

## Spatial Environmental Criteria for Siting Industries

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**Abstract:** The paper presents the solution for identifying appropriate locations for industrial setup in Lahore district using GIS based multi-criteria decision analysis as decision support tool (DST). Several environmental indicators were used in this study including air quality index, water quality index, landcover, and built-up/settlements. Thematic layers were developed for these indicators followed by analysis in ArcGIS software's model builder using various geo-processing techniques. As a result the study area is divided into four types of zones (e.g., not suitable, less suitable moderately suitable and suitable) depending on environmental criteria and industrial categorization. The results reveal that 52 % of district area goes to environmentally sensitive zone. In remaining areas possibility of setting industries with their pollution index is proposed. The areas are proposed considering the industry categories such as schedule I industries which are air emission industries and Schedule II industries which are effluent discharge industries as per sectoral guidelines of Pakistan.

**Keywords:** Industrial siting, multi-criteria analysis, environmental perspective, land suitability.

### Introduction

Industrialization is the fundamental condition and backbone for the economic growth of a country. But expansion of industries and location is not supported in sustainable manner. In these scenarios some areas are more susceptible to adverse environmental impacts than others (Hazra, and Acharya, 2015). So land suitability for industrial siting with desired environmental criteria is one of the basic vital decisions. GIS and remote sensing can provide data on land use, topography, drainage system and soil type etc. The integration of non-spatial data with spatial data and the applications of GIS made it an effective tool in field of spatial planning. (Sarath, 2018)

A set of criteria has been developed to evaluate the environment condition of the study area using MCDA technique which helps to evaluate different scenarios (Gonzalez and Enriquez-de-Salamanca, 2018). High spatial resolution and multi spectral information is the major achievement in precise decision making which requires various datasets regarding the problem. It is estimated that mostly data used by managers are spatial in nature. In past selection of site is based on economic and technical criteria but today environmental and social aspect is of prime importance for government regulations. So the criteria must satisfy the environmental considerations (Rikalovic et al., 2014). The focus of this study presents the solution for identifying appropriate locations for industrial setup in Lahore district using GIS based multi-criteria decision analysis (Rikalovic et al. 2014) as decision support tool (DST).

The objectives of the present study are:

- Risk Analysis and GIS mapping of environment-

ally sensitive areas in Lahore district

- Development of MCDA for environmental sensitivity and identification of zones/areas for industrial development.
- Help regulatory bodies to plan pollution control and monitor programs and infrastructure facilities such as manpower, laboratory facilities, etc. well in advance

Lahore, being the capital of the province Punjab, is second largest city of Pakistan with an area of about 1772 square kilometers and densely populated cities around the globe. It is located on the left bank of the river Ravi river. It spreads within the geographical limits of the 31°15' and 31°45' latitude and 74°01' and 74°39' longitude (Fig 1). The growth rate of population is 3% per year. At present its population is more than 11 million (PBS, 2017).

### Materials and Methods

Different thematic layers have been generated for the district's physiography, soil, landuse/cover, air quality, ground water quality, irrigation network, protected areas, sensitive/incompatible land use and industry data that have been used as the baseline information for this study.

The data were collected from different sources and departments which is prepared, processed for spatial representation in the form of thematic maps. A GIS layer was developed from each data set. The maps for each dataset have been analyzed in a methodical manner using GIS techniques in ArcGIS platform and

afterwards derived maps have been prepared for each environmental criterion for the purpose of industrial siting (Fig. 2).

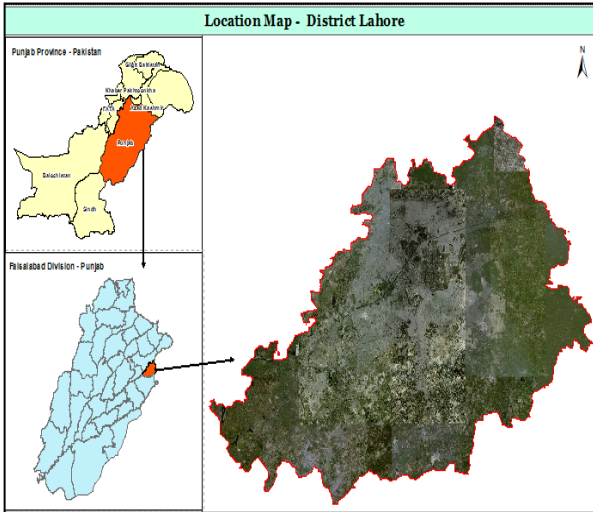


Fig. 1 Location of study area.

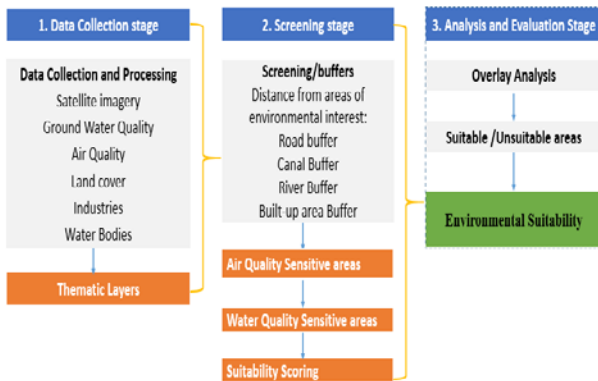


Fig. 2 Methodological workflow

### Water Quality Index Calculation and Mapping

The ground water quality data have been collected from environment protection department and EIA reports for Lahore district. Data of various water quality parameters like total dissolved solids (TDS), Nitrates (NO<sub>3</sub>), hardness, chloride and fluoride were collected in point form which then were interpolated using inverse distance weightage (IDW) technique in ARCGIS. The overall water quality has been assessed through water quality index (WQI), objective of which is to change complex data on water quality to an understandable and usable information (Akter et al., 2016). The standard WQI from excellent water quality to unsuitable quality is given in Table 1.

Table I Water Quality Index standards.

WQI	0 to 25	26 to 50	51 to 75	76 to 100	>100
Water Quality	Excellent	Good	Poor	Very Poor	Unsuitable for drinking

Water quality index calculation involves three steps. First of all, each of the four parameters were given a weight (wi) in accordance with the relative importance of drinkable water quality (Table 2). For determining the quality of water, weightage value from 1 to 5 was assigned depending on the importance of individual parameter. The maximum weight of 5 was assigned to parameters such as nitrate and arsenic due to their primary importance for assessing the water quality. In the second step the relative weight (Wn) is computed using the equation described below (Muralitharan, 2018)

$$W_n = \frac{w_i}{\sum_{i=1}^n w_i}$$

Where Wn is the relative weight, wi is the weight of individual parameter and n is the no of parameters (Etim, 2013). Weights and relative weight of parameters are mentioned in Table 2.

Table 2 Weights and relative weight of parameters.

Parameter	PEQS limit	Weightage (wi)	Relative weight (Wn) $\frac{w_i}{\sum_{i=1}^n w_i}$
TDS	1000	4	0.22
As	0.05	5	0.28
NO <sub>3</sub>	50	5	0.28
F	1.5	4	0.22

A quality rating scale Qi is calculated in the third step for each parameter by dividing the difference between observed value and ideal value of parameter with the difference in standard value and ideal value.

$$Q_n = \frac{V_n - V_i}{S_n - V_i} * 100$$

After that WQI is calculated by multiplying the quality rating scale (Qn) of each parameter with its relative weight, then dividing it by sum of the relative weight as per the following equation:

$$WQI = \frac{W_n * Q_n}{\sum W_n}$$

The WQI map was prepared to use it in siting criteria (Fig. 3).

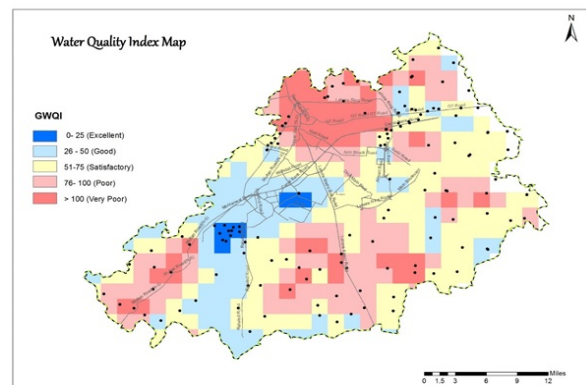


Fig. 3 Water quality index map – Lahore district.

### Air Quality Index Calculation and Mapping

Air quality has been assessed through air quality index (AQI). It is used to define the whole condition of the gaseous pollutant in particular area (USEPA, 2017). The AQI is based on particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide. In this study the air quality index used for calculating the AQI was adopted for US-EPA 2014, given below:

$$\text{Air Quality Index} = (\text{NO}_2/80) + (\text{SO}_2/120) + (\text{PM}_{10}/150) + (\text{CO}/5) \times 4 \times 100$$

The AQI standards (USEPA, 2017) used are show in table 3.

Table 3 Air quality index standards.

AQI	0-50	51-100	101-150	151-200	201-300	>300
Air Quality	Clean	Moderate	Unhealthy for sensitive people (e.g. old, children or sick people)	Unhealthy	Very Unhealthy	Hazardous

After calculating the AQI, a layer is made which was then used as one of the criteria of assessment (Fig. 4).

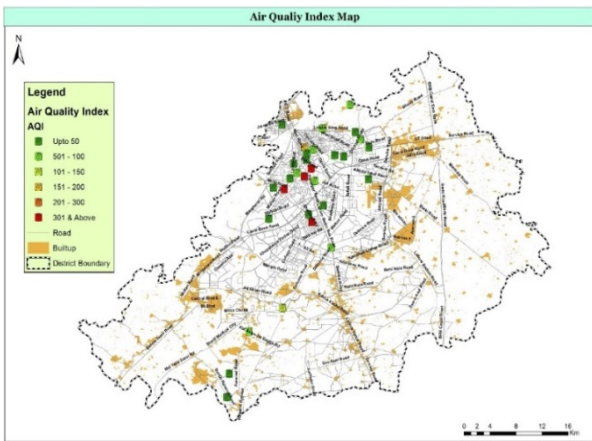


Fig. 4 Air Quality index (AQI) map.

### Irrigation/Distributaries

Canal network’s data were collected form the Punjab irrigation department (Fig. 5).

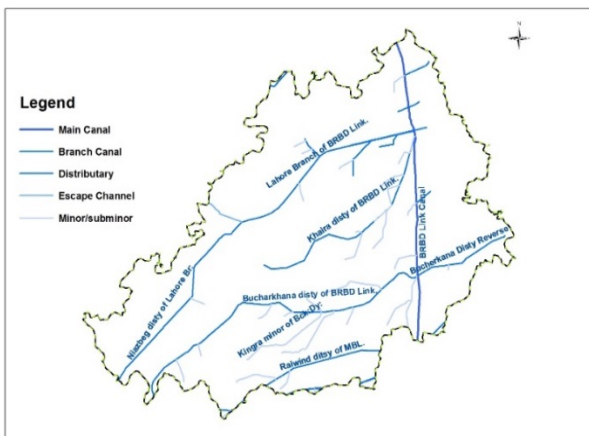


Fig. 5 Irrigation network.

### Land cover

Land cover describes the physical material at the surface of the earth. Fig. 6 shows the land cover of Lahore division. Landsat 8 OLI imagery 2017 was used for supervised classification of Lahore district using maximum likelihood classification method. The information on OLI bands ranges and resolutions are given in Table 4.

Table 4 Landsat 8 operational land imager (OLI) bands information.

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100

Four main classes named; barren land, vegetation, built-up and water were developed. Conclusively, the maximum i.e 33.7 % of the land was covered with vegetation, 28 % barren land, only 0.3% water and 26.1% with built-up area. Figure 5 shows Landcover map of Lahore district.

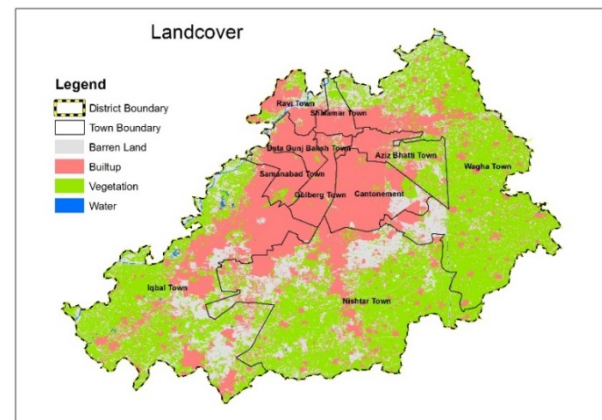


Fig. 6 Land cover map.

### Categorization of Industries

Data of industries were collected from Census of manufacturing industries. According to type of waste industries have been classified into two major categories called schedule I industries and schedule II industries as per self-monitoring and reporting by Industry Rules (EPA, 2001). Schedule I industries are classified as liquid effluents industries. Whereas schedule II are classified as gaseous emission industries.

**Sub-Categorization of Industries for Site Selection**

There is no sub-categorization of industries based on the pollution index. Therefore, a pollution index should be defined for sub classification of Schedule I and II industries so that it should be considered in final site selection. According to Central Pollution Control Board of India on the basis of composite score (0-100) of pollution index with weightage is described in Table 5 the categorization should be done accordingly (CPCB, 2016).

Pollution Type	Score Weightage
Air Pollution Index	40
Water Pollution index	40
Hazardous waste	20

Table 5 Pollution index and industrial categorization.

Pollution index score for industries	Industrial categorization
=>60	Hazardous
41 – 59	Critical
21 – 40	Poor
=<20	Non polluting

(CEPC, 2016)

impact of infrastructure development in terms of air pollution, water quality and natural features and is the most used parameter within the reviewed papers (Navarro, et al. 2019).

Different ranks were given to different zones based on their suitability as moderately, less and unsuitable. The criteria, zones, suitability and score values are summarized in Table 6. AQI and WQI were calculated and categorized into Moderate, poor and very poor points for applying proximity analysis as per AQI and WQI criteria. Accordingly, land suitability maps for Schedule I and Schedule II for industries have been prepared with identified zones in Lahore for allocation of industries.

On the similar spatial layers have developed for each criterion including water channels, rivers, roads landuse and settlements/builtup by collecting spatial data and produces standardized maps for GIS-MCDA analysis. Keeping in view the type of industry and region of interest, optimal site locations have been identified. This consideration is important because it eliminates all the areas outside the selected regions from the list of the potential site locations. The standards for buffer distance have been adopted from the sectoral

Table 6 Environmental criteria for industrial siting.

Criteria	Score value	Suitability	Buffer distance	Source
Air Quality Index (AQI)	0-50	Suitable	-	P.B., H., & Acharya, A., 2015
	51-100	Moderately Suitable	2 km	
	100-150	Less Suitable	3 km	
	above 150	Not Suitable	5 km	
Water Quality Index (WQI)	0-25	Suitable	-	EPA, 2001 (SMART Rules)
	26-50	Moderately Suitable	500 m	
	50-75	less Suitable	1000 m	
	Above 75	Not Suitable	1500 m	
Canal/ distributaries	-	Not Suitable	500 m	
Water Bodies	-	Not Suitable	500 m	
Roads	-	Not Suitable	200m	
Flood Plains	-	Not Suitable	500 m	
Protected Area	-	Not Suitable	25Km	

**Results and Discussion**

**Spatial Multi-criteria Analysis (MCA)**

Criteria have been developed depending on the main objectives, type of industry keeping in view the environmental sensitivity. Table 6 shows the criteria used for industrial site selection. The criteria incorporates the environmental consideration and

guidelines of EPD Punjab, Pakistan.

**Screening/ Areas to be Avoided**

Constraint maps is prepared for water bodies, builtup areas, canals and roads which acted as avoided areas in multi-criteria analysis. Avoided area maps for road, canal, builtup and river buffers are shown in the Figure 7.

**Air Quality Sensitive Areas**

As a result of MCA for air quality sensitive areas, suitable and unsuitable zones are shown in Figure 8. Red pockets are air polluted areas and industrial development causes serious damage to air environment. The green areas are suitable for establishing industries with gaseous emissions having A and B categories of industry as per industrial classification of Pakistan.

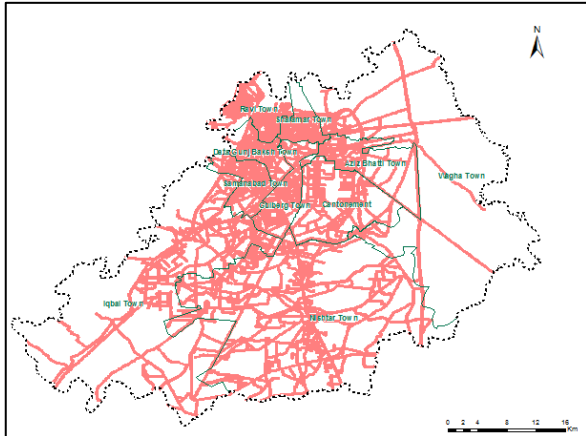


Fig. 7(a) Road buffer.

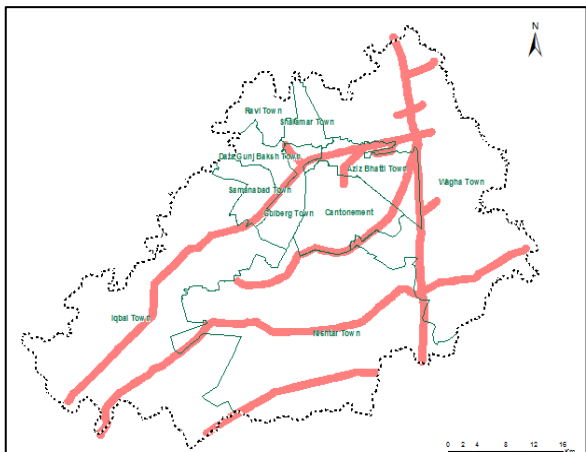


Fig. 7 (b) Canals buffer.

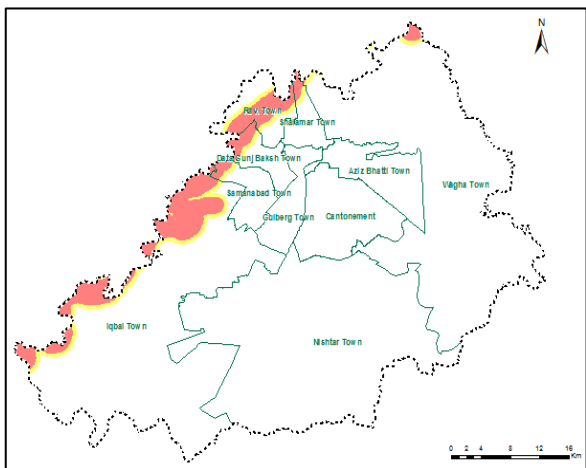


Fig. 7(c) River buffer.

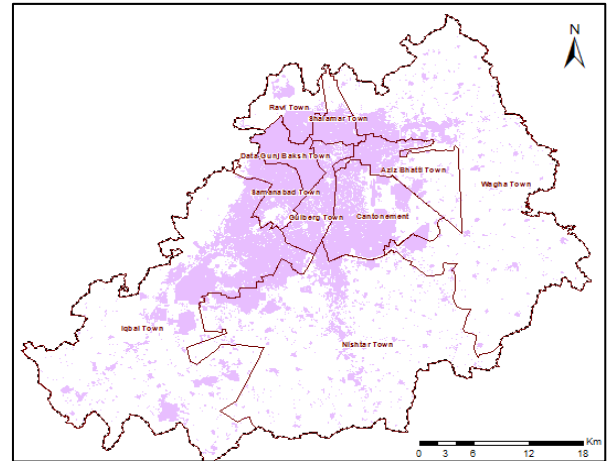


Fig. 7(d) Built-up areas.

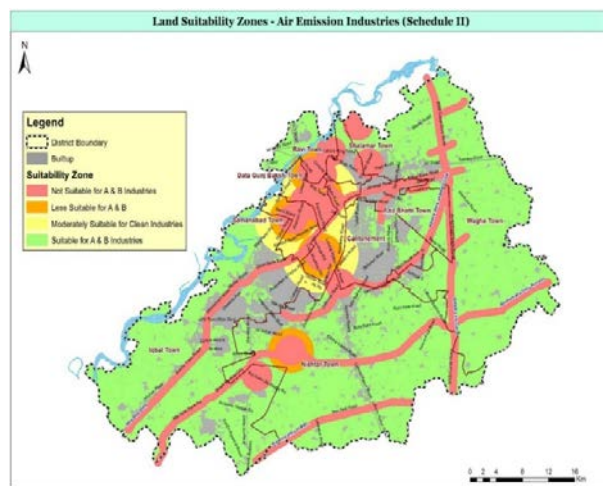


Fig. 8 Suitability zones for schedule II industries.

**Water Quality Sensitive Areas**

The map for water quality sensitive areas is represented in the Figure 9. Red areas are unsuitable zones for effluent discharge industrial development.

**Environmentally Sensitive Areas for Industrial Development**

The overall environmental sensitivity is represented in suitability map for industrial siting (Fig 10). As a result of multi-criteria overlay analysis, land has been divided into four categories e.g., not suitable, Less suitable, moderately suitable and suitable. Red areas are completely unsuitable as per environmental criteria and also called as negative areas for industrial development. These areas are environmentally sensitive and any development may affect the environment which will result in negative impact on human health. Yellow areas are moderately suitable and certain type of development may be done with some mitigation measures. Green areas are suitable areas for development of industrial zones, but with environmental mitigation measures so that any

industrial development does not pollute the environmental sustainability.

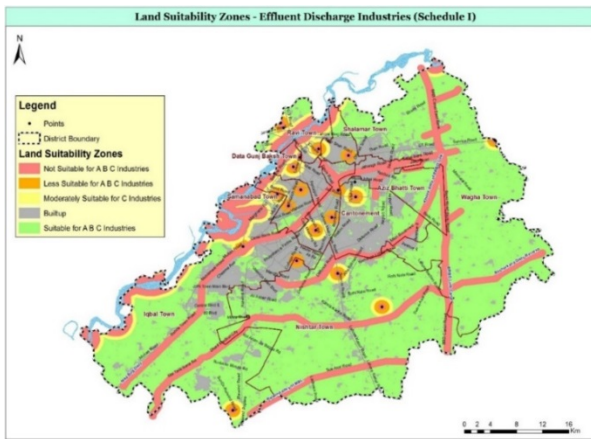


Fig. 9 Suitability zones for schedule I industries.

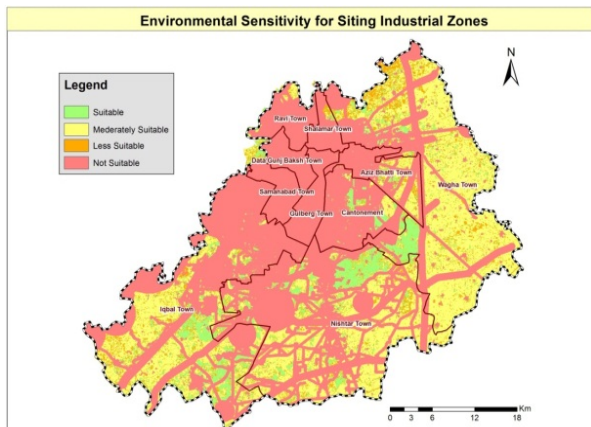


Fig. 10 Environmentally suitable/unsuitable areas for industrial siting.

**Conclusion**

The study estimated that nearly 52 % of the area of the district goes to environmentally sensitive zone where no industry should be permitted to establish. Rest of the study area is ranked into suitability zones, the site selection in suitable zones should also consider the type of industries to be established at particular location. Therefore on the basis industrial categories and sub categories, following conclusions for siting the industries have been made (table 7).

Table 7 Industrial siting categories.

Pollution index score	Industrial categorization	Decisions/Recommendations
$\geq 60$	Hazardous	Should not be permitted to establish in sensitive zone (red).
41 – 59	Critical	Should place in yellow zone using cleaner technologies to reduce the pollution load.
21 – 40	Poor	Could be placed in green and yellow zones with some mitigation measures.
$\leq 20$	Non polluting	Considered as non-polluting industries and can be set up anywhere excluding constraint areas.

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