.

Table 4. Reclassified values of preference to areas located at specific distances from selection parameters.

Input Parameter	References	Suitability Scores	9	7	5	3	1
RLNG pipeline	[1-3, 7, 11, 13]	Buffers (km)	5	20	50	100	300
Power Transmission Lines			3	12	36	72	150
Major Water Sources			3	10	35	75	150
Proximity to major Road Network			3	10	30	60	150
Proximity to major City Centers			150	90	40	15	5
Digital Elevation Model		Elevation Range (meters)	21 to 50	51 to 100	101 to 200	201 To 500	-187 to 20 & 500 to 2152
Slope		Degrees	0 to 1.5	1.5 to 2.7	2.7 to 4.2	4.2 to 6.6	6.6 to 76.5

Once the criteria layers were reclassified and weights were assigned, the spatial analyst tool overlayed all seven raster datasets using a standard measurement scale with weights assigned to each parameter based on its importance. The overlay method permits regulating the effect of different criteria in the suitability model by giving a weight to each raster. The final generated suitability map is divided into five categories based on suitability scores, with the most preferred zone having the highest score. Finally, the existing CCPPs will be mapped onto the site suitability map to validate the results of the model.

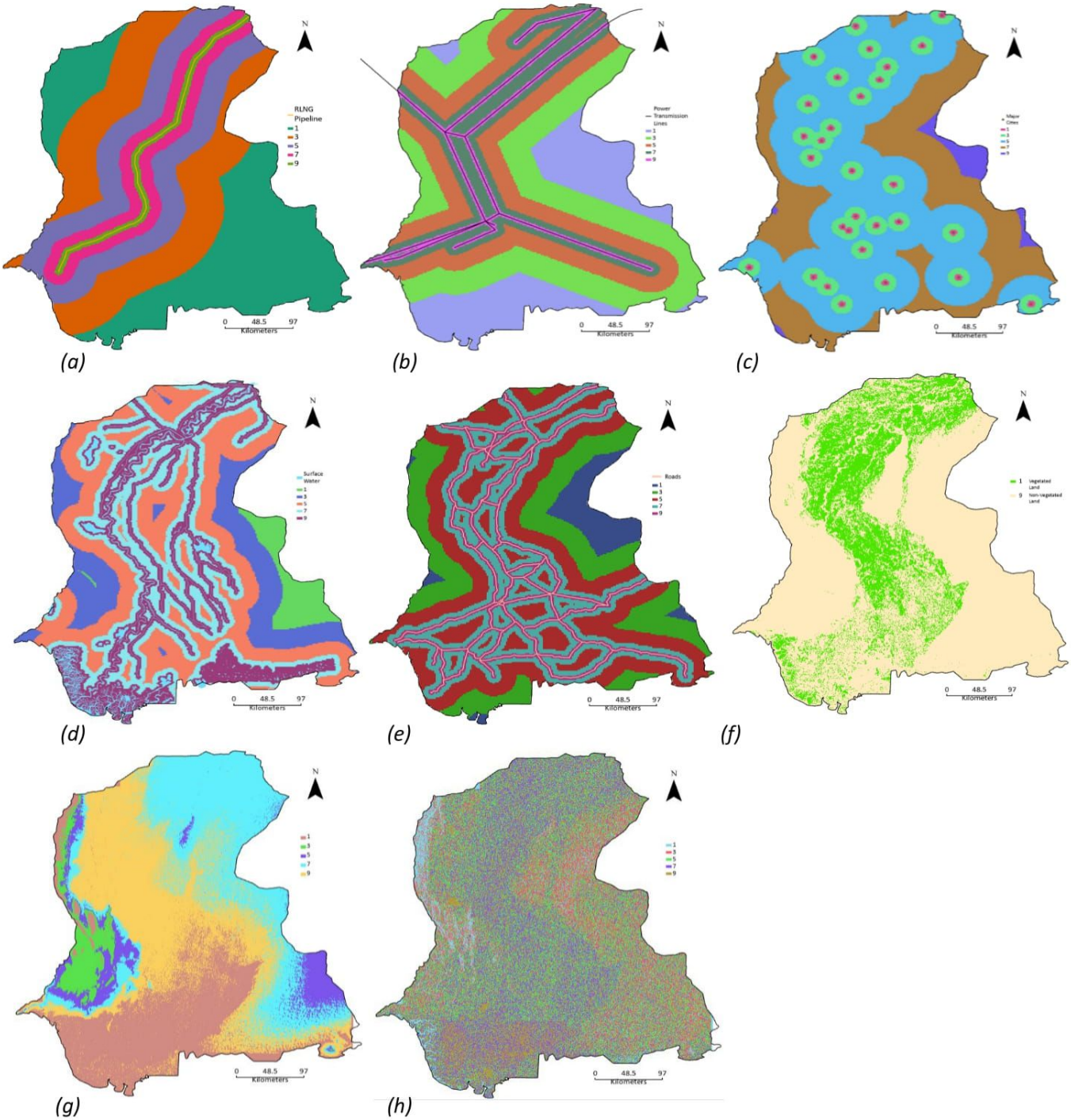


Figure 4: Reclassified Raster datasets of a) RLNG Pipeline, (b) Power Transmission Lines, (c) City Centers, (d) Surface Water Sources, (e) Road Network, (f) Site Elevation, (g) Vegetated Land, and (h) Slope

The other part of the site suitability was to generate a tessellated grid of regular hexagon features to cover the entire study extent. The zonal statistics as a table tool was used to estimate the mean suitability score of each hexagon bin. Subsequently, an optimized hot spot analysis on a finer-resolution hexagonal dataset, with which the mean suitability values were calculated.

Results

The final suitability maps shown in figure 5 categorize the AOI land into five categories based on the suitability scores. According to the criteria weights, over 1/4th of preference was given to gas availability; therefore, the areas with the highest suitability were found in and around the RLNG pipeline. It is pertinent to mention that the final suitability maps generated using Weighted Overlay and Weighted Sum were identical. Because of that, only a weighted overlay map was used to estimate the area percentages for each of the five categories.

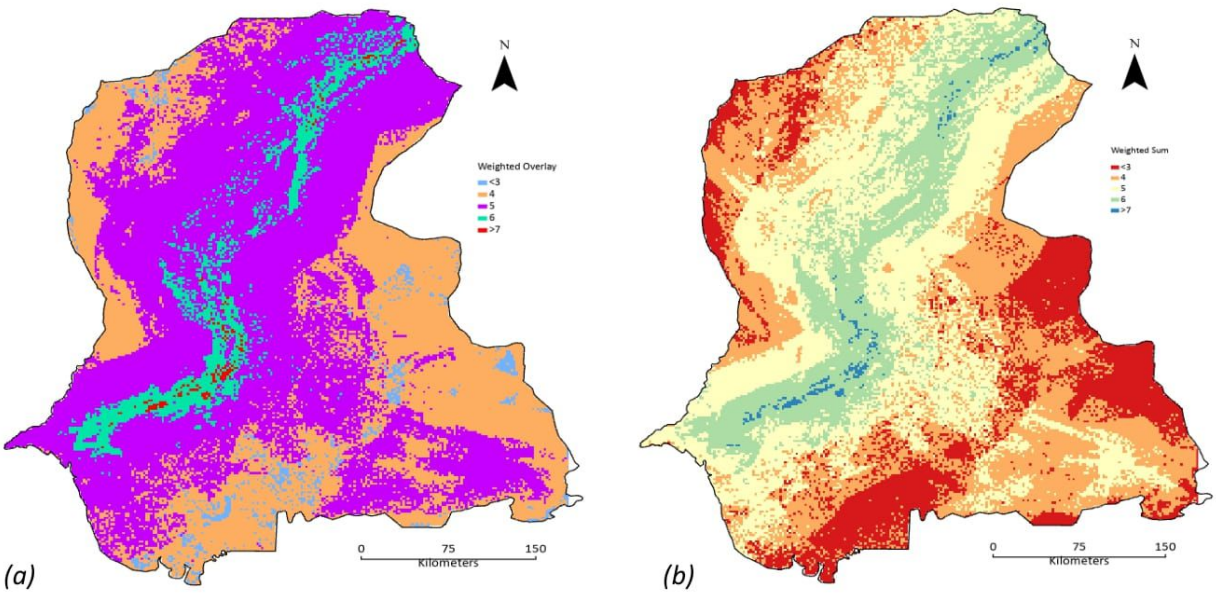
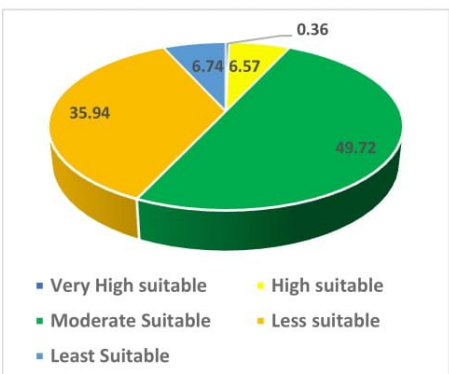


Figure 5: Suitability map using (a) Weighted Overlay and (b) Weighted Sum tools.

The results show that less than 1% of the studied region is very highly suitable for CCPP placement. The regions are mostly in and around the RLNG pipeline, water sources, and power grid, as shown in figure 6 (a). On the other hand, more than 1/3rd of the land was deemed unsuitable based on the criteria and weights used. It is mainly due to the extended distance from the gas source in the east, low elevation in the south, and some bordering areas of the region.

Table 5. Land Suitability Scores, Area for percentages for CCPP installation through Weighted Overlay.

Technique	Suitability Score	Definition	Area (km^2)	Percent (%)
Weighted Overlay	<7	Very highly suitable	503.63	0.36
	6	High suitable	9307.44	6.57
	5	Moderate suitable	70483.75	49.72
	4	Less suitable	50946.25	35.94
	>3	Not suitable	9560.56	6.74



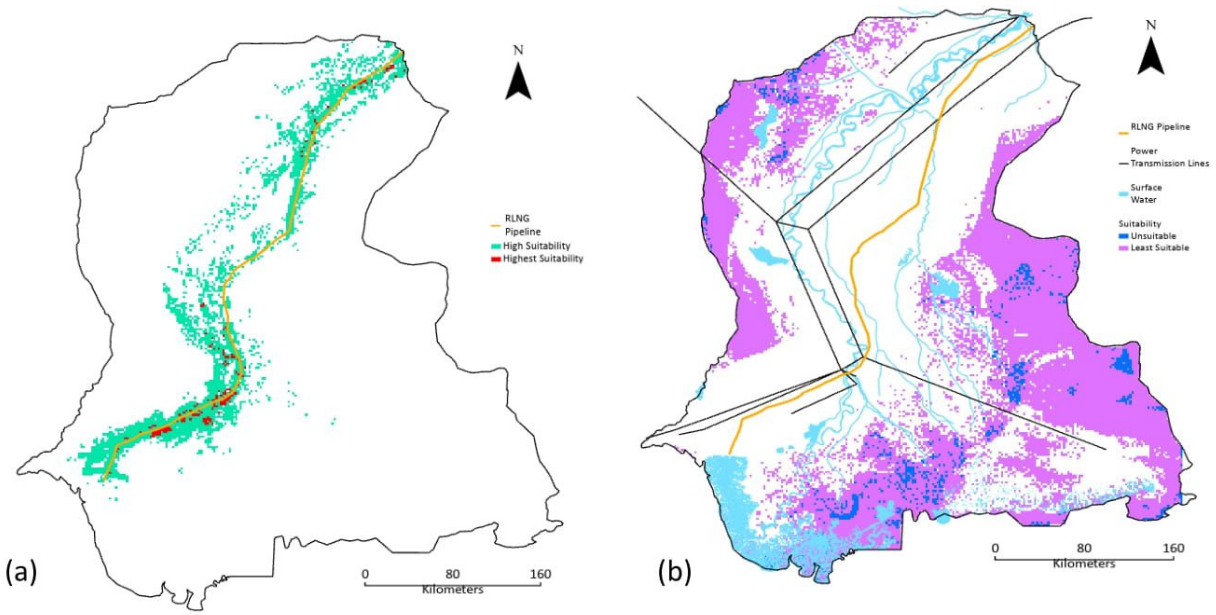


Figure 6:

The other part of the site suitability was to generate a tessellated grid of regular hexagon features (with each size of 10 square kilometers) to cover the area of interest. As per the results, the highest & lowest suitability scores for hexagon bins were 7.80 & 2.7, respectively. The mean came out as 4.95, which is actually not bad considering all the weights and criteria. The optimized hotspot analysis was used to locate the locations with the highest and lowest suitability scores. It also identified high (hotspots) and low (coldspots) clusters at various confidence intervals. This provides a different lens for analyzing suitability areas but is equally useful. For this project, the hot spots were found at the center of the province, while the eastern and western parts were all coldspot clusters, as shown in figure 8 (b).

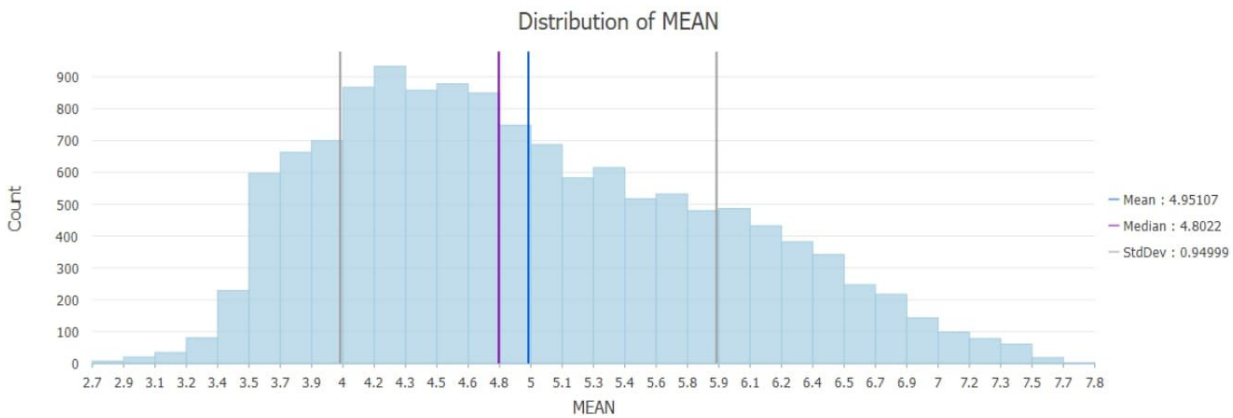


Figure 7: Mean, Median and Standard Deviation of Suitability Scores for each tessellated hexagon.

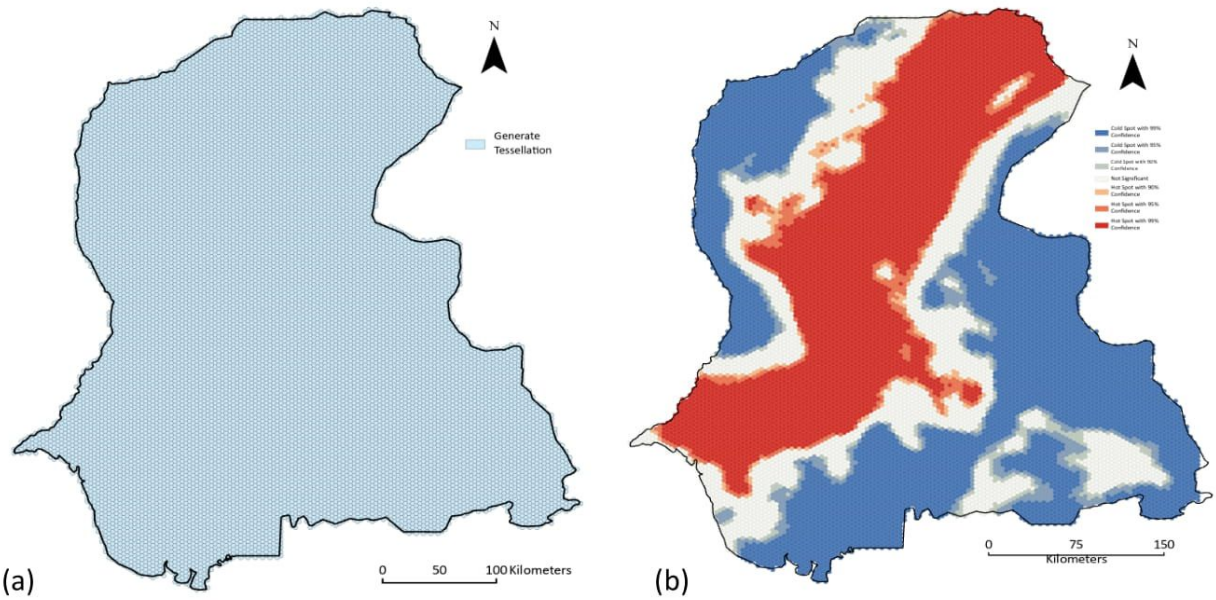


Figure 8: Tessellated hexagon grid and optimized hotspot analysis results.

Results Verification

The results of the model are verified by plotting the existing CCPPs in the area of interest and checking their suitability according to the model suitability maps. Figure 9 reveals that there are no CCPPs installed in the central part of Sindh province but locates two in the south and twice as many in the north.

Figure 9: All existing CCPPs in the area of interest.

It was found that the Gas Turbine Power Station Kotri, Engro Powergen Qadirpur and Guddu Thermal Power are installed in the high suitability regions for both overlay techniques. As per the

selection criteria, weight estimation method, and analysis techniques used in this research study, all existing CCPPs in Sindh are located in moderate to high suitability regions, as shown in figure 10. Considering the depleting indigenous gas reserves in the country, it is quite likely that RLNG may be used as a fuel source for the existing CCPPs in the future. However, the major challenge for energy policymakers is to reinforce the RLNG infrastructure before making such a transition.

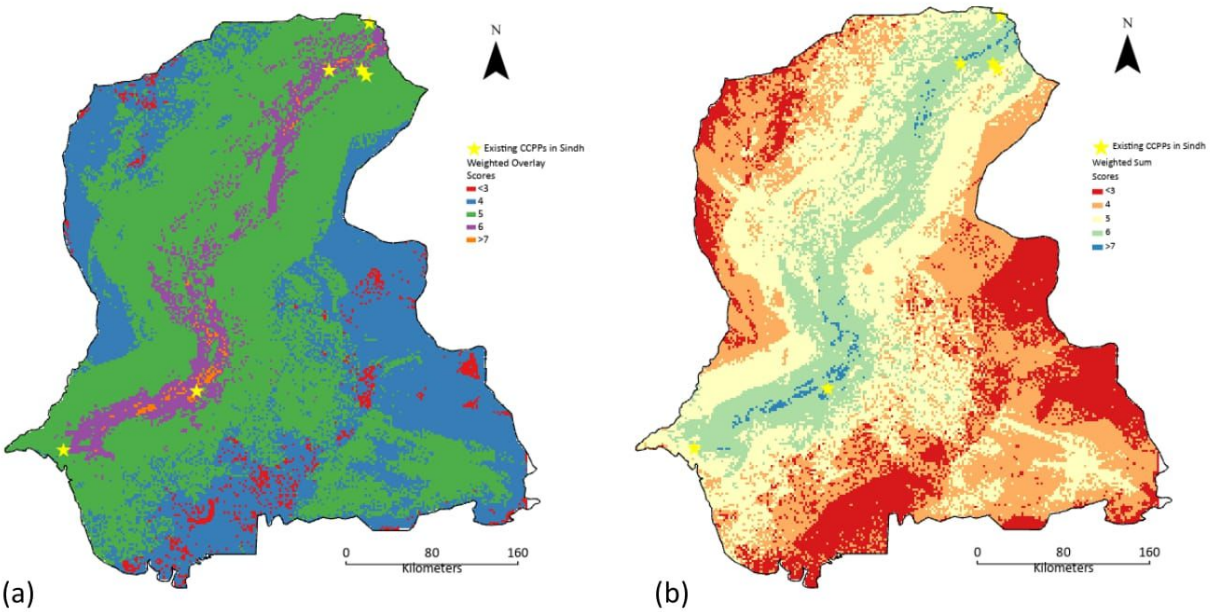


Figure 10: Mapping of existing CCPPs in Sindh on site suitability maps generated using (a) Weighted Overlay and (b) Weighted Sum.

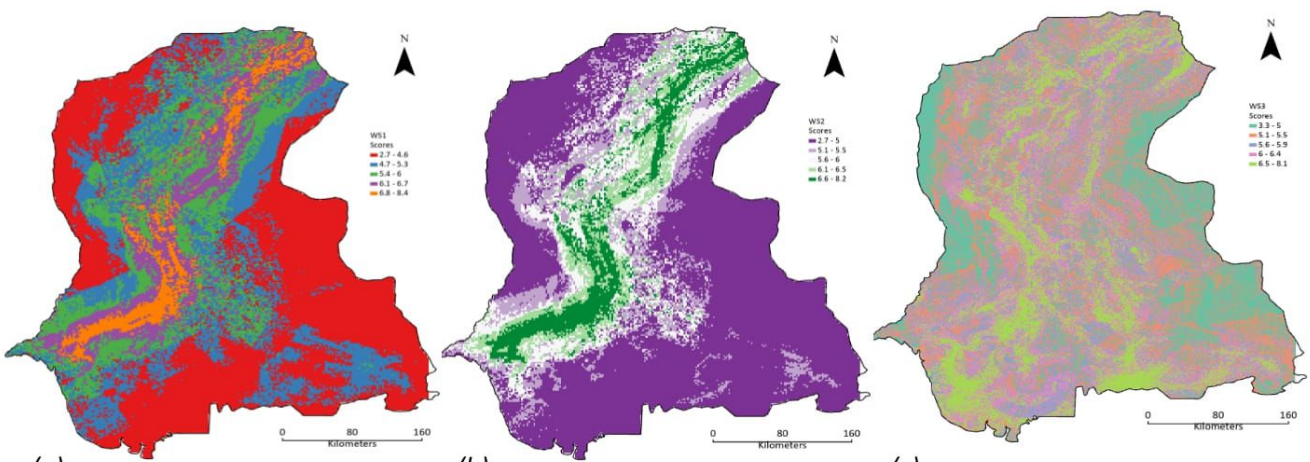
Table 6. Existing CCPPs in Sindh with their respective suitability.

S. No.	Existing CCPPs in Sindh	Technique	Suitability	Score
1.	Guddu Thermal Power	WO	High	6.67
		WS	High	6.88
2.	Fauji Foundation Power Company Ltd., Daharki	WO	Moderate	5.25
		WS	Moderate	5.43
3.	Liberty Power Project, Daharki	WO	High	6.08
		WS	High	6.35
4.	Engro Powergen Qadirpur Ltd., Ghotki	WO	High	6.95
		WS	High	6.89
5.	Gas Turbine Power Station, Kotri	WO	High	6.99
		WS	High	6.88
6.	K-Electric's Korangi GT Power Station, Karachi	WO	Moderate	5.67
		WS	Moderate	5.07

Moreover, the model was rerun after altering each criteria's weight in the decision-making process, and different suitability maps were generated and compared. The results revealed that gas availability is a very highly sensitive parameter in the suitability classification for CCPP installation; whereas the distance from cities is highly sensitive, the elevation and slope are moderately sensitive. This implies that each factor must be given suitable weighting reflecting its importance for the suitability of CCPP in the study area.

Table 7. Some of the different criteria weightage combinations for sensitivity analysis.

Criteria	Weights		
	Scenario A	**Scenario B**	**Scenario C**
RLNG pipeline	10	5	3
Power Transmission Lines	10	5	2
Major Water Sources	15	15	20
Road Network Proximity	10	10	15
Proximity to City Centers	10	15	25
Vegetation	15	15	10
Digital Elevation Model	15	20	5
Slope	15	15	20



(a) *(b)* *(c)*

Figure 11: Suitability Maps generated for some of the different Weight Combination Scenarios.

Discussion and Conclusion

The project's primary aim was to investigate optimal sites for the CCPP installation in Sindh province, Pakistan using an integrated GIS-based MCDM approach. Eight parameters as inputs were identified from the literature and based on consultation with professionals working in different existing powerplants. The input shapefiles were created using spatial and attribute data obtained from secondary sources such as SSGC, NTDC, WAPDA, and USGS. Subsequently, the AHP approach was used to assign weights to evaluation factors based on their relative importance to each other. The decision makers' preferences in determining restrictive and assessment criteria and their weights significantly impact the final suitability map.

The project aims to streamline the site suitability process and make the model as scalable as possible and workflow transferable. Some parameters were dominant contributors in the decision-making process, while others had minimal impact. Due to that, ideal regions for CCPP construction are found in the center & north of the study area. According to the suitability analysis, all existing combined cycle powerplants in Sindh are located in moderate to high suitability regions. Considering Pakistan's depleting indigenous gas reserves, it is quite likely that RLNG can be used as a fuel source for the existing CCPPs in the future. It is suggested that more selection inputs should be considered, and hybrid integrated MCDM techniques such as Fuzzy AHP, TOPSIS, and SMARTS should be used to produce more precise and accurate results.

By working on this project, I did a lot of data wrangling, analysis of historical maps, and image georeferencing to create input shapefiles. I was then able to use different geoprocessing tools and continued to work with raster and vector datasets. Finally, I created suitability maps using two overlay techniques and used Data Management tools to generate a grid of tessellated hexagons, making my results more meaningful. All in all, I found the project very challenging at the start as I spent hours and hours googling stuff, but later it became fun to work on.

References

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Self-score

Category	Description	Points Possible	Score
Structural Elements	All elements of a lab report are included **(2 points each)**: Title, Notice: Dr. Bryan Runck, Author, Project Repository, Date, Abstract, Problem Statement, Input Data w/ tables, Methods w/ Data, Flow Diagrams, Results, Results Verification, Discussion and Conclusion, References in common format, Self-score	28	28
Clarity of Content	Each element above is executed at a professional level so that someone can understand the goal, data, methods, results, and their validity and implications in a 5 minute reading at a cursory-level, and in a 30 minute meeting at a deep level **(12 points)**. There is a clear connection from data to results to discussion and conclusion **(12 points)**.	24	22
Reproducibility	Results are completely reproducible by someone with basic GIS training. There is no ambiguity in data flow or rationale for data operations. Every step is documented and justified.	28	28
Verification	Results are correct in that they have been verified in comparison to some standard. The standard is clearly stated **(10 points)**, the method of comparison is clearly stated **(5 points)**, and the result of verification is clearly stated **(5 points)**.	20	20
		100	98