COMPARATIVE ASSESSMENT BETWEEN AREA BASED AND PATCH BASED GIBBS-MARTIN DIVERSIFICATION INDEX FOR LAND USE PATTERN ANALYSIS

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Abstract
Fragmentation of the land covers and land use comprises both the area and patch dimensions. In the present study, we have employed the Gibbs-Martin (GM) diversification index in order to determine the diversification in rapidly urbanizing Ranchi city, capital of Jharkhand state, India, considering both the area and patch dimension of the different land use and land covers present in the area. Comparative analysis of the area and patch based GM index shows significant difference in the magnitude and pattern of the GM index scores determined for the 30 successive spatial buffers of 100m interval delineated around the major roads in the study area. The land use and land covers were mapped from the Landsat ETM data of 2013. The results demonstrated that it is judicious to consider both the area and patch dimension of the fragmenting land use and land covers to construct accurate inference about the land use and land cover diversification in an area that could serve as vital information for the urban planners.
Keywords: Gibbs-Martin Diversification index; Fragmentation; Land use and Land covers; Area and Patch.

1. INTRODUCTION

It is trivial that land use and land cover change induced either due to urbanization or otherwise will invariably lead to the diversification of land use and land covers. The term land cover refers to the type of feature present on the surface of the earth whereas land use relates to the human activity or economic function associated with a specific piece of land (Lillesand et al 2008). In order to carry out sustainable planning and development in an area, it is highly vital to determine the magnitude of diversification on a spatio-temporal basis. One of the powerful yet methodologically simple index of diversification was proposed by Gibbs and Martin (1962) referred to as the Gibbs-Martin index or G-M index of diversification. The index, which is discussed below has been applied in a diversity of

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disciplines with considerable success (Bhatia 1965). The index is determined by considering the proportion of the area of the different land use and land cover categories present in an area. As per the index, if an area is comprised of only one land use or land cover, the G-M index will be zero. On the other hand, if the area consists of an infinite number of categories with equal proportion of the area in each category, the G-M index will be equal to 1. If the number of categories increases, the score of the G-M index also increases. For example, for 4 categories, each with 25% areal extent, the G-M index score=0.75, for 5 categories with 20% areal extent of each, G-M index score=0.8 (Patil 2008). However, the diversification of land use and land cover categories cannot be explained solely by their areal proportion, since this would also be significantly influenced by the number of patches of the different categories present in an area. For example, consider two different situations in which the number of categories is same; say only two with equal areal extent of each i.e. 50% and the total number of patches of both the categories is also same in both the situations; however in the two different situations, the number (or proportion) of the patches of the two categories is different. Consider that in each situation the total number of patches of both the categories is say 20; however, in the first situation, each category has10 polygons that indicates the occurrence of 50 % proportion of each category, while in the second situation, one category consists of 15 patches and the other 5 patches that results in the proportion of the patches of the two categories as 75:25. The first situation indicates that both the categories are fragmented with equal magnitude while in the second situation, one category is fragmented three times more than the other category. The prevalence of these two kinds of situations is certainly indicative of different magnitudes of diversification of the land use and land cover categories. Therefore, the areal extent of the categories remaining same, the magnitude of diversification will be different, which is influenced by their number of patches.

The Gibbs-Martin index has been widely used in several fields due to the flexibility and reliability of the index such as urbanization pattern analysis, crop diversification and demographic studies. Recently crop diversification analysis has been carried out by Datta (2012) in Hugli district, West Bengal, India, using Gibbs-Martin diversification index. The study provided clear areal differentiation among the crops grown that would subsequently provide an avenue to future planners to establish more economically sustained agricultural system. Crop diversification study was also carried out by Das and Mili (2012) in Dibrugarh district, Assam, India who reported that it is vital to promote crop diversification in the district in order to improve the agricultural sustainability. Gibbs-Martin index of diversification has been used to determine the caste diversification in the Kathmandu Metropolitan area, Nepal (Subedi 2010). The study examined the population dynamics from a socio-geographic perspective by focusing on the concentration of caste/ethnic groups, migration into the city and apparent ethnic diversification. The index of ethnic diversification clearly demonstrates a geographic pattern associated with distance. Sajjad and Prasad (2014) attempted to assess the spatio-temporal dynamics of crop diversification using the Gibbs-Martin index of diversification in Jalandhar district, Punjab, India. The study shows decline in crop diversification in most of the study area. Declining diversity of crops in the area shows serious repercussions for natural resources, ecology and socioeconomic condition of the farmers. Gotham and Campanella (2013) used the Gibbs-Martin index of diversification to study the diversification pattern in ethnography. They used multi-level census data, in-depth interviews, ethnographic and Geographical Information Systems (GIS) methods to determine the effects of median household income, ethnoracial diversity, and flood damage on rates of post-Katrina repopulation in New Orleans. In the present paper, our main objective is to carry out comparative analysis between the area based and patch based Gibbs-Martin index of diversification computed based respectively on the proportion of area and patch frequency of the different land use and land cover categories present in the study area.

2. STUDY AREA

The investigation was carried out, in and around the Ranchi city, the capital of Jharkhand state, India, covering a total area of 760 sq. km, bounded between longitudes 23°10' to 23°30'E and latitudes 85°10' to 85°30' N in the Survey of India toposheet number 73E/7 (Figure 1). Formed after the partition of Bihar in the year 2000 the city has been witnessing rapid urbanization at the cost of agricultural land and vegetation. As per latest 2011 India census Ranchi is 37th largest urban city in India and third largest city in Jharkhand after Jamshedpur and Dhanbad in terms of population. NH 33 and NH 23 pass through the city, connecting major cities, and providing movement for passenger and freight traffic. The study area receives an average 1300-1400 mm rainfall. Major crops grown in the study area are paddy, pulses, and millets. Average height from the mean sea level is around 650–700 m, having low to moderate slope of 5^{o}–15^{0}. Although Ranchi has a humid subtropical climate, temperatures in summer ranges from 20°C to 42° C degrees while, in winter temperature ranges from 0°C to 25° C degrees.

Seven major land use/cover types dominant in the study area have been considered for performing the present investigation such as built-up, built-up with vegetation under the impervious categories and agricultural land, dense vegetation, sparse vegetation, plantation and water bodies under the pervious categories. The study area comprises the Ranchi Municipality corporation (RMC) area and seven km buffers around the RMC boundary (Figure 1).

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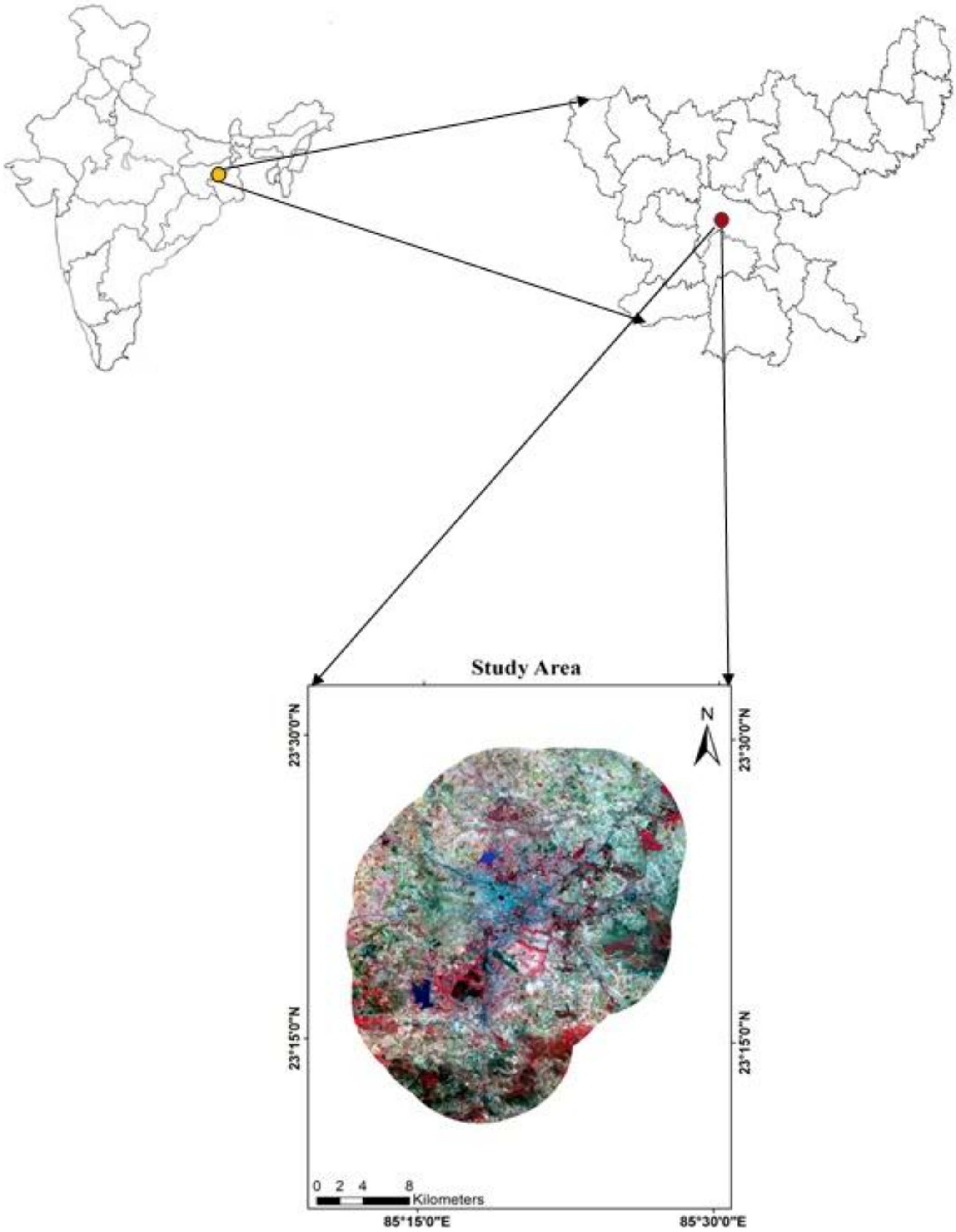

FIGURE 1 - STUDY AREA

3. MATERIALS AND METHODS

Initial tasks comprise rectification and georeferencing of the Landsat ETM satellite image of April 2013 with reference to the Survey of India (SoI) toposheet No. 73 E/7 using the Erdas Imagine 9.1 software.

Subsequently, resolution merge with the PAN band was carried out in order to enhance the spatial resolution of the image for easy and clear demarcation of the different land use/ land cover categories considered in the present study. Delineation and digitization of the various land use and land cover categories was carried out through visual interpretation using Arc GIS 10.1 (Figure 2).

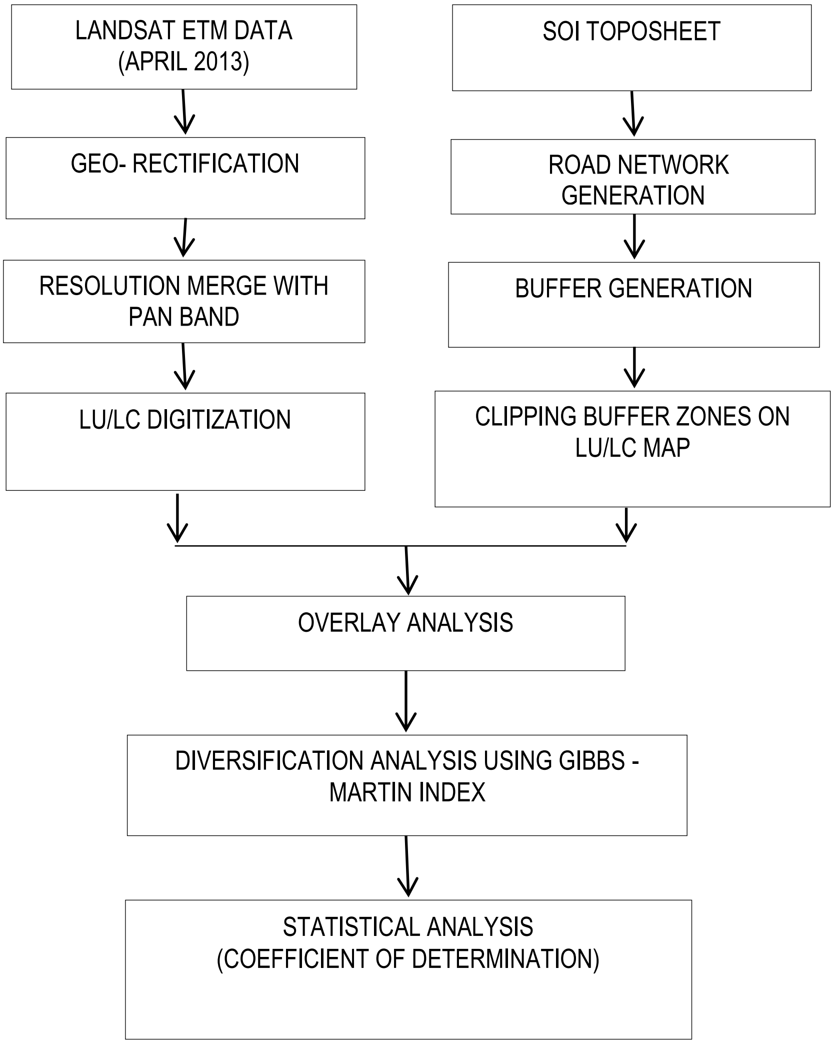

FIGURE 2 - FLOW CHART OF METHODOLOGY

The road network was demarcated from the SoI toposheet number 73E/7 and further updated with satellite imagery. Thirty buffer zones, each of 100 meters were generated around the eight major roads (Figure 3). Thus, each buffer zone covers a buffer width of 200m. The area and number of patches of the different land use and land covers in each buffer zone were determined through the GIS based overlay operation. Then for each buffer zone, Gibbs-Martin Diversification index was calculated based on the area and number of patches of the various land use and land cover categories present in each buffer zone. In the final step, buffer wise comparative analysis between the Gibbs-Martin index determined based on area and patch parameters was performed.

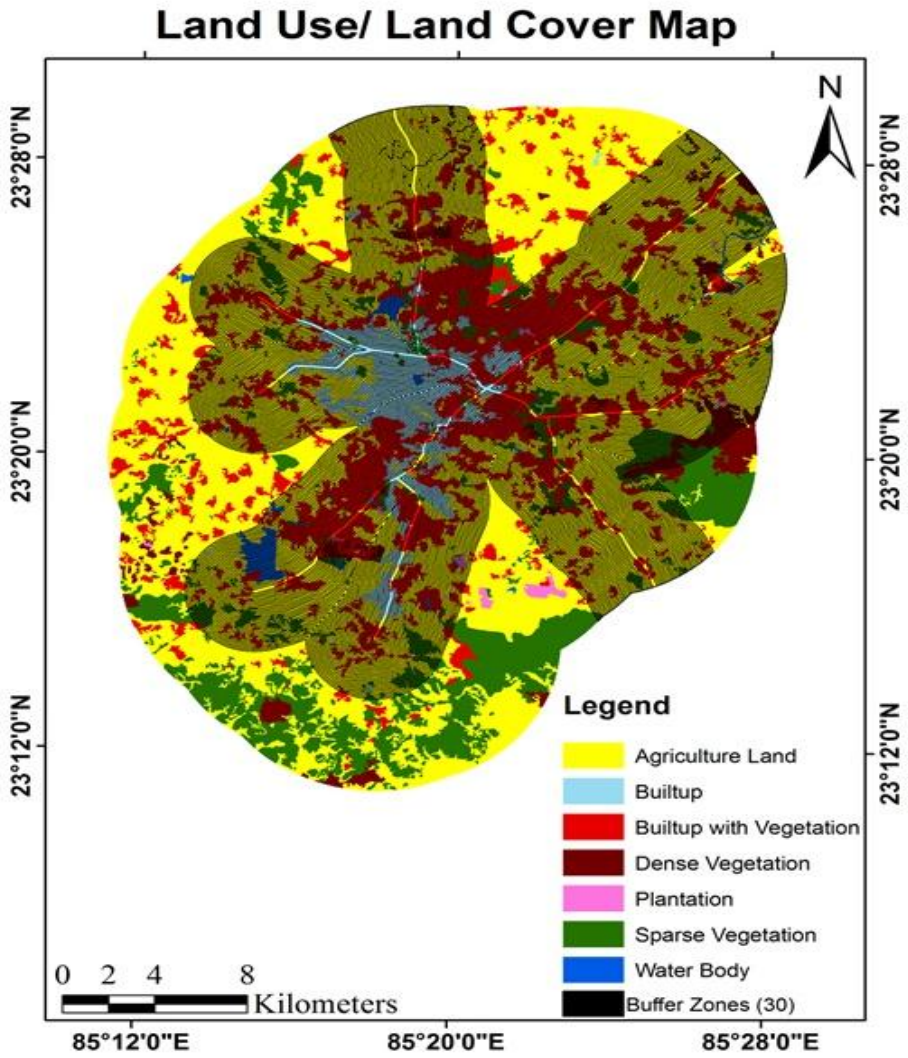

FIGURE 3 - LAND USE / LAND COVER MAP WITH DIFFERENT BUFFER ZONES

The Gibbs-Martin index used for measurement of diversification among the land use and land cover categories is given by the following equation (Gibbs and Martin 1962).

$$GM = 1 - \frac{\sum fi^2}{\sum (fi)^2}$$

where GM is the Gibbs-Martin diversification index and fi is the area of land use type i; if there is only one land use type then GM is zero while GM becomes one when the land uses are distributed evenly in each type. For a particular study area comprised of a definite number of land use and land cover categories, greater the value of Gibbs-Martin index lesser is the magnitude of diversification among the different land use and land covers while the smaller GM index values would indicate greater magnitude of diversification. Therefore GM index can be employed to analyze the diversification degree of the land use in a region.

The buffer wise area and patch distribution of the different land use and land cover categories are shown in Figures 4 (a) and 4 (b) respectively. Table 1 presents the coefficients of determination (R^2) of area wise and patch wise spatial trends of different categories across the 30 successive buffers. Comparison of the R^2 values pertaining to area and patch reveals the following information.

Most of the categories exhibit highly systematic variation of their area with increasing distance from the major roads as indicated by the prevalence of high values of R^2 as compared to the variation of their corresponding patch frequency. This observation further indicates that these categories are fragmented more systematically in terms of their area as compared to their patches across the different buffers. Among the different categories, built up with vegetation exhibits the highest value of R^2 (0.937) in terms of its area which is thoroughly in contrast to its patch based coefficient of determination (R^2=0.402). This observation signifies the prevalence of more systematic fragmentation of the built-up category in terms of its area as compared to its patch across the successive buffers delineated around the major roads of the study area.

TABLE 1 - COEFFICIENT OF DETERMINATION (R^2) OF BUFFER WISE VARIATION OF AREA AND PATCH OF DIFFERENT CATEGORIES

SL NO.	LAND USE/ LAND COVER CATEGORIES	R^2 (AREA)	R^2 (PATCH)
1	Agriculture land	0.840	0.059
2	Builtup	0.811	0.700
3	Builtup with Vegetation	0.937	0.402
4	Dense Vegetation	0.062	0.309
5	Sparse Vegetation	0.623	0.188
6	Plantation	0.046	0.016
7	Water Body	0.607	0.006

4. RESULTS AND DISCUSSIONS

The primary purpose of performing this investigation is to carry out comparative analysis between the area based and patch based Gibbs-Martin diversification index determined by considering the area and the number of patches of the seven different land use and land cover categories occurring within the 30 individual buffer zones delineated in the study area. The bufferwise variation of area and patch based Gibbs-Martin index along with the coefficient of determination (R^2) values are shown together in Figure 5 and Table 2.

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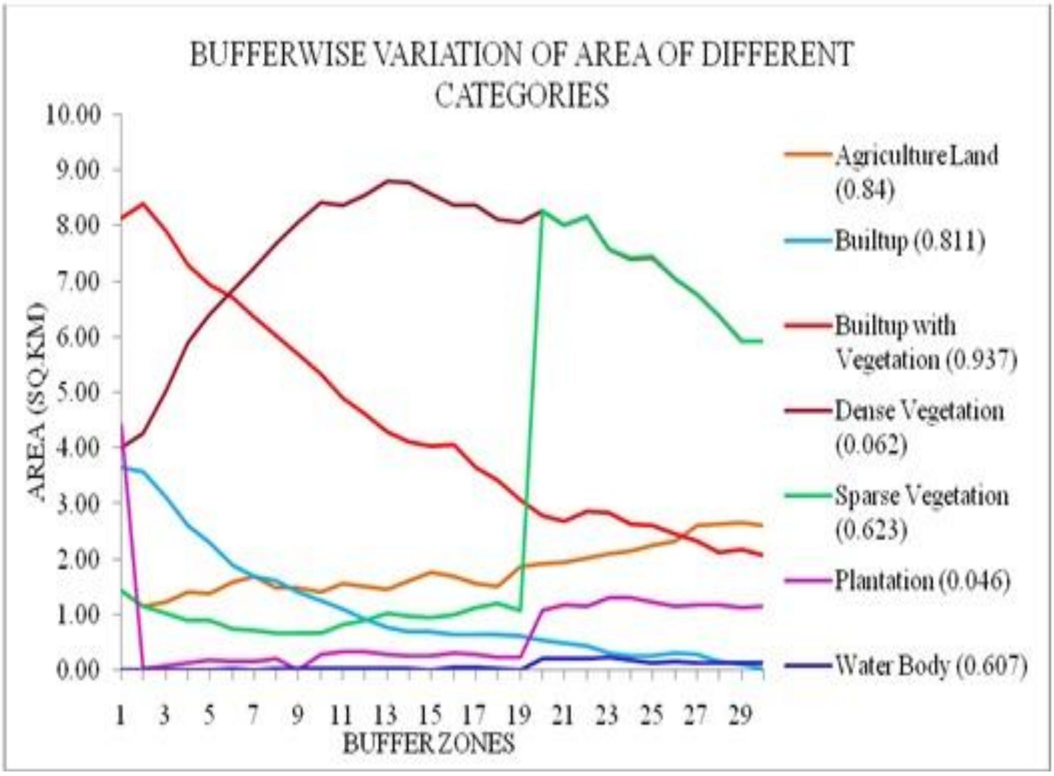

FIGUER 4 - (A). BUFFER WISE VARIATION OF AREA OF DIFFERENT CATEGORIES

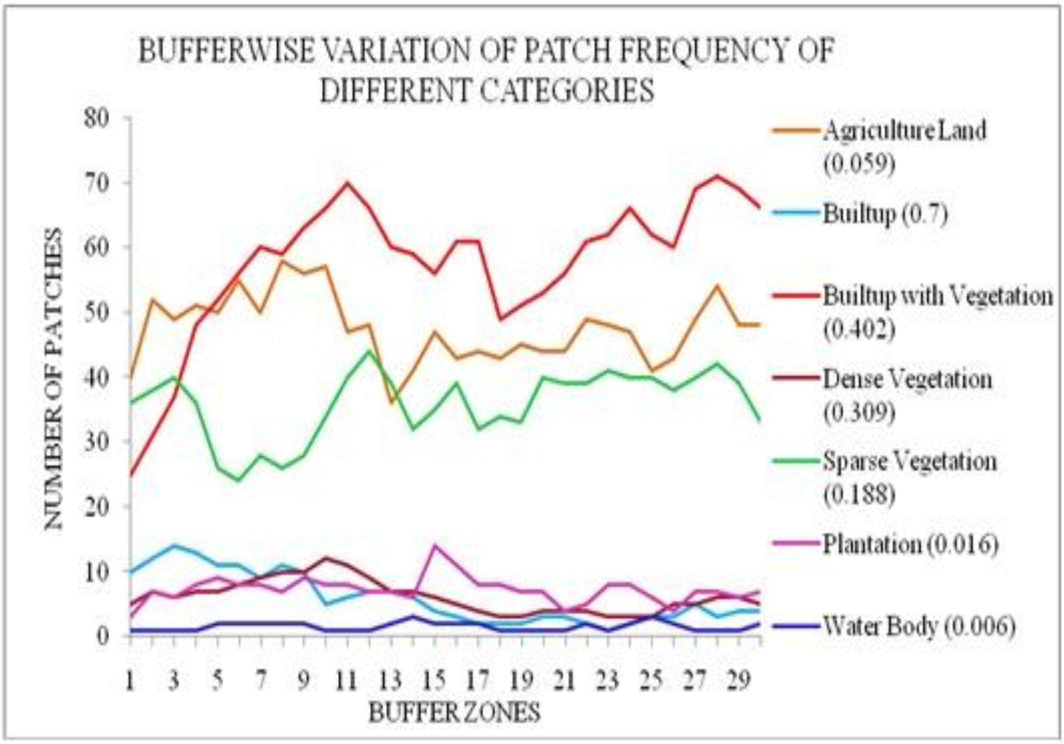

FIGURE 4 - (B). BUFFER WISE VARIATION OF PATCH FREQUENCY OF DIFFERENT CATEGORIES

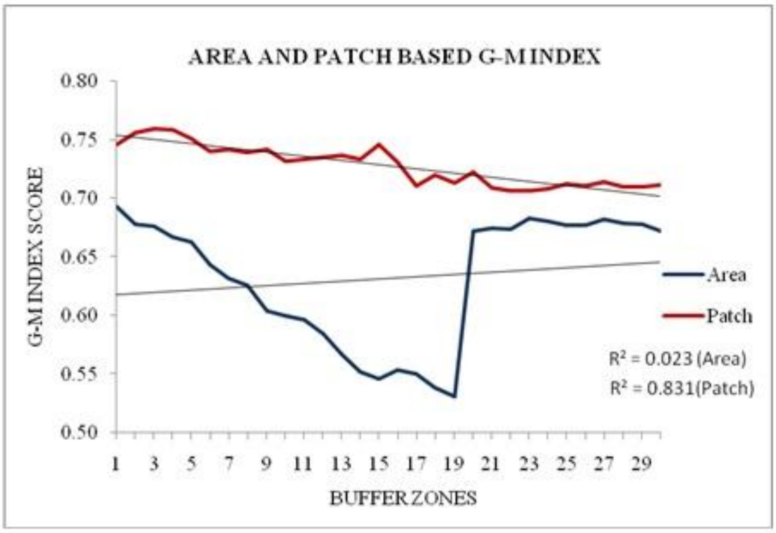

FIGURE 5 - BUFFER WISE VARIATION OF AREA AND PATCH BASED GIBBS-MARTIN INDEX

TABLE 2 - AREA AND PATCH BASED G-M INDEX

SL NO.	BUFFERS	AREA BASED G-M INDEX	PATCH BASED G-M INDEX
1	100	0.69	0.75
2	200	0.68	0.76
3	300	0.68	0.76
4	400	0.67	0.76
5	500	0.66	0.75
6	600	0.64	0.74
7	700	0.63	0.74
8	800	0.63	0.74
9	900	0.60	0.74
10	1000	0.60	0.73
11	1100	0.60	0.73
12	1200	0.58	0.74
13	1300	0.57	0.74
14	1400	0.55	0.73
15	1500	0.55	0.75
16	1600	0.55	0.73
17	1700	0.55	0.71
18	1800	0.54	0.72
19	1900	0.53	0.71
20	2000	0.67	0.72
21	2100	0.67	0.71
22	2200	0.67	0.71
23	2300	0.68	0.71
24	2400	0.68	0.71
25	2500	0.68	0.71
26	2600	0.68	0.71
27	2700	0.68	0.71
28	2800	0.68	0.71
29	2900	0.68	0.71
30	3000	0.67	0.71

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Comparison of the trends of the area based and patch based G-M index scores reveals the following observations. First, there occurs significant difference in the range of the area based G-M index and patch based G-M index among the different buffers with the former showing a much larger range of 0.13 (0.53 - 0.69) in contrast to the occurrence of a much smaller range (0.05) of the patch based G-M scores (0.71 - 0.76). In addition, one to one comparison between the area based and patch based G-M index for the corresponding buffers shows higher values of the latter. Second, there occurs gradual decrease of the patch based G-M index scores from the first buffer located close to the major roads till the last buffer whereas in case of the area based G-M index, there occurs rapid decline of the G-M index scores from the 1st buffer till the 19th buffer followed by reversal in the trend with a sudden increase to the next buffer after which the trend stabilizes. Lastly, as expected, the occurrence of gradual decline of the patch based G-M index scores from the 1st buffer till the last buffer results in significantly higher value of coefficient of determination R^2 (0.831) whereas in case of area based buffers, the sudden increase of the G-M index score at the 19th buffer yields a much smaller R^2 value of 0.023. From these observations, the following inferences can be made. First, the declining trend of the G-M index scores signifies the occurrence of corresponding increase in the degree of diversification among the different land use and land covers across the different buffers. Second, the prevalence of the larger patch based G-M index scores as compared to the area based G-M index scores in the corresponding buffers indicates the occurrence of greater magnitude of area based diversification than the patch based diversification. Third, association of greater R^2 value with the patch based G-M index scores indicates consistent increase in the magnitude of patch based diversification till the last buffer. In the case of area based G-M index scores, similar inference can be drawn till the 19th buffer; however the sudden increase in the G-M index score at the 19th buffer indicates considerable decrease in the degree of diversification that persists till the last buffer. Lastly, it can also be inferred from the results of the investigation performed that the major roads in the study area have significant influence on both the area based and patch based fragmentation of the different land use and land cover categories and also, the resulting diversification among them.

5. CONCLUSIONS

The present investigation was conducted with the aim of performing comparative assessment between the area based and patch based Gibbs-Martin diversification index considering the fact that the fragmentation of the different land use and land cover categories comprises both their area and patch components. From the analyses performed in the present study, the following inferences can be made. First, there occurs significant difference in the area based and patch based G-M index in the same spatial domain (in this case, the spatial buffers delineated around the major roads). Second, the major roads in the study area have significant influence on the fragmentation and diversification of the different land use and land cover categories. Therefore, it is necessary to consider both the area and patch based G-M diversification index in order to carry out effective and sustainable planning in urban areas.

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