

GIS-based multi-criteria analysis modeling used to locate suitable sites for industries in suburban areas in Bangladesh to ensure the sustainability of agricultural lands

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Abstract Land use changes significantly affect the sustainability of food security, environmental quality and the ecological balance in developing countries. Bangladesh is one such country, and it faces challenges caused by its limited resources of arable land. The urbanization of agricultural lands and urban developments in suburban areas add to these challenges. Therefore, the aim of this study is to characterize the land use changes that occur over time in suburban areas that have potential for industrial growth. This study also assesses potential locations for industrial development by using land suitability analysis (LSA) to emphasize both agricultural and industrial development in terms of sustainable growth. A geographical information system (GIS)-based multi-criteria analysis (MCA) model is developed for the LSA to distinguish compact parcels that are suitable for industrial economic zones. Nine criteria, including seven constraints and 23 factors, are evaluated using the spatial analysis tools in ArcGIS[®]. An analytical hierarchy process (AHP) is applied to prioritize these criteria based on experts opinion for the decision-making process of LSA. This study finds that the construction of densely clustered industrial areas has decreased the area of agricultural land by more than 10% in the last two decades. Furthermore, the results of the LSA show that only 4% of the land was highly suitable for industrial sites. On the other hand, four compact parcels that contain 16–10 ha of land and suitable for small industrial zones exist within the study area. Thus, the integrated GIS-MCA model can serve as a policy and planning tool for locating industrial economic zones while preserving agricultural lands and retaining environmental protections.

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1 Introduction

Land use changes significantly affect the sustainability of food security, environmental quality and the ecological balance in developing countries. To compensate for land losses and the degradation of the best lands, the usage of fertilizer has increased to improve crop production and the yield per hectare, resulting in a decline in energy efficiency (Tong et al. 2003). Bangladesh is the 10th most densely populated country in the world, and it has 1237 people per sq. km of land area (World Bank 2015). It also faces challenges due to its limited resources of arable land. Thus, agricultural land use has become an important domain in carrying out sustainable development while feeding increasing numbers of people. However, several studies have noted that the area of agricultural lands in Bangladesh has decreased over time. Aerial photographs and Landsat images were analyzed by the Soil Resource Development Institute (SRDI) of Bangladesh to characterize this land transformation. Approximately 0.13% of agricultural land was transformed to non-agricultural land per year from 1963 to 1983 (Rahman and Hasan 2003). Also, according to the Rio +20: National Report on Sustainable Development, Bangladesh has lost 1% of its agricultural land every year to non-agricultural purposes (Bangladesh Ministry of Environment and Forests 2012). In addition, one study that utilized satellite images and GIS techniques stated that Bangladesh lost 23,391 ha of agricultural land per year from 1976 to 2000. This annual loss increased drastically to 33,140 ha during the period 2000–2010. In total, 8% of the agricultural land of Bangladesh was lost from 1976 to 2010 (Hasan et al. 2013). On the other hand, the total areas of urban and industrial areas increased from 26,799 to 87,616 ha from 1976 to 2010, as indicated by the same study.

The loss of agricultural land and increases in the land area dedicated to urbanized areas and industry reflect unsustainable land use practices. Industries have expanded from city areas into suburban areas and have occupied agricultural lands, leading to a major challenge for food production in the long run. Because of the lack of availability of land, the National Strategy for Accelerated Poverty Reduction II (NSAPR II) emphasized developing efficient land markets and modern economic zones to improve land use management and to achieve environmentally and socially compliant industrialization (Planning Commission 2009). Furthermore, according to the Bangladesh Economic Zones Act (No. 42 2010), the Bangladesh Economic Zones Authority (BEZA) aims to establish economic zones in all potential areas of Bangladesh, including underdeveloped regions. In addition, according to this act, the government can declare any specific land area to be an economic zone. Since the economy is growing, there is a high probability that land encroachment will occur across the country as the industrial and manufacturing sectors become established. However, priority should be given to protecting existing agricultural lands and

minimizing environmental issues while identifying land sites that are suitable for development. In this regard, land suitability analysis (LSA) may be the most appropriate approach for evaluating and fulfilling the requirements of these facilities. Therefore, the hypothesis of this empirical research is that identifying suitable locations for industrial sites could reduce the pressure caused by the transformation of agricultural lands to industrial areas scattered throughout the suburban areas as the economy grows.

LSA is a tool that is used to identify the most suitable places for locating particular land uses in the future (Collins et al. 2001). Land use suitability analysis identifies the most appropriate spatial patterns for future land uses according to specific requirements, preferences or predictors of some activity (Malczewski 2004). In other words, LSA is a spatial decision-making process in which a number of elements are evaluated to conform to the requirements of stakeholders and environmental issues.

Thus, this study implements multi-criteria decision analysis (MCDA) with spatial solutions in a geographic information system (GIS) and uses this technique to conduct an LSA. Multi-criteria analysis (MCA) with GIS has advantages in that it supports decision-making processes in a systematic way and provides a transparent reflection of this decision through the use of thematic maps (Ferretti and Pomarico 2013). This multi-disciplinary approach has diverse applications in spatial analysis for land use (Hassan and Nazem 2016, Hossain et al. 2009, Ferretti and Pomarico 2012) and has been identified as a powerful integrated method for use in complex land use scenarios (Saleh et al. 2015). Furthermore, LSAs have been conducted that emphasize the needs of different crops, aquaculture, ecotourism, landfill site selection and wind and solar power plants over different periods of time (Chandio et al. 2013). In recent studies, a macro-level-based approach for industrial site selection that uses GIS, fuzzy inference systems (FIS) and AHP has been employed. In these studies, FIS and AHP were used to establish the weights for the different criteria, and the final aggregation was done in MCDA4ArcMap (Rikalovic et al. 2015). However, this system is useful only when the spatial analysis is performed on vector-based polygon databases. Another study was conducted that performed industrial site selection using GIS and AHP and employed seven criteria for evaluation (Edrahim et al. 2015). In this study, AHP was conducted based on the opinion of one expert, suggesting the possibility of bias. In addition, the scoring of the individual criteria was not explained properly. Furthermore, Eldin and Sui (2003) used the component object model (COM) to design a two-phase decision-support system for industrial site selection. The first phase, site screening, was carried out using an expert system (ES) and GIS. In the second phase, AHP was used to evaluate non-spatial criteria. However, a prototype approach was applied that was unable to address the complexities of GIS and could only address a limited range of industrial facilities and criteria. Again, the COM was applied to integrate loose and tight coupling in the industrial site selection (Eldrandaly et al. 2005). It was not clear how the criteria were prioritized for the industrial site selection in this study.

Furthermore, few attempts have been made to perform industrial site selection using GIS-based MCDA. GIS-based MCDA has been described as a procedure that accumulates and transforms spatial and non-spatial data (input) into a resultant decision (Malczewski 2004). MCDA builds a connection between the input map and the output map using geographical data and the judgments and values of decision makers according to the facts and correlates the specified decision rules. MCDA methods, such as Boolean overlays, weighted linear combinations (WLC), ordered weighted averaging (OWA), the analytical hierarchy process (AHP) and multiple-objective land allocation (MOLA), can be used in a GIS environment (Rikalovic et al. 2014). The integration of multi-criteria methods for LSA within GIS environments has broadened the spatial proficiencies of GIS and increased the analytical power of this system as a decision-support tool. GIS-based decision tools have immense application potential in a wide array of regional applications. They can enhance economic growth through enabling better spatial decisions, including the selection of suitable sites for industrial lands, while incorporating the opinions of stakeholders and experts.

Bangladesh has mixed land use, so including stakeholders and experts' opinions in LSA studies is important. The AHP is the most widely used MCDA method, and it has the flexibility to include the judgments of experts. The AHP is a systematic decision-making technique that decomposes a problem into a hierarchy of subproblems to enable easier subjective comprehension and evaluation of the problem (Saaty 1980). A numerical scale is used to rank subjective evaluations, which are transformed into numerical values (Bhushan and Rai 2004). The AHP is also a multi-criteria decision-making tool that employs the spatial analysis functions of GIS in LSA to produce suitability maps (Chandio et al. 2011). LSA is an application-based approach that can be used in long-term planning and site selection. The studies mentioned above have substantial limitations, and the introduction of an LSA model is needed for industrial site selection using GIS and AHP. The great flexibility of the LSA model enables its application in industrial site selection at scales ranging from the local level to the national level. The most effective part of this study is that the model efficiently attempts to preserve existing agricultural lands and considers the opinions of experts from different fields.

Therefore, the objective of this study is to carry out an LSA to locate the areas that are most suitable for industrial economic zones without affecting existing agricultural land uses. Furthermore, the land use changes that exhibit greater influence on industrialization in suburban areas are considered for spatial analysis to determine the sustainable uses of agricultural lands and the growth of industries. As part of the search for potential regions to complement the Bangladesh Economic Zones Act of 2010, this study selected Savar, an adjacent sub-district of the capital city of Dhaka, for use as a case study. However, the research approach also focuses on applications at larger spatial scales, especially micro- to macro-level geographical extents.

2 Materials and methods

2.1 Conceptual framework

This research was conducted in two phases. During the first phase, an analysis was conducted to assess agricultural land use changes in terms of the effects of industrial growth on agricultural land use (Fig. 1). The study area mostly reported rapid growth from urbanization and industrialization over the last three decades (Rashid 2003; Sharif and Esa 2014). Thus, statistical data describing agricultural land use was collected from the local agricultural office. A map was prepared in ArcGIS 10.3[®] based on statistical agricultural land use data covering the period from 2002 to 2011. On the other hand, the geographical positions of 420 factories were collected with a Garmin eTrex 30 during the field surveys. The geographical positions of the factories within the study area were mapped, and the growth of industrial areas into the agricultural lands during 2002 to 2011 was noted.

In the second phase, LSA was performed to locate sites that are suitable for the expansion of industry. Studies suggest that 80% of the data used by decision makers and managers are related to geographical matters (Worall 1991). Thus, a GIS-based implementation of the AHP, which is a multi-criteria analysis (MCA) technique, was adopted to carry out the LSA. This combination of methods is widely used in the spatial decision making. The MCA was conducted with 23 factors, seven constraints and nine criteria, which were selected based on field surveys, previous research and discussions with experts. The AHP approach was used to incorporate the preferences of the experts and assign weights to the criteria. On the other hand, GIS was applied to manage the thematic spatial data set of the criteria and to prepare the factors and constraints layer maps using spatial analysis tools. A decision rule was applied to integrate the GIS and the AHP to extract a suitability map.

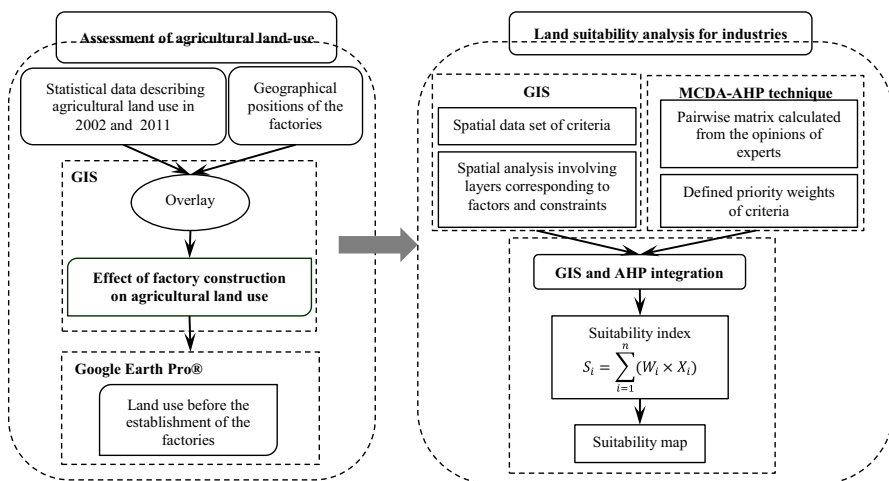


Fig. 1 Conceptual framework for the agricultural land use assessment and land suitability analysis

2.2 MCA procedure for LSA

LSA is a difficult task because different domains, such as socioeconomic conditions, environmental aspects and topography, are involved. In addition, the suitability of land is also affected by local legislation and the availability of land. The complexity of LSA increases when areas with mixed land uses and densely populated areas are considered. Hence, this study applied MCA in seven steps in the spatial environment (Fig. 2). The study selected nine criteria to conduct MCA, according to the research goal and objectives. Beinat and Nijkamp (1998) defined a criterion as a basis for decisions that can be measured and evaluated. In selecting criteria for the locations of industries, Ramcharan and Dey (2005) stated that environmental and social factors are the most important aspects for the sustainable development of industries. Ensuring these that these conditions are met during site selection help to maintain a high level of productivity throughout the lifetimes of projects. Thus, the criteria selected for the current study focused primarily on environmental and social aspects.

The criteria used in this study were the proximity to (1) major roads and (2) local roads; the distance from (3) rivers, (4) water bodies, (5) settlements and (6) agricultural lands; (7) the presence of flood flow zones; (8) slope; and (9) elevation. These criteria were further classified into factors and constraints for assessment. According to Beinat and Nijkamp (1998), a factor is a criterion that enhances or detracts from suitable alternatives for the activity under consideration, and a constraint serves to limit any alternatives. This study focused on 23 factors and seven constraints based on these definitions. Furthermore, expert opinions were obtained using a questionnaire designed for use with the AHP technique to evaluate the priority weights of the criteria. A score was assigned to each factor on a scale of 1–10, and the constraints were stated as “restrictions.” To aggregate the weights of the criteria and the scores of the corresponding factors and constraints under each criterion, a decision rule called weighted linear combinations (WLC) was applied to determine suitable locations for industrial sites. The resulting map was further analyzed to distinguish compact parcels that could be suggested for development as industrial zones. The final result was then displayed in Google Earth Pro[®] to evaluate the results.

2.3 Study area

The study was conducted in Savar, 25 km from the capital city of Dhaka. Savar is a part of RAJUK (Rajdhani Unnayan Kartripakkha), the Capital Development Authority of the Government of Bangladesh. According to data covering the Savar Agricultural Department in 2011, 63.75% of the area of Savar was made up of agricultural lands. The interface between rural and urban areas is significant in the northwestern and southeastern areas of Savar. Savar is located between the latitudes of 23°44′15.51″N and 24°1′29.19″N and between the longitudes of 90°11′22.78″E and 90°21′31.17″E (degrees–minutes–seconds, WGS84). The total area of Savar is 280.13 km², and its neighboring sub-districts are Kaliakair and Gazipur Sadar to the north; Keraniganj to the south; Mirpur, Mohammadpur, Pallabi and Uttara Thanas

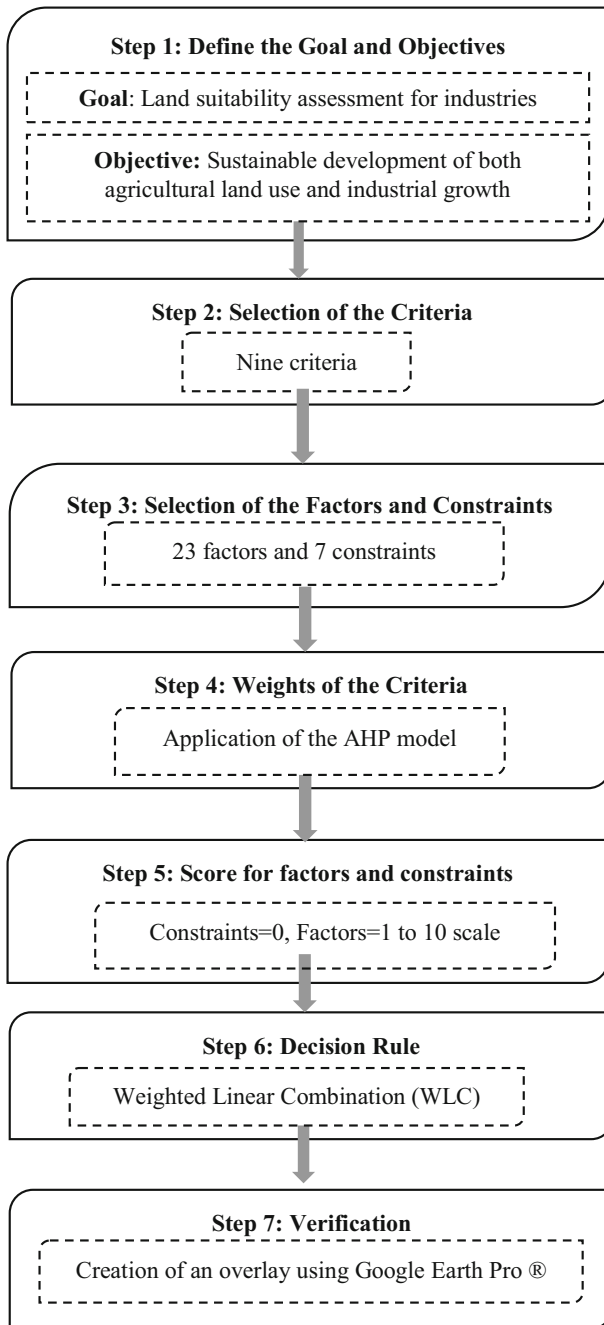


Fig. 2 Multi-criteria analysis for determining land suitability

of the Dhaka City Corporation to the east; and the Dhamrai and Singair sub-districts to the west (Fig. 3). The land height gradually increases from east to west, and the area is bounded by the Bangshi, Turag, Buriganga and Karnatali rivers. The population density of Savar was 4948 per km² in 2011, an increase of 8.84% per year from the previous census in 2001. Approximately 78.6% of the population was distributed within rural areas, whereas the rest lived in urban areas (BBS 2011).

The study area contains several types of landscapes, including highlands, moderate highlands, lands of moderate elevation, low lands and very low lands, based on their drainage, elevation and pedological properties (Rashid 2003). The highlands do not flood and are mostly used for growing vegetables throughout the year. These lands are relatively less productive for rice. The highlands are the most suitable areas for the development of permanent infrastructure. The lands of moderate elevation are used for single crops such as high-yielding variety (HYV) rice and Boro rice because these areas are fertile lands. The lowlands and very low lands are very suitable for agricultural purposes because these lands receive prolonged flood waters from the Dhaleshwari, Bansi and Turag rivers. According to the data from 2011–2012 from the Savar Agricultural Office, Savar produces rice (Boro, T-aman and Aus), wheat, maize, mustard, nuts, pulses, vegetables, fruits, spices, etc. According to employment data covering Savar, 14.54, 42.57 and 42.89% of the population were engaged in agriculture, industry and the service sector, respectively (BBS 2011). The agricultural industries found in Savar include

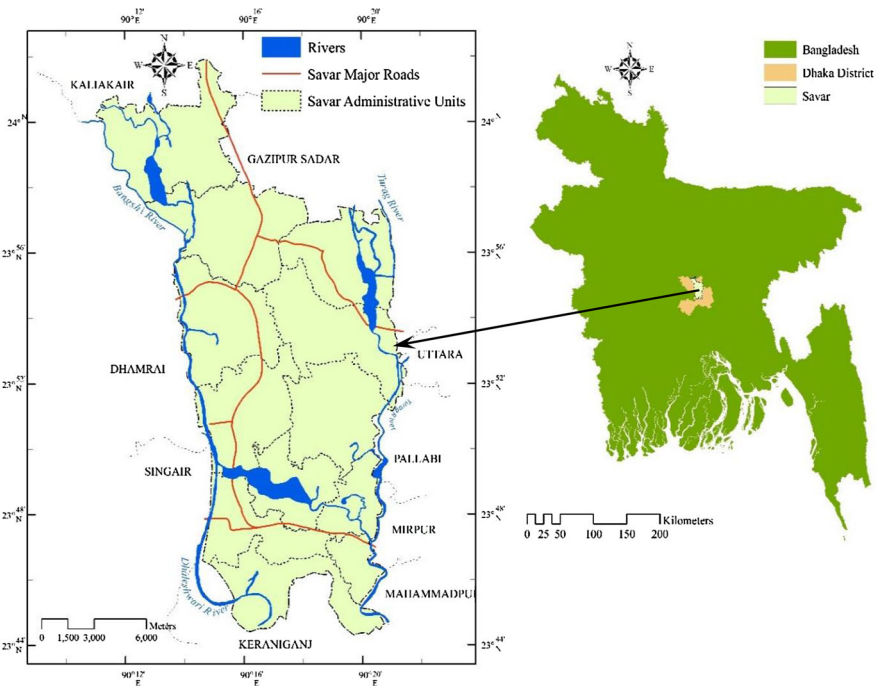


Fig. 3 Location map of the study area (modified from LGED base maps)

combined fisheries, dairies, poultries and hatcheries. On the other hand, Savar is mostly known as an industrial hub, due to the number of industries that manufacture products such as ceramics, beverages, garments, footwear, jute, textiles, automobiles, pharmaceuticals and bricks. The second largest export processing zone (EPZ) of Bangladesh, the Dhaka EPZ, was established in Savar in 1993.

2.4 Field survey

Statistical data describing the extent of agricultural land in 2002 and 2011 were collected from the local agricultural office during a field survey in Savar. A list of cloth-producing industries in Savar was obtained from the Bangladesh Garment Manufacturers & Exporters Association (BGMEA). A GPS unit (Garmin eTrex 30) was used to collect the geographical positions of 420 factories. Nine criteria were selected based on field observations and discussions with stakeholders. A questionnaire based on the AHP method was used to record the opinions of experts in terms of pairwise comparisons of criteria. In addition, spatial maps of the geographic features relevant to the criteria were obtained from different organizations for GIS analysis (Table 1).

2.5 Criteria, factors and constraints

One of the major steps in locating suitable sites is to identify a set of dominant factors that are applicable to site selection (Rikalovic et al. 2014). Thus, the combination of knowledge from local stakeholders, discussion with experts, field observations and previous studies can be applied to select and score the factors, constraints and criteria (Table 2).

Table 1 List of feature maps that were analyzed in GIS

No.	Map	Source	Scale
1	Savar administrative boundary map, 2010	LGED, Bangladesh	1:50,000
2	Savar main roads map, 2013	LGED, Bangladesh	1:50,000
2	Savar local roads map, 2013	LGED, Bangladesh	1:50,000
3	Savar settlement boundary map, 2010	LGED, Bangladesh	1:50,000
4	Savar rivers map, 2010	LGED, Bangladesh	1:50,000
5	Savar water bodies map, 2010	LGED, Bangladesh	1:50,000
6	Savar agricultural land map, 2013	RAJUK, Bangladesh	1:50,000
7	Savar flood zone map, 2013	RAJUK, Bangladesh	1:50,000
8	Digital elevation model (DEM)	Shuttle radar topography mission (SRTM)	1 arc-second for global coverage (~ 30 m)

LGED Local Government Engineering Department, RAJUK Capital Development Authority, Rajdhani Unnayan Kartripakkha

Table 2 Scores and suitability classifications of the factors and constraints

No.	Name of criterion	Factor/constraint	Classification	Score*	Suitability
1	Proximity to major roads	0–100 m	Constraint	0	Not suitable
		100–500 m	Factor	10	Most suitable
		500–1000 m	Factor	8	Moderately suitable
		1000–1500 m	Factor	6	Less suitable
		1500–2000 m	Factor	4	Least suitable
		>2000 m	Factor	2	Suitable but avoided
2	Proximity to local roads	0–50 m	Constraint	0	Not suitable
		50–200 m	Factor	10	Most suitable
		200–400 m	Factor	6	Less suitable
		>400 m	Factor	2	Suitable but avoided
3	Distance from rivers	0–500 m	Constraint	0	Not suitable
		500–750 m	Factor	4	Least suitable
		750–1000 m	Factor	8	Moderately suitable
		>1000 m	Factor	10	Most suitable
4	Distance from water bodies	0–100 m	Constraint	0	Not suitable
		>100	Factor	10	Most suitable
5	Distance from settlements	0–50 m	Constraint	0	Not suitable
		>50 m	Factor	10	Most suitable
6	Flood flow zones	Flood flow zone	Factor	2	Suitable but avoided
		Non-flood flow zone	Factor	10	Most suitable
7	Distance from agricultural lands	0–50 m	Factor	2	Suitable but avoided
		>50 m	Factor	10	Most suitable
8	Slope	0–5%	Factor	10	Most suitable
		6–10%	Factor	8	Moderately suitable
		11–15%	Factor	6	Less suitable
		>15%	Constraint	0	Not suitable
9	Elevation	0–5 m	Constraint	0	Not suitable
		6–10 m	Factor	6	Less suitable
		11–15 m	Factor	8	Moderately suitable
		>15 m	Factor	10	Most suitable

* Scores are based on field observations, discussion with experts and previous studies

2.5.1 Proximity to major roads

Access to roads is the most important criterion when selecting a factory site. Imports of raw materials and exports of the final goods are conducted through the main port. National highways, regional highways and district roads are the main routes to the port of Chittagong in Chittagong city. Chittagong is located 308 km away from Savar in the southeastern part of the country, and it is the second largest city in Bangladesh. The national highway N1 (the Dhaka–Chittagong national route) connects the two largest cities in Bangladesh and is 250 km long; approximately 7–8 h of travel time is required to traverse this road. Emphasizing the efficiency of the road communication network, as of 2016, the N1 national highway has four lanes to reduce the travel time. Thus, assessing the distances from the factories to the national highway is very important. An increase in distance results in higher transportation costs and production lead time. The closer a factory is to the national highway, the lower the transportation costs and production lead time are. In addition, buffer zones were constructed with different widths, considering the existing distribution of factories, which are mostly located near the local and major roads. Distances of 100–500 m were assigned a score of “10” to indicate “most suitable”; distances of 500–1000 m were assigned a score of “8” to indicate “moderately suitable”; distances of 1000–1500 m were assigned a score of “6” to indicate “less suitable”; distances of 1500–2000 m were assigned a score of “4” to indicate “least suitable”; and distances greater than 2000 m were assigned a score of “2” to indicate “suitable but avoided.” However, buffer zones with a width of 100 m were established that are not suitable for any industrial site to maintain a safe distance from major roads; thus, the 100-m buffer area around major roads were considered as constraints of the criterion and assigned a score of “0,” i.e., “not suitable” (Anurag et al. 2010).

2.5.2 Proximity to local roads

Most of the factories were connected to major roads via local roads. Therefore, buffer zones with widths of 50–200 m around these roads were assigned a score of “10” to indicate “most suitable”; buffer zones with widths of 200–400 m were assigned a score of “6” to indicate “less suitable”; and areas that lay more than 400 m from local roads were assigned a score of “2” to indicate “suitable but avoided.” A 50-m buffer zone around local roads was taken as a constraint and assigned a score of “0,” i.e., “not suitable,” to indicate that industrial operations should maintain a safe distance from roads (Anurag et al. 2010).

2.5.3 Distance from rivers

The study area is surrounded by rivers. Considering the environmental aspects, hazards and risks, the “most suitable” industrial sites were considered to be 1000 m from the rivers, which were assigned a score of “10.” In addition, a 500-m buffer zone around the rivers was considered “not suitable” for any industrial site. This requirement was considered a constraint, and these areas were assigned a score of

“0.” Beyond this constraint, the 500–750-m buffer zone was assigned a score of “4,” i.e., “least suitable,” and the 750–1000-m zone was assigned a score of “8,” i.e., “moderately suitable.”

2.5.4 *Distance from water bodies*

Water bodies are also a concern because of environmental hazard issues. Industrial wastewater and solid waste can affect water bodies and the agricultural lands. Thus, a 100-m buffer zone around water bodies was treated as a restriction, i.e., “not suitable,” and assigned a score of “0.” Areas beyond this restriction zone were considered “most suitable” and scored “10.”

2.5.5 *Distance from settlements*

Settlements were the most significant criteria. The rapid transformation of land use and the growth of urbanization and industrialization have resulted in a complex distribution of land cover types within Savar. Industries are scattered from city areas to suburban areas and influence rural settlements. However, industrial sites must maintain a certain distance from the settlements to prevent environmental hazards. Ramcharan and Dey (2005) suggested a 100-m buffer between residential areas and limestone quarry operations for use in the cement industry. However, the current study focuses on searching for suitable sites for compact zones that will be separated from other urban settlements. Considering the vacant land crisis in Bangladesh, 50-m buffer zones around settlement areas were assigned a score of “0” for “not suitable.” Other locations were considered “most suitable” and assigned a score of “10.”

2.5.6 *Flood flow zone*

Flood flow zones are mostly located in the eastern and western parts of Savar. Floods occur primarily during the monsoon season. Once the flood waters begin to decline, the land becomes usable for agriculture. Thus, flood flow zones were assigned a score of “2” for “suitable but avoided,” and non-flood zones were considered the “most suitable” places under this criterion and assigned a score of “10.”

2.5.7 *Distance from agricultural lands*

The agricultural lands are located mostly in the central portion of Savar. As mentioned above, the areas that experience flood risks are also used for agricultural purposes after the water level declines. In Bangladesh, agricultural lands are mostly owned by small-scale farmers; thus, it is comparatively inexpensive and easy to convert land to non-agricultural purposes. Studies have also found that the land ownership size of a household and the non-agricultural occupation of heads of households were the two primary reasons for agricultural land transformation, resulting in declines in agrarian income and productivity (Quasem 2011). On the

other hand, the existing land use policies, the 1950 State Acquisition and Tenancy Act and the 2001 National Land Use Policy of Bangladesh, have seen little implementation and have had relatively small effects (Alam et al. 2016). Although these historical land policies emphasize the conservation of agricultural lands and limit their transformation to non-farming purposes, they leave room for flexibility, which has caused the policies to be ineffective (LANDac 2016). The most recent initiative from the Ministry of Land is a draft of the “Agricultural Land Protection and Land Use Act of 2015,” which will soon be finalized (Karim 2015). However, existing policies indicate that agricultural lands should not be used for non-agricultural purposes. Thus, a buffer zone of 50 m around the agricultural lands was considered as “suitable but avoided” and assigned a score of “2,” and areas beyond 50 m were taken to be “most suitable.”

2.5.8 Slope

Higher slopes increase the cost of constructing a facility and the inconvenience of the transportation of goods. The study area contains no steep slopes; however, slope is considered to be a basic criterion for LSA. Thus, areas with slopes of 0–5% were considered “most suitable” and were assigned scores of “10,” and areas with slopes of 6–10%, 11–15% and greater than 15% were considered to be “moderately suitable,” “less suitable” and “not suitable” and were assigned scores of “8,” “6” and “0,” respectively.

2.5.9 Elevation

Elevation is another important criterion for any industrial site. Highlands are always the first choice for infrastructure projects. The elevation of the central administrative area of Savar is 15 m. However, flood zones also exist in the eastern and western areas. Thus, areas with elevations greater than 15 m were considered to be “most suitable” and were assigned a score of “10”; areas with elevations of 11–15 m were assigned a score of “8,” i.e., “moderately suitable”; areas with elevations of 6–10 m were considered “less suitable” and were assigned a score of “6”; and areas with elevations less than 5 m were taken as a constraint and assigned a score of “0.”

2.6 AHP

The most difficult task in carrying out the LSA approach for a particular land use type is to assign the relative weights of the individual criteria that are to be used. The AHP technique allows the calculation and evaluation of relative weights (Duc 2006). In addition, one of the most important benefits of using the AHP is that experts from different backgrounds can provide their opinions, thus helping to evaluate the diverse dimensions of the problem being considered (Oguzitmur 2011). However, many studies have questioned the validity of the AHP; in particular, Belton and Gear (1982) first noted the phenomenon of rank reversal. Rank reversal occurs when adding or removing an alternative to the AHP changes

the relative rankings of the existing alternatives. To address this rank reversal problem, studies and discussions have been conducted, and new mathematical approaches have been introduced (Shin et al. 2013; Wang and Elhag 2006). On the other hand, the legitimacy of rank reversal has also been debated (Saaty and Vargas 1984; Saaty 1987a, b). In addition, researchers have proven that rank reversal also appears in other multi-criteria decision-making (MCDM) approaches, such as the Borda–Kendall (BK) method, the technique for order preference by similarity to ideal solution (TOPSIS) method and the simple additive weighting (SAW) method (Shin et al. 2013; Wang and Luo 2009). Nevertheless, researchers believe that the AHP is also practiced outside of academia and that the use of AHP in the real world will be continued by its practitioners (Ishizaka and Labib 2011; Chandio et al. 2013).

Following the successful applications of the AHP in LSA, this study applied the technique to prioritize the weights of the criteria. A questionnaire was designed according to the AHP model to enable pairwise comparison of each criterion with another criterion based on a nine-point scale (Table 3). Saaty (1990) stated that the number of elements for the comparison must be less than or equal to 9 to ensure consistency and the corresponding accuracy of the measurements. Saaty (1987a, b) also noted that, if the number of elements is large, then their relative priorities will be small; in such cases, the judgments of the queried experts may contain errors. Thus, the study limited the criteria to the nine most important aspects.

Table 3 Nine-point scale (Satty 1990)

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	Evidence that favor one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocals	If activity i is assigned one of the above numbers compared to activity j , then j has the reciprocal value compared to i	
Rational	Ratios that arise from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

The judgments of the experts were used to prepare a pairwise matrix, and normalization was then performed. That is, the columns in the matrix were summed individually, and then each cell in the column was divided by the sum of the corresponding column. The column sum of the resultant matrix was equal to 1. The pairwise matrix can be expressed as follows:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \quad (1)$$

where C_{ij} is the value of row i (the first row) and column j (the first column) in the pairwise comparison matrix. The column sum of the pairwise matrix can be expressed as follows:

$$C_{ij} = \sum_{i=1}^n C_{ij} \quad (2)$$

Therefore, the normalization for each column value can be expressed using the following equations:

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^n C_{ij}} = \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \quad (3)$$

After normalization, the row sum in the new matrix was divided by the total number of criteria. This process and the resulting vector of weights can be expressed as follows:

$$W_{ij} = \frac{\sum_{j=1}^n X_{ij}}{n} = \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} \quad (4)$$

This matrix of weights can only be used after calculating the consistency ratio (CR), as it evaluates the credibility of the judgments of the individual respondents. The pairwise matrices are considered to be consistent when the CR is less than 0.1 (10%). The pairwise matrices are considered to be inconsistent, and the resultant weight matrix of the criteria is not acceptable, when the CR is greater than 0.1 (Saaty 1980).

The initial consistency vectors were derived by multiplying the pairwise matrix by the vector of weights:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} = \begin{bmatrix} C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31} \\ C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31} \\ C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31} \end{bmatrix} \quad (5)$$

The principal eigenvector (λ_{\max}) was then calculated by averaging the values of the consistency vector:

$$\lambda_{\max} = \sum_i^n CV_{ij} \quad (6)$$

The consistency index (CI) was calculated as:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (7)$$

Here, n is the total number of criteria. The consistency ratio was calculated as:

$$CR = \frac{CI}{RI} \quad (8)$$

where RI is the random index from Table 4.

2.7 GIS application for LSA

The GIS analysis was designed to be conducted in ArcGIS 10.3[®] using vector and raster layers. Initially, seven thematic vector layers that represent the major roads, local roads, rivers, water bodies, settlements, flood flow zones and agricultural lands were expressed in a base geographical coordinate system, WGS 1984. These vector layers were then projected into WGS 1984 UTM Zone 45N to obtain the same geographic extent. The thematic layers were then converted to raster layers to conduct the spatial analysis. Here, the polyline feature layers representing major roads and local roads were converted to raster layers using the “Polyline to Raster” conversion tool. The polygon feature layers representing rivers and water bodies were then converted to raster layers using the “Polygon to Raster” conversion tool, and the three remaining polygon layers, which included settlements, flood flow zones and agricultural lands, were converted using the “Feature to Raster” tool (Fig. 4).

A DEM of the study area with a resolution of 30 m was extracted from the SRTM data set. However, before the extraction was performed, the “Mosaic” spatial analysis tool was used to obtain a seamless data set from the two tiles of the SRTM data that cover the study area. The slope layer was obtained from the DEM using the “Slope” spatial analysis tool. The results were expressed as percentages and classified according to the factors and constraint intervals. The SRTM elevation map was also used as a reference layer to synchronize the raster layers in terms of cell size and processing extent. Thus, the rasterized thematic layers were assigned a cell size of 30×30 m.

Table 4 Random inconsistency indices for $n = 10$ (Saaty 1987a, b)

n	1	2	3	4	5	6	7	8	9	10
Random inconsistency index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

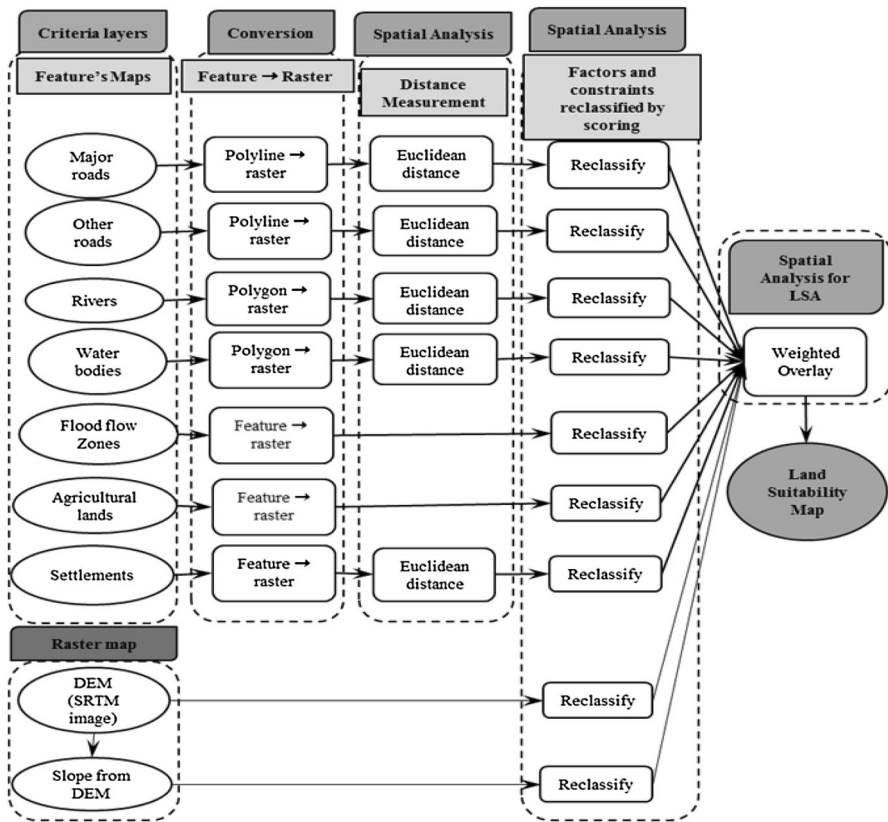


Fig. 4 Model diagram for the land suitability analysis

The “Euclidean distance” spatial analysis tool was used to determine the proximity to major roads and local roads and to determine the distances from rivers, water bodies and settlements. The Euclidean distance tool measures the distance from each cell to the closest feature of a given type. Further, the distance ranges were classified according to the factors and constraints of each criterion.

Further, the “Reclassify” tool was applied to the raster layers using the score rankings of the factors and constraints. Here, the constraints were given the number “1,” and the factors were assigned using numerical values ranging from “2” according to the ranking order of their scores. Output raster layers associated with the individual criteria were generated that show the suitability ranking as a color gradient.

2.8 Suitability of land for industrial development

To aggregate the factors and constraints with the weights of the criteria, the “Weighted Overlay” spatial analysis tool was used. This tool worked as a decision rule to integrate the AHP and GIS for the LSA. The weighted overlay procedure

followed the principle of weighted linear combinations (WLC), in which the weights of the criteria are combined with the scores of the factors and constraints to produce a suitability index for each cell of the output map (Eastman et al. 1995). The following expression describes the suitability index:

$$S_i = \sum_{i=1}^n (W_i \times X_i) \quad (9)$$

Here, W_i is the weight of each criterion i , which is calculated from the AHP technique of the MCDA, and X_i is the score of each factor and constraint. The scale was set to 1–10 within the “Weighted Overlay” tool. The constraints, which were given a ranking of “1” in the reclassification stage, were stated as “restrictions” while applying the “Weighted Overlay” function. The factors were assigned scores between 1 and 10 according to Table 2. The resulting map indicated the suitability of land for industrial development. On this map, each cell of the raster layer was assigned a suitability index on a 0–10 scale, where “0” was assigned to the restricted cells. The map was further classified into four clusters, which were assigned scores of “0” (“not suitable”), “1–5” (“less suitable”), “5–7” (“moderately suitable”) and “8–10” (“most suitable”).

2.9 Industrial zone selection

Once the LSA had been performed for the industrial sites, GIS was further utilized to select compact areas for industrial zones. The “Set Null” spatial analysis tool was used to identify the “most suitable” cells. An Structured Query Language (SQL) expression was written to identify cells with values less than 8; i.e., cells with values between 8 and 10 would be the true values of the most suitable places. Further, the raster layer was converted from a raster to a feature using the “Raster to Polygon” conversion tool. The raster cells for the “most suitable” areas were transformed into individual polygons, and the areas of each polygon were calculated. The “select” spatial analysis tool was applied to the feature classes to find polygons covering the most suitable places that contained at least 10 ha of land to build industrial zones. The SQL was set to a value that was less than or equal to 100,000 m².

3 Results

3.1 Agricultural land use changes vs. industrial growth

The statistical data from the local agricultural office showed that Savar lost an average of 6% of its agricultural lands from 2002 to 2011 from each administrative unit. In total, 1064 ha of agricultural land was lost from 2002 to 2011. However, four administrative units in Savar, namely “Yearpur,” “Ashulia,” “Tetuljhora” and “Dhamsona,” exhibited greater losses of agricultural land, 15, 9, 8 and 7%, respectively (Fig. 5a). A visual representation of the agricultural land use changes was produced using GIS, where the color gradient shows the locations of the highest

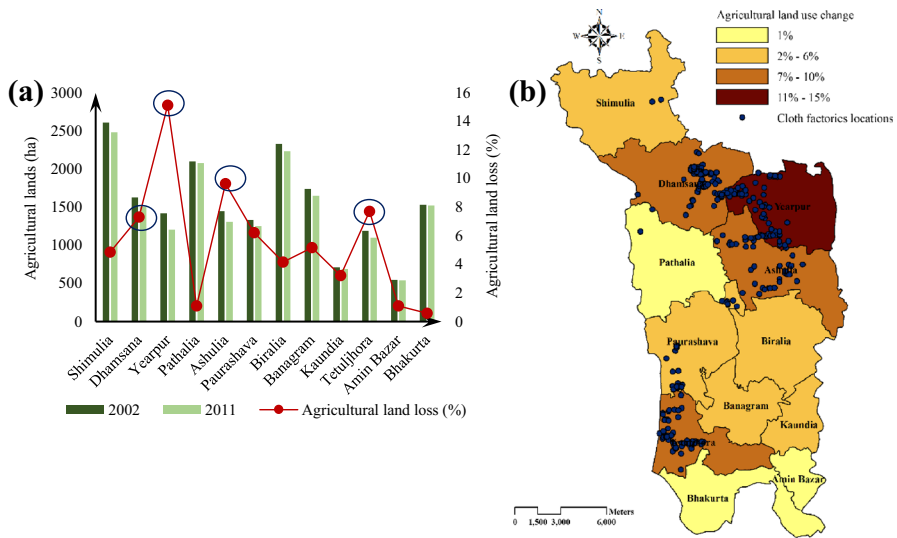


Fig. 5 a Statistical representation of agricultural land use changes in 2002 and 2011 (Source: Savar Agricultural Office 2014); b interpretation of the agricultural land use changes in GIS

agricultural land losses (Fig. 5b). According to the BGMEA database of 2013, approximately 577 cloth factories are located in Savar and were scattered among the urban, suburban and rural areas. The study succeeded in collecting the geographical locations of 420 factories during the field survey, and these locations were mapped using GIS. The map shows that the factory locations were most densely clustered in areas where the agricultural land decreased the most from 2002 to 2011 (Fig. 5b).

3.2 Expert judgment

An AHP-based pairwise matrix was developed from the responses of the experts. After normalizing the matrix, the weights of each criterion were calculated based on the judgment of individual experts, followed by the consistency measures, consistency indices and CR values. The CR values of the judgments of the five experts were less than 0.1; i.e., the judgments for the pairwise comparisons proved to be consistent. The average weight for each criterion derived using the individual judgments was used for the LSA. Based on these judgments, the highest priority was given to proximity to major roads (22%), followed by proximity to local roads (14%), elevation (14%) and distance from agricultural lands (13%) (Table 5).

3.3 GIS spatial analysis

The “Reclassify” tool in ArcGIS was used to categorize the study area based on the ranking order of the factors and the constraints associated with each criterion. The first map (Fig. 6a) shows the proximity to major roads, for which 13% of the area was found to be “most suitable,” reflecting areas located between 100 and 500 m

Table 5 The judgments of experts in prioritizing the weights of the different criteria (A–E, experts from different fields)

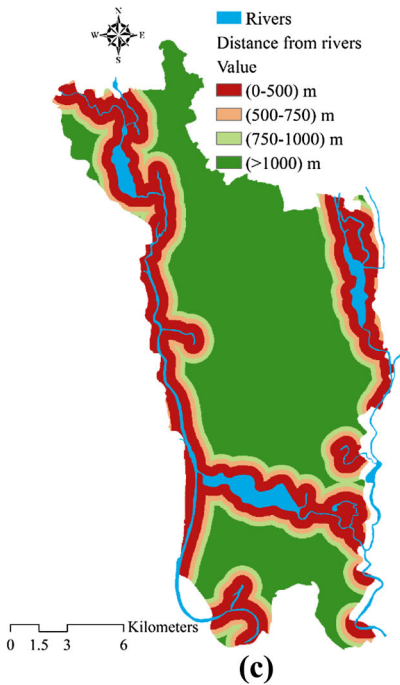
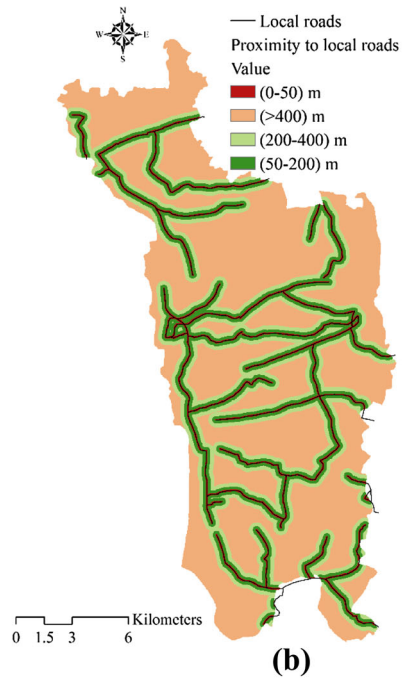
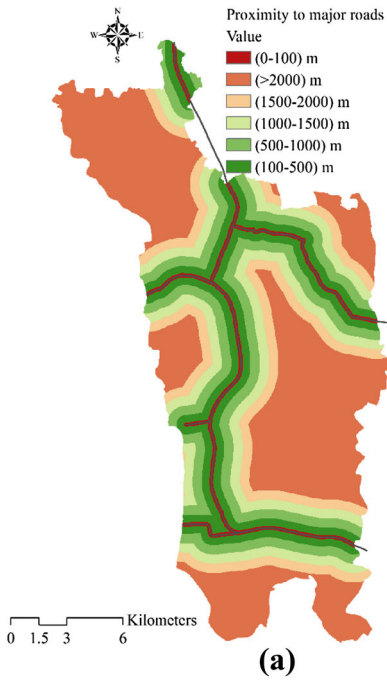
Criteria	A	B	C	D	E	Mean
Proximity to major roads	0.23	0.30	0.09	0.26	0.25	0.22
Proximity to local roads	0.18	0.19	0.08	0.18	0.06	0.14
Distance from rivers	0.07	0.02	0.09	0.07	0.10	0.07
Distance from water bodies	0.11	0.06	0.11	0.06	0.06	0.08
Distance from settlements	0.09	0.10	0.14	0.05	0.05	0.09
Distance from flood flow zones	0.05	0.06	0.15	0.05	0.06	0.08
Distance from agricultural lands	0.11	0.15	0.24	0.14	0.03	0.13
Slope	0.04	0.03	0.06	0.02	0.11	0.05
Elevation	0.13	0.09	0.06	0.17	0.28	0.14
CR	0.08	0.06	0.06	0.09	0.09	

Fig. 6 Maps resulting from the reclassification of layers using criteria according to the factors and constraints: **a** proximity to major roads; **b** proximity to local roads; **c** distance from rivers; **d** distance from water bodies; **e** distance from settlements; **f** flood flow zones; **g** distance from agricultural lands; **h** slope; **i** elevation

from the major roads. Based on this criterion, the moderately suitable, less suitable and least suitable areas were found, and these zones corresponded to 15, 13 and 12% of the total area, respectively. However, the largest fraction of the area, i.e., 44%, was assigned to zones that are “suitable but avoided.” The proximity to major roads was selected as the first priority in the LSA of industries by the experts. Therefore, given that only 13% of the area corresponds to areas that are most suitable for industrial development, in terms of their proximity to major roads, limited the possibility of obtaining considerable land areas for industries. The map resulting from application of the second highest priority criterion, proximity to local roads, found that 15% of the study area was “most suitable,” followed by 19% that was “less suitable” and 6% that was “not suitable.” Sixty percent of the land area was determined to be “suitable but avoided” (Fig. 6b).

Approximately 54% of the study area was located more than 1000 m away from rivers and was therefore “most suitable.” Because most of the rivers are situated along the administrative boundaries of the study area, only 29% of the study area was found to be “not suitable” (Fig. 6c). In addition, due to the small number of water bodies, 95% of the study area was found to be more than 100 m from them and was therefore classified as “most suitable” (Fig. 6d).

Settlements were an important determinant of the available areas. Fifty-four percent of the land was located 50 m away from the settlements and was therefore “most suitable” (Fig. 6e). To identify the hazard-free lands, 22% of the study area was found to lie within flood zones, whereas the remainder (78%) was found to be “most suitable” (Fig. 6f).



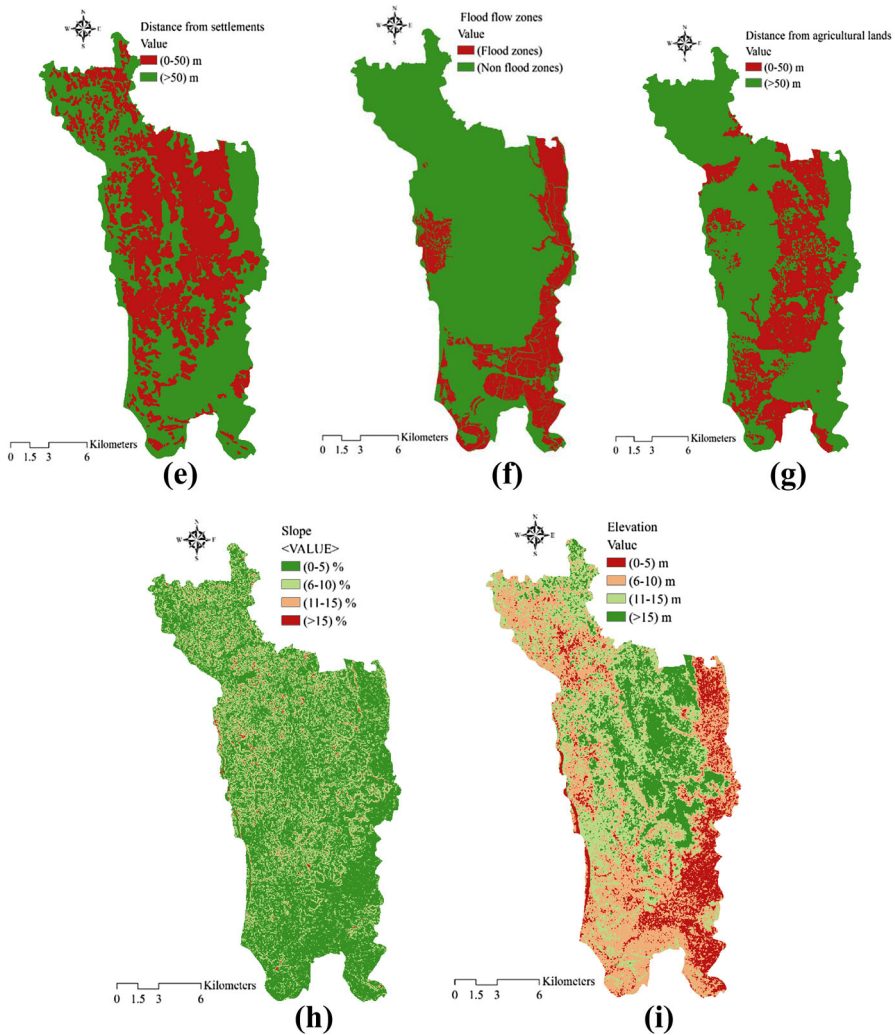


Fig. 6 continued

In addition, the spatial analysis found that 69% of the study area lay at least 50 m from agricultural lands and was therefore “most suitable.” On the other hand, the remainder (31%) lay within 50 m of agricultural lands (Fig. 6g). This result played an important role in determining the final outcome of the LSA because the study was intended to preserve the existing agricultural lands.

Furthermore, under the slope criterion, 66% of the study area was found to be “most suitable” and 29% of the study area was found to be “moderately suitable” (Fig. 6h). On the other hand, based on elevation, 19% of the study area was found to have an elevation greater than 15 m, corresponding to the “most suitable” category (Fig. 6g). The details of the land suitability classification based on the individual criteria are given in Table 6.

Table 6 Scores and suitability classifications of the factors and constraints

Name of Criterion	Factor/constraint	Classification	Suitability	Area (%)
Proximity to major roads	0–100 m	Constraint	Not suitable	4
	100–500 m	Factor	Most suitable	13
	500–1000 m	Factor	Moderately suitable	15
	1000–1500 m	Factor	Less suitable	13
	1500–2000 m	Factor	Least suitable	12
	>2000 m	Factor	Suitable but avoided	44
Proximity to local roads	0–50 m	Constraint	Not suitable	6
	50–200 m	Factor	Most suitable	15
	200–400 m	Factor	Less suitable	19
	>400 m	Factor	Suitable but avoided	60
Distance from rivers	0–500 m	Constraint	Not suitable	29
	500–750 m	Factor	Least suitable	9
	750–1000 m	Factor	Moderately suitable	8
	>1000 m	Factor	Most suitable	54
Distance from water bodies	0–100 m	Constraint	Not suitable	5
	>100	Factor	Most suitable	95
Distance from settlements	0–50 m	Constraint	Not suitable	46
	>50 m	Factor	Most suitable	54
Flood flow zones	Flood flow zone	Factor	Suitable but avoided	22
	Non-flood flow zone	Factor	Most suitable	78
Distance from agricultural lands	0–50 m	Factor	Suitable but avoided	31
	>50 m	Factor	Most suitable	69
Slope	0–5%	Factor	Most suitable	66
	6–10%	Factor	Moderately suitable	29
	11–15%	Factor	Less suitable	4
	>15%	Constraint	Not suitable	1
Elevation	0–5 m	Constraint	Not suitable	15
	6–10 m	Factor	Less suitable	36
	11–15 m	Factor	Moderately suitable	30
	>15 m	Factor	Most suitable	19

3.4 Industrial zone selection

The map resulting from use of the “Weighted Overlay” tool shows the land suitability raster layer. In this map, the cells with different scores were clustered into four groups, “0,” “1–5,” “6–7” and “8–10,” which correspond to areas that are “not suitable,” “less suitable,” “moderately suitable” and “most suitable” (Fig. 7). Based on the calculated areas of the polygons, 93% of the land in the study area was found to be “not suitable” for industrial sites. On the other hand, only 4% of the land in the study area was “most suitable” (Table 7). The results showed that the

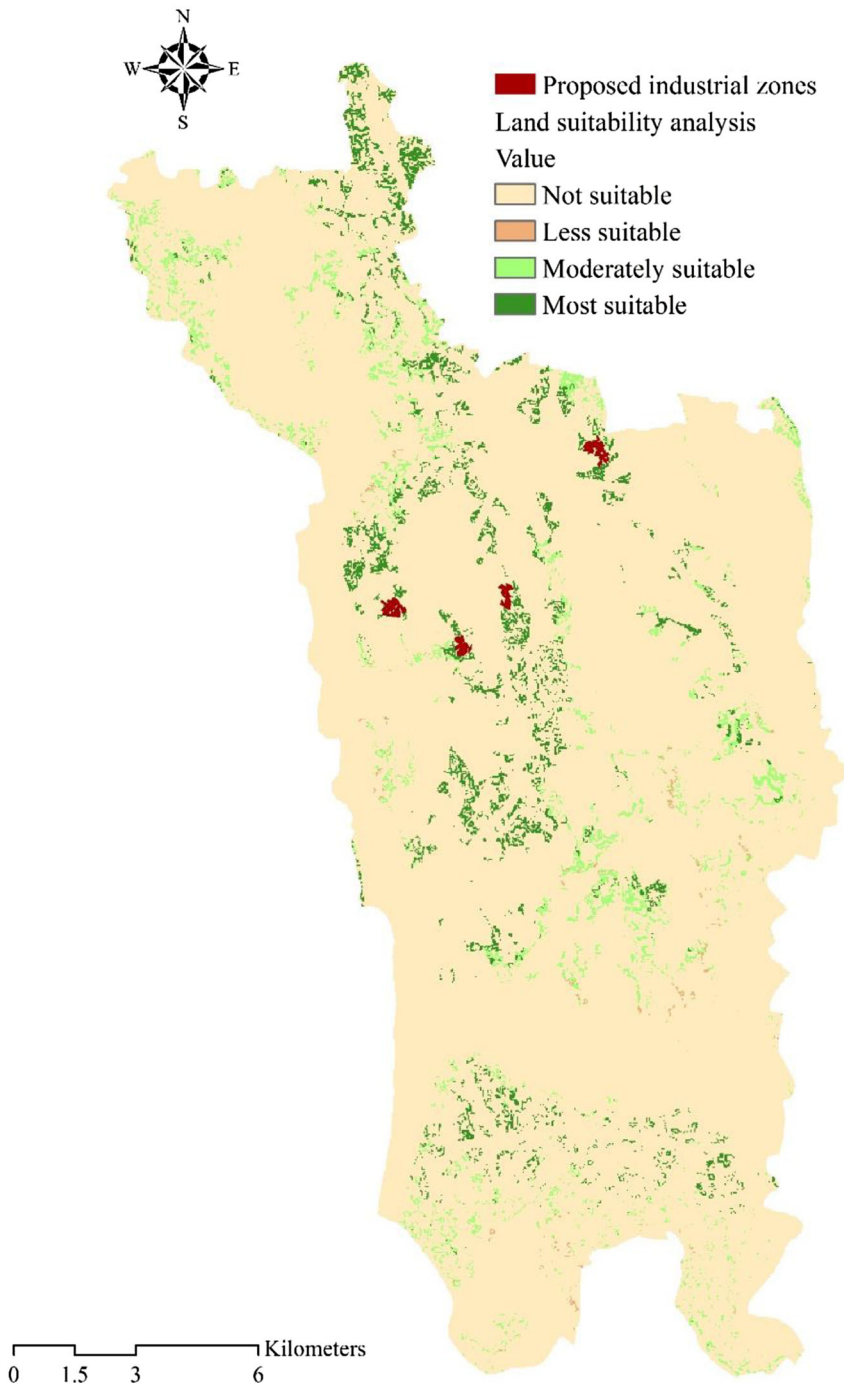


Fig. 7 Land suitability analysis for industrial sites

Table 7 Area assigned to each group on the land suitability map for industries

Ranking	Recommendation	Area (ha)	Proportion (%)
0	Not suitable	26052.09	93
1–5	Less suitable	0	0
6–7	Moderately suitable	840.39	3
8–10	Most suitable	1120.52	4

**(a)** 15.17 ha**(c)** 10.11 ha**(b)** 10.28 ha**(d)** 16.50 ha**Fig. 8** The four most suitable areas identified in this study, which have areas of **a** 15.17 ha, **b** 10.28 ha, **c** 10.11 ha and **d** 16.50 ha (Source: Google Earth Pro[®], 2016/08/08)

spatial analysis worked properly, based on the priority weights of the criteria that were incorporated into GIS using the MCA technique. The lands that were classified as “most suitable” for industries were converted from raster layers into vector polygons. According to the measured area for each polygon, only four compact zones were found which had areas of at least 10 ha, and these zones are marked in red in Fig. 7.

3.5 Verification of the LSA

The feature map showing the potential industrial zones within the study area was exported to Google Earth Pro[®] so that it could be verified using the current satellite image. The four most suitable locations were recommended as potential sites for

industrial zones. The individual parcels contained 15.17, 10.28, 10.11 and 16.50 ha (Fig. 8a–d). These areas were mostly vacant, situated adjacent to major and local roads, and not within flood zones or agricultural lands. However, the images show water bodies and settlements within the most suitable sites, indicating that the results contain some errors. These deviations occur because the base vector layers representing the settlements and water bodies were not updated after 2010. The land use within these areas changed subsequently to settlements and water bodies.

4 Discussion

The study focused primarily on statistical data covering the agricultural lands within Savar, and these data showed that Savar lost 6% of its agricultural lands over 10 years. However, four of the administrative areas within Savar lost more than 6% of their agricultural lands. The greatest loss was noted for Yearpur, which lost 10% of its agricultural land. On the other hand, the geographical locations of 420 cloth factories which were collected during the field survey showed that the growth of the industries was denser within those four areas. The industries, particularly cloth factories, expanded in Savar over the last three decades. In addition, according to BGMEA data, 77% of the cloth factories were established after 2000. Bangladesh is the second largest exporter of readymade cloth, and 81% of the export earnings came from this industry in FY2013–14. The economic growth of the nation through expanding manufacturing units influenced the transformation of agricultural lands of suburban areas to industrial zones. Therefore, industrialization has been an important cause of the reduction in agricultural lands within the study area. Savar has always been a promising area for the establishment of industries because it is near the capital city of Dhaka and is well connected with the Chittagong port area. In addition, the Dhaka EPZ is also located in Savar.

The novel approach used in this study involved conducting an LSA for industries to determine whether any areas exist that are suitable for the future development of industrial zones. The GIS-based spatial analysis proved to be an efficient tool for identifying suitable lands within large areas with mixed land use distributions while evaluating multiple criteria for the location of new industries. The AHP, a widely used multi-criteria method, enabled ranking and weighting of the criteria used in this study. The technique showed that the proximity to major roads had the highest weight (22%) of the nine criteria used, followed by the proximity to local roads (14%) and elevation (14%). The fourth most highly prioritized criterion was distance from agricultural lands (13%). Because Bangladesh is an agricultural country, it is difficult to avoid agricultural lands altogether during the development of new infrastructure. However, the approach used in this study succeeded in protecting the core agricultural lands using spatial data sets in a GIS environment. Considering the agricultural lands as an individual criterion helped to protect the existing agricultural lands.

Finally, combining the factors and constraints using the decision rule in the “Weighted Overlay” tool, the LSA found that only 4% of the study area could be used for industrial expansion in the future. The results certainly showed the most

significant aspects of the land use pattern within Savar. Based on the results from the designed LSA, which represents the relevant criteria and factors, the study area is not suitable for further expansion of industries. The area is already occupied with built-up areas and lacks proper land use management. In addition, the study also tried to identify compact zones for industrial development; the use of such zones could be more effective than current practices in promoting sustainable land use. This study found only one potential economic zone that contains 16 ha of land.

However, the outcome of LSA depends mostly on the spatial data set, which must be upgraded with recent changes. In particular, land use maps with settlements are key elements that change frequently. Nevertheless, open-source satellite images have made land use management easier and more relevant for policy makers and researchers. This research approach has the potential to gain credibility in practical implementations in Bangladesh. However, such research needs to include collaborations with government organizations in order to draw the attention of both policy makers and researchers. Furthermore, abandoned property or old industries could be utilized as part of the process of identifying new economic zones to increase the efficiency of land use management. As one example, the Adamjee Jute Mill was established in 1951 in the Narayanganj district of Bangladesh and eventually became the largest jute mill in the world. However, in the 1970s, polypropylene replaced jute, and the mill faced heavy losses beginning in the 1990s. Finally, in 2002, the mill was shut down and handed over to the Bangladesh export processing zones authority (BEPZA) for conversion into an EPZ. The Adamjee EPZ was opened in 2006. The process of transforming old or abandoned industrial sites into new industrial sites is a long-term planning process, and large investments are needed to remove the disused industrial buildings and reform the operating processes used in these areas. In such cases, economic and environmental assessments are also needed. Thus, the government of Bangladesh encourages the private sector and foreign investors to transform old industries or abandoned and unproductive lands into economic zones. This micro-research approach can be used to consider the different districts surrounding Dhaka, where new and abandoned properties or old EPZs can be included in the analysis as alternative most suitable locations for economic zones.

5 Conclusions

The unplanned growth of industries in the suburban areas of a country drives significant changes in the degree of agricultural land use, and these changes may affect food security in the long run. To address these questions, an LSA model was developed to assess suburban development, particularly industrial growth, and the suitability of further industrial growth, considering environmental restrictions and agricultural land use changes. The model also recommended the further expansion of the most suitable industrial sites and economic zones using GIS and multiple criteria based on environmental factors and the opinions of stakeholders and experts. The GIS-MCA model demonstrated that the transformation of agricultural lands to industrialized areas or urban areas over time reached 11–15% in the suburban areas

in the research area. The LSA showed that only 4% of the land within the study area satisfied the basic requirements for industrial expansion. However, locating potential economic zones where industries could be established in compact areas that comply with industrial requirements and environmental ethics was prioritized, and four compact zones that could be recommended for industrial expansion were identified. Furthermore, spatial validation analysis and time-series data enabled us to observe the land use changes associated with industrial facilities. We found that more than 200 industries were constructed, transforming the agricultural lands, during the last decade. Unlike most developing countries, Bangladesh has a high population density. The lack of land use policies and environmental legislation and the transformation of agricultural lands to industrial areas increase the risk of losing agricultural lands. Therefore, this integrated GIS-MCA model could serve as a policy planning tool for sustainable land use management, which would balance the transformation of land into industrial economic zones with environmental restrictions and management.

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