Application of Multi Criteria Analysis in Delineation of Peri-Urban Area: A Case Study of North 24 Parganas District, West Bengal

Geography

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ABSTRACT Urbanization imposes rapid change in peripheral areas of a city. This paper discusses the technique of Peri-urban area delineation of North 24 Parganas district near Kolkata city. To find out the Peri-Urban area of the district Multi Criteria Analyses (MCA) of different bio-physical indices are made. Analytical Hierarchy Process (AHP) method was used to determine the weights of different criteria. Consistency ratio (CR) was calculated to make sure of judgment of the weights given to the indices for Peri-urban delineation. Weighted linear combination method has been adopted in GIS platform. The influence of peri-urban growth has been quantifies with the help of bio-physical indices and census data. Hypothetical test of the variables are made to establish the associated and non-associated impact of urbanization.

INTRODUCTION

North 24 Parganas is the district which is growing at a fast rate of urbanization in the state of West Bengal. With the spread of urban sprawl, a drastic change in land use land cover and socio-economic environment have been takes place. After independence, huge migration causes urbanization especially in the district of North 24 Parganas due its bordering location of Bangladesh. Urbanization is continuously changing its peripheral rural areas in many aspects. So the peri-urban areas need to get special emphasis so that to ensure sustainable urban development. The term "Peri-urban" was first used by the Office of Rural and Institutional Development (ORID) in late 1980s in the process of explaining schemes of development assistance aid to priority areas (Rohilla, 2005. Cavailhes & Wavresky (2003) attempted to define peri-urban territory by analyzing residential and agricultural land price using a theoretical microeconomic residential location model and an econometric model. Peri-urban areas are dynamic and also rural-urban mixed land use in nature. For delineating peri-urban region no particular mechanism has yet been used. According to Saba R. S, et. al. (2011), choosing a small number of criteria might result in over simplifications and each evaluation criterion must be comprehensive and measurable and the set must be complete (cover all aspects of the problem), operational (meaningful in analysis), decomposable (broken into parts to simplify the process), non-redundant (avoid double counting) and minimal. The impact of peri-urban growth has been assessed by many research scholars are may divided into two categories. One is the impact on physical environment and another is on socio-economic environment.

Study area: Geographical location of North 24 Parganas is between 22°05′54″N to 23°16′39″N of latitude and 88°20′03″E to 89°06′34″E of longitude (Figure 1). Total area of the district is 4168.86 km2. River Hooghly flows along the western boundary and Bangladesh is in the eastern side. Some small tidal rivers and creeks in this lower course of Hooghly River mark the physical landscape of this district. Tropical monsoon climate is the prime climatic characteristics of this district. Temperature varies from 41°C to 10° C in the month of June to December. The district consists of 22 blocks with 27 municipalities and 200 Gram Panchayats. The CBD of Kolkata city is only 10 km from the district headquarters Barasat.

Figure 1: Location map of North 24 Parganas district
Data used and Methodology
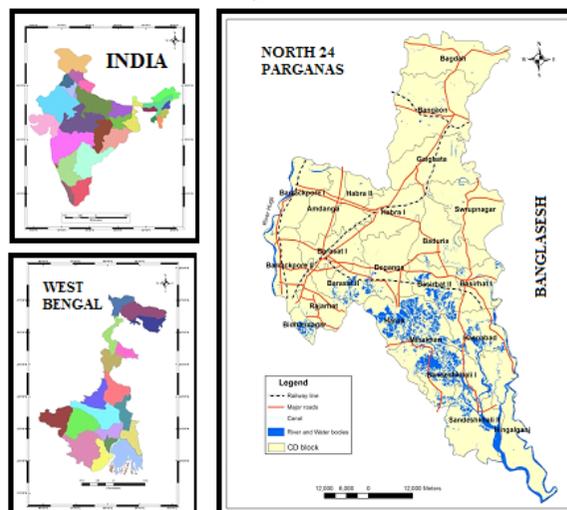
Different types of bio-physical data have been used in this study; (i) Landsat Thematic Mapper (TM) image of 2010 of Path 138 and row 44 and 45 of 6th February 2010 at 4:21:53 and 4:22:17 pm respectively were covering the area of North 24 Parganas district. Clear and cloud free images were acquired in the month of February (post monsoon season) of the study area. (ii) Several Topographical sheets of Survey of India (iii) block maps of North 24 Parganas have been used to prepare infrastructure map of the study district.

Geometric correction:

Skew distortion of two Landsat images are corrected or deskewed with the help of systematic or predictable approach (Lillesand & Kiefer, 2004). The Root Mean Square Errors (RMSE) of the images is 0.40 and 1.57. Geometrically corrected images are then mosaic. The scanned paper map of North 24 Parganas district is geometrically corrected with the help of well distributed ground control points (GCP) from mosaic image (image to image rectification) and calculated RMSE of the district map is 0.10. The images are geo-referenced with UTM zone N45 projection and WGS 84 datum system using polynomial function and nearest neighbor resampling method. The geo-referencing function is chosen in order to preserve the radiometry and spectral information in the imagery (Richards and Jia, 1999)

Assessment of bio-physical character of the study area for delineating peri-urban zone:
Different indices are carried out from Landsat TM band to assess the bio-physical character of the district. According to the application of different indices, authors have been selected seven indices as important indicator of Peri-urban environment.

Vegetation coverage and its characteristics:
Normalized Difference Vegetation Index (NDVI) is a sensitive bio-physical parameter that correlates with photosynthetic activity of vegetation and provides an indication of the greenness of vegetation (Sellers, 1985). Soil Adjusted Vegetation Index (SAVI) (Huete A R, 1988) is another index which we have taken in to consideration viewing that the soil moisture is another important environmental condition which gradually goes down from rural areas to urban area. In the peri-urban areas, the character of vegetation and soil moisture coverage is of medium range, i.e. crop field, uncultivable waste land and residential housing etc. grouped together forming mixed character of land use pattern. In this study NDVI and SAVI images have been classified into five equal ranges to regionalize the district according to high vegetative cover to no or less vegetative cover.

Built up land and its character:
Normalized Difference Built-up Index (NDBI) has been proposed by Yong Cha et. al in 2003. This index is based on the rule that the building-up/concrete area has higher reflection in mid-infra-red band than near infra-red band. So this index is very much useful to estimate the concrete area and differentiate rural and urban areas of a region. Zha (2003) also that the non-urban and urban areas are distinguished based on a urban built-up index (UBI).The non-urban areas include forest land, farmland (rice fields and upland fields) and parks, while commercial fields, public fields, resident areas and empty land belong to the urban area category. To assess and regionalize the character of built-up area NDBI and UBI index are classified into five ranges. Both the indices are clearly indicates the built-up land and barren land with very high and high range of index value. Moderate built-up and barren land found in the middle and northern part of the district. Low and very low categories of built-up values appeared in mangrove and water bodies of the district.

Water bodies and its character:
According to Hanqiu Xu, (2007) with the help of MNDWI image water has the higher value and by threshold value of MN-DWI urban area can be extracted, because water bodies and its quality changes from urban areas to rural areas sharply. Lacaux et al. (2007) have defined the Normalized Differenced Pond Index based on the fact that water has a very low reflectance in the middle infrared wavelength. Here in this study MNDWI and NDPI are taken into consideration because the water bodies and its quality decrease from rural area to urban area. These indices are classified into five classes to stratify the quality and distribution of water bodies. From MNDWI image, very high and high concentrations of water bodies are found in southern part of the district. Moderate type found in the middle part. Low and very low quality of water bodies are found in the barren land areas. In case of NDPI, lower value denotes pond and other low turbid water bodies. So, with this index the study district has been classified into five classes.

Barren land and its character:
Normalized Difference bareness Index (NDBaI) is an index which helps us to find out the bare area. Although the bare soil and urban concrete area gives quite similar NDBaI values and it is difficult to distinguish urban and bare soil by this index value, but by some special precaution it is possible to create threshold value of NDBaI to differentiate urban bare grounds and rural cultivable waste land. Due to urbanization, bare and open spaces are decreasing in urban and Peri-urban areas. In case of Peri-

urban area bare or open areas gets special hike for new concrete built-up area and in this way its characters being changed. To regionalize the bare space of the district NDBaI image has been classified into five equal classes. The highest range of NDBaI appeared in red colour in the northern part of the district. High to moderate classes are found in middle part of the district.

MCA for Peri-urban suitability assessment using indices:
In the context of GIS based MCA, decision maker has to choose and select one or more alternatives from a set of variable. Here the variables are the different indices criteria. Depending on the specific nature of different criteria and alternative a probability-weighted index criteria approach has been adopted. To delineate peri-urban area a weighted alternative has been chosen from different bio-physical environment i.e. indices. The choice among a set of indices for delineation of peri-urban area is based on above discussed multiple criteria. This process is most commonly known as Multi-Criteria Analysis (MCA) (Voogd, 1983). Mathematically, this can be defined as-the ranges of each index which are categorized into 5 equal classes to stratify the bio-physical character from different indices in the study area. Every strata of each index are designated as alternative (A) for peri-urban environment (Table 2). Alternative (A) of different indices are given different weight on the basis of important indicator of peri-urban area. Highest weight is given to the class that is most favourable, either to potential and lowest weight is given to the class that is least favourable.

Analytical Hierarchy Process:
In 1977, T. L. Saaty said that three methods are usually applied for the establishment of weights: ranking, scoring, and pair-wise comparison. The pair-wise comparison method is more advanced, enabling a relatively reliable examination of real world conditions. Using this method, a matrix is developed in which every criterion attains a value based on its importance in relation to all other criteria and the weight of its relative importance is calculated for each criterion. In general, the method implements a comparison between every possible pair of alternative by means of an appreciation scale generally ranging between 1 and 9 in the form of a relative matrix as described in Table 4. So, we provided a matrix of 5×5 alternative for seven criterions to be filled by the relevant experts. Working with matrices of 5×5 criteria for peri-urban area necessitates an examination of the experts' consistency in developing the matrix. Looking the consistency ratio (CR) of different experts, the minimum CR of different alternative has been selected.

Starting at the top of the hierarchy and working down, the pair-wise comparisons at a given level can be reduced to a number of square matrices $A = [a_{ij}]_{nxn}$ (1)

The matrix has reciprocal in nature, as shown in formula 2

$$a_{ji} = \frac{1}{a_{ij}}$$ (2)

After all pair-wise comparison matrices of different alternatives are formed, the vector of weights, is computed on the basis of Satty's eigenvector procedure. The process of eigenvector calculation comprises of two steps. In the first step, the pair-wise comparison matrix $A = [a_{ij}]_{nxn}$ is normalized by the formula 3 and then the weights are calculated using the formula 4

$$a_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$ (3)

For all j=1,2,...,n

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{n}$$ (4)

From the pair-wise comparison matrix, weights of the alternatives are calculated using formula 5

$$Aw = \lambda \max w \qquad (5)$$

The λmax value is an important validating parameter in AHP and is used as a reference index to screen information by calculating the Consistency Ratio (CR) of the estimated vector. To calculate the CR, the Consistency Index (CI) for each matrix of order n can be obtained from formula 6.

$$CI = \frac{\lambda max - n}{n - 1} \qquad (6)$$

Then the CR has been calculated using formula 7.

$$CR = \frac{CI}{RI} \qquad (7)$$

RI is the random index developed by T. L. Satty in 1977. This is a constant that depends on the number of criterion on the matrix. In this study with 5 criteria, the appropriate value of RI is 1.12

From the views of experts, the minimum CRs of different alternatives are taken into consideration and the weights for factors were determined. For the high assurance of judgments, CR of less than 0.1 have been selected for all the pair-wise matrixes were filled by 5 experts. Then, by averaging the weights, the single rank of each factor was determined, and so was the total rank (Table 1).

Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong to extreme strong importance
9	Extreme importance

Table 1: Importance scale of alternative

Calculation of weightage for different alternative and MCA using Weighted linear combination method:
First, standardization processes of the alternatives (A) to a continuous scale were implemented. Standardization is necessary to transform the disparate measurement units of the alternatives of different index (C) into comparable suitability values. These transforming standards have been considered through the literature reviews and discussions with researchers and local experts on land resources, environmental protection, urban planning and social development.

Criterion	Weights	Sub category Range	Alternative	Weights
NDVI (Consistency ratio= 0.068)	0.147	0.163 to-0.346	1	0.051671441
		0.020 to -0.163	2	0.111853065
		0.204 to 0.020	3	0.535319872
		0.387 to 0.204	4	0.230040745
		0.571 to 0.387	5	0.071114878
NDBI (Consistency ratio= 0.006)	0.147	-0.573 to -0.777	1	0.053266619
		-0.369 to -0.573	2	0.053266619
		-0.165 to-0.369	3	0.515709178
		0.039 to-0.165	4	0.285398566
		0.243 to 0.039	5	0.092359017

		-0.718 to -0.896	1	0.060087349
NDBaI (Consistency ratio= 0.003)	0.147	-0.540 to -0.718	2	0.060087349
		-0.362 to -0.540	3	0.587053697
		-0.185 to -0.362	4	0.186055134
		-0.007 to-0.185	5	0.10671647
SAVI (Consistency ratio= 0.6)	0.147	0.255 to-0.020	1	0.051671441
		0.530 to 0.255	2	0.111853065
		0.806 to 0.530	3	0.535319872
		1.081 to 0.806	4	0.230040745
		1.357 to 1.081	5	0.071114878
NDPI (Consistency ratio= 0.02)	0.147	-0.595 to -0.857	1	0.042260797
		0.334 to -0.595	2	0.070248045
		-0.073 to -0.334	3	0.233620802
		0.188 To -0.073	4	0.546386441
		0.449 to 0.188	5	0.107483915
UBI (Consistency ratio= 0.06)	0.147	-0.941 to -1.249	1	0.043188146
		-0.634 to -0.941	2	0.043188146
		-0.326 to -0.634	3	0.116650997
		-0.018 to -0.326	4	0.525249014
		-0.288 to-0.018	5	0.271723697
MNDWI (Consistency ratio= 0.10)	0.147	0.080 to -0.313	1	0.102951021
		0.153 to -0.080	2	0.5241686
		0.386 to 0.153	3	0.230405675
		0.620 to 0.386	4	0.110660171
		0.853 to 0.620	5	0.031814533

Table 2: Factors of peri-urban area and associated weights

Author assigns the weights of relative importance directly to each attribute map layer. The total score for each alternative is obtained by multiplying the importance weight assigned to each attribute by the scaled value given for that attribute to the alternative and then summing the products over all attributes. The scores are calculated for all of the alternatives and that with the highest overall score is chosen. The methods can be implemented in both raster and vector GIS environment. In this weighted linear combination factors or criterion are combined by applying a weight of each alternative followed by a summation:

$$S = \sum w_i \; x_i \qquad (8)$$

Where S is the suitability, is weighted factor of i and is the criterion score of factor i.
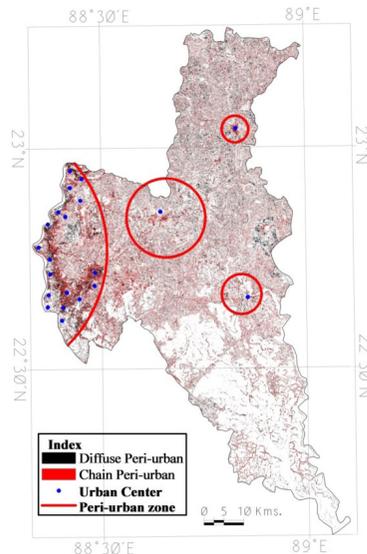

Figure 2: Peri-urban area of North 24 Parganas, 2010

Impact of peri-urban growth:

Contemporary growth of peri-urban area is the driving force of socio-economic change. Rural agrarian based socioeconomic features are penetrated by an urban way of life. Peri-urbanization causes conversion of farmland to urban uses. The emergence of non-farm activities in the peri-urban areas generates new opportunities for livelihood diversification and additional income for the peasants (Wisnu Pradoto, 2002). The peri-urban areas have become the home of many economic activities and the destination of middle class for residential purposes has brought multidimensional changes. In the particular phase of peri-urban growth, these areas suffer from the negative consequence of urban growth, rapid social change, land use change and degradation of natural resources (Wisnu Pradoto, 2002). The strategic location in the interface of urban and rural areas makes the peri-urban zones more complicated and their growth tends to be uncontrolled. Urbanization in the city outskirts has transformed space and fostered socio-economic change.

To quantify the impact of peri-urban growth, we apply some socio-economic parameters and one of the important bio-physical indices NDBI, which is discussed earlier. Considering:

a. Peri-urbanization (PU): Mean of NDBI is high in area (A) peri-urban areas.
b. Peri-urban House density (PUHD): Higher the mean of NDBI in area (A), the larger the house density in area (A) is.
c. Peri-urban Population density (PUPD): Higher the mean of NDBI in area (A), higher the population density in area (A) is.
d. Peri-urban worker composition: Higher the NDBI in area (A), percentage of Non-farm Worker (NFW) is higher in area (A) is.

Impact assessment
Quantification of different variables:
The built-up area and other three variables of socio-economic environment (population density, house density and percentage of non-farm workers) are considered as the indicator of peri-urbanization. Built-up areas of the peri-urban area are extracted from normalized built-up index (NDBI). The mean value of NDBI is selected as representative value for the consecutive peri-urban areas. Higher the mean of NDBI, higher the peri-urbanization is. The mean of NDBI of then peri-urban patches are taken for the year 2010. The other variables house density; population density and percentage of non-farm worker to total worker are calculated from census data of 2011 (Table 3).

Classification of peri-urbanization has been done into two, high and low. The mean of NDBI from -0.155129 to -0.227129 is considered as high peri-urban areas and the rest which is from -0.295374 to -0.330641 as low peri-urbanized areas. The other three variables are classified into three classes i.e. high (H), medium (M) and low (L). Ten peri-urban patches are classified into 2 X 3 matrixes (Table 4 a, b, c).

PLACE	(a)	(b)	(c)	(d)
RAJARHAT URBAN	-0.155	98.94	3385.27	13769.29
BARRACKPORE II URBAN	-0.183	98.98	4237.70	17716.73
BARASAT II URBAN	-0.190	97.85	2411.16	9761.77
BARRACKPORE I URBAN	-0.227	98.17	3191.92	14599.85
BARASAT I URBAN	-0.295	96.67	2824.09	11465.04

PLACE	(a)	(b)	(c)	(d)
BIDHAN NAGAR URBAN	-0.307	98.14	1467.73	6465.94
HABRA I URBAN	-0.325	95.49	1593.89	6435.58
BASIRHAT I URBAN	-0.329	92.05	1539.84	6649.11
BONGAON URBAN	-0.331	96.94	1066.07	4407.45
BADURIA URBAN	-0.340	78.39	618.41	2664.64

Table 3: Observed value of different variables of ten peri-urban patches, 2010-11 Where, (a)- MEAN OF NDBI, 2010; (b)-% of NON FARM WORKER TO TOTAL WORKER, 2011; (c)-HOUSE DENSITY, 2011; (d)-POPULATION DENSITY, 2011

PERI-URBANIZATION	% OF NON FARM WORKER TO TOTAL WORKER, 2011			
	H	M	L	TOTAL
HIGH	3	2	0	5
LOW	1	1	3	5
TOTAL	4	3	3	10

Table 4a: Observed frequencies of peri-urban areas in different categories of selected variables

PERI-URBANIZATION	HOUSE DENSITY,2011			
	H	M	L	TOTAL
HIGH	3	1	0	4
LOW	0	3	3	6
TOTAL	3	4	3	10

Table 4b: Observed frequencies of peri-urban areas in different categories of selected variables

PERI-URBANIZATION	POPULATION DENSITY, 2011			
	H	M	L	TOTAL
HIGH	4	1	0	5
LOW	0	0	5	5
TOTAL	4	1	5	10

Table 4c: Observed frequencies of peri-urban areas in different categories of selected variables

Test of significance:
The stratified sample of 10 peri-urban patches were classified according to built-up ness along with population density, house density and percentage of non-farm worker to total worker separately to taste whether the conditions of built-un ness and population density, built-up ness and house density and built-up ness and percentage of non-farm worker to total worker are associated or not. The null hypothesis is that the attributes are independent. The expected frequencies are calculated as follows:

$$f_e = \frac{A_i \, B_i}{N} \qquad (9)$$

Where, A_i is the Row Total, B_i is the Column total and N is the total frequency of observed frequency

PERI-URBANIZATION	% OF NON FARM WORKER TO TOTAL WORKER, 2011			
	H	M	L	TOTAL
HIGH	2	1.5	1.5	5
LOW	2	1.5	1.5	5
TOTAL	4	3	3	10

Table 5a: Expected frequencies of Peri-urban areas.

PERI-URBANIZATION	HOUSE DENSITY 2011			
	H	M	L	TOTAL
HIGH	1.2	1.6	1.2	4
LOW	1.8	2.4	1.8	6
TOTAL	3	4	3	10

Table 5b: Expected frequencies of Peri-urban areas.

PERI-URBANIZATION	POPULATION DENSITY 2011			
	H	M	L	TOTAL
HIGH	2	0.5	2.5	5
LOW	2	0.5	2.5	5
TOTAL	4	1	5	10

Table 5c: Expected frequencies of Peri-urban areas.

(i) For peri-urbanization and population density, the value of percentage point of chi-square distribution (X^2) has been calculated.

$$X^2 = ++++ \qquad (10)$$

$X^2 = 10.0$ for degree of freedom 2.

The observed value of X^2 exceeds 1% tabulated value, which is highly significant and the peri-urbanization and population density are not independent; they are highly associated.

(ii) For peri-urbanization and house density, the value of percentage point of chi-square distribution (X^2) has been calculated.

$$X^2 = ++++ \qquad (11)$$

$X^2 = 6.875$ for degree of freedom 2.

In case of peri-urbanization and house density, it is observed that the X^2 exceeds 5% tabulated value, which is significant and they are not independent, they are associated.

(iii) For peri-urbanization and percentage of non-farm population, the value of percentage point of chi-square distribution (X^2) has been calculated.

$$X^2 = ++++ \qquad (12)$$

$X^2 = 4.33$ for degree of freedom 2.

For peri-urbanization and percentage of non-firm population, X2 is below 5% tabulated value, which is less significant and they are not independent and are associated.

Result and discussion:
In case of NDPI and UBI the 4th alternative gets highest weights, defining peri-urban environment. The other criterion, their 3rd alternatives are in the highest weight in defining peri-urban areas of the district. From the MCA analysis of different indices, it seems that the changing environment in the eastern part of river Hooghly, mainly the outgrowth of the municipalities of Barrackpore I and II blocks and municipalities along the national highways Barasat, Habra, Bongaon and Basirhat maximum peri-urban growth has taken place. At the same time result shows that except southern part, the district is in the face of peri-urban growth. From the result derived in the MCA process, it is seen that the peri-urbanization have been taken place mainly in two places, one is in the peripheral zone on municipalities and urban centres and the another is in the daily commuters zones. Through the consequence of some basic process like distance from nearest city etc., Peri urban environment has been classified into two types- (a) Diffuse Peri-urban and (b) Chain peri urban. Diffuse Peri urban is area of fragmented outskirts area of city environment. Chain peri urban usually develops along the railways, highways. It is the daily commuters' zone to the nearest cities (Figure 2).

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