American Journal of Mathematical Analysis, 2014, Vol. 2, No. 1, 1-3
Available online at http://pubs.sciepub.com/ajma/2/1/1

DOI:10.12691/ajma-2-1-1

Spatial Pattern Analysis of two Landscape in North-Western Parts of Orissa, India

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Received May 10, 2013; Revised July 24, 2013; Accepted January 10, 2014

Abstract Landscapes are heterogeneous spatial unit. The spatial heterogeneity is determined with the help of mathematical indices. Information index indicate order and disorder in landscape pattern formation. Fractal pattern of landscape indicate spatial heterogeneity. Propagation of disturbances across spatial pattern could also be described by percolation values. A comparison of three indices helps us to visualize the pattern formation across landscapes with probable causes. Two typical landscapes of north-western parts of Orissa, India is taken as sample study. The obtained entropy values, fractal dimensions and percolation pattern indicate complexity in the pattern development due to intense anthropogenic activities rather than natural one.

Keywords: *spatial heterogeneity, fractal pattern, percolation pattern, anthropogenic activities*

Cite This Article: Uttam Ghosh, and Dilip Kumar Khan, "Spatial pattern analysis of two landscape in North-western parts of Orissa, India." *American Journal of Mathematical Analysis* 2, no. 1 (2014): 1-3. doi: 10.12691/ajma-2-1-1.

1. Introduction

Landscapes are mosaic of different mixtures of natural and human influenced patches. Patch shape, size, heterogeneity and boundary characteristics influence the ecological processes across landscape. Analysis of landscape pattern is a meaningful way to understand ecological flow and interactions. Considerable progress has been achieved in landscape pattern analysis viz. patch shape (Burgess and Sharpe 1981, Forman and Godron 1981, 1986, Krummel *et al* 1987, Turner and Ruscher 1988), fractal dimensions (Milne 1988, O'Neill 1988) and neutral model (Gardner et al 1987, Turner 1990, Gardner and O'Neill 1991). Imre *et al* (2011) used fractal dimension to characterize patchiness of fragmented habitats and to detect secondary processes, like re-forestation. Spatial pattern in a landscape has evolved from the complex interactions between physical, biological and social forces. Thus Landscape heterogeneity is regarded as an essential and consequence of diversity and complexity in both natural and social systems (Wu 2006). Percolation theory is applied in ecology to develop neutral model for landscape patterns (Riitters et al 2009).

2. Material and Method

Two sample landscapes covering north-western parts of Orissa, India is taken for study. Survey of India topographical map (73J/8/NE) of scale 1:25000 forms basis of the study. The existing spatial pattern across the landscape is identified and raster data is generated which is presented in Figure 1.

Quantitative measures of spatial pattern of two landscape mosaics are obtained by using mathematical metrics e.g. information theory, fractal geometry and percolation theory. Spatial entropy is obtained by using information theory (Shannon and Weaver 1949, 1962). Landscape patchiness is obtained by using fractal dimension (Mandelbrot 1967) while the extent of ecological processes is obtained by using percolation pattern. Spatial heterogeneity of landscape is obtained from information theory. The first index H (entropy) is a measure of diversity.

$$H = -\sum_{k=1}^{m} P_k.\log_2^{P_k} \tag{1}$$

Where P_k is the probability of occurring of the landscape cover type k, and m is the number of land cover type observed.

The second index H´ is a measure of dominance calculated as the deviation from the maximum possible diversity.

$$H^{'} = H_{\max} + \sum_{k=1}^{m} P_k.\log_2^{P_k} \tag{2}$$

Where Hmax normalizes the index for differences in number of land cover types between landscapes.

The third index H´´ measures contagion or the adjacency

$$H^{"} = 2m\log_2^{m} + \sum_{i=1}^{m}\sum_{j=}^{m} a_{ij}\log a_{ij} \tag{3}$$

Landscape-I

F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	A	A	A	A	F	F	A	F	F	F	F	F	F	F	F	F	F
F	F	A	A	A	A	A	A	F	F	F	F	F	F	F	F	F	F	F	F
F	A	A	A	A	A	A	A	A	F	F	F	F	F	F	F	F	F	F	F
A	A	A	A	A	A	AS	AS	A	F	F	F	F	F	F	F	F	F	F	F
A	A	AS	AS	A	A	AS	F	F	F	F	F	F	F	F	F	F	F	F	F
F	A	AS	A	A	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	A	A	F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	A	F	F	F	F	F	F	F	F	F	F	F	F
F	F	FS	F	F	A	A	F	F	F	F	F	F	F	F	F	F	F	F	F
F	A	AS	AS	A	A	A	A	F	F	F	F	F	F	F	F	F	F	F	F
A	A	A	A	A	A	A	A	F	F	F	F	F	F	F	F	F	F	F	F
A	F	F	F	A	A	A	A	F	F	F	F	F	F	F	F	F	F	A	A
AS	AS	F	FS	A	A	A	A	F	F	F	F	F	F	F	F	F	A	A	A
A	A	A	AS	AS	A	A	A	A	F	F	F	F	F	F	F	A	A	A	A
A	A	A	W	A	A	A	A	A	A	F	F	F	F	F	A	A	A	A	A
F	F	A	A	A	A	A	A	A	A	A	A	A	AS	AS	A	A	A	A	A

Landscape-II

A	AS	AS	AS	A	A	A	A	A	A	A	A	A	A	A	AS	AS	A	A	A
A	A	AS	A	A	A	A	A	A	A	A	A	A	A	A	AS	AS	A	A	A
AS	A	AS	A	A	A	A	AS	AS	A	A	A	A	A	A	AS	AS	A	A	A
AS	A	A	A	A	A	F	A	F	A	A	F	A	A	A	A	AS	A	A	A
A	A	A	A	A	A	A	A	F	F	F	F	A	A	A	AS	A	A	A	A
A	A	A	A	A	A	F	F	F	F	F	F	A	A	A	F	A	A	A	A
A	A	A	A	A	A	F	F	F	F	F	F	A	A	F	F	A	A	A	A
A	A	A	A	A	A	F	F	F	F	F	F	F	F	F	A	F	A	F	F
A	W	W	A	A	F	F	F	F	F	F	F	F	F	F	A	F	F	F	F
A	A	A	A	F	F	F	F	F	F	F	F	F	F	A	A	F	F	F	F
A	A	A	A	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	A
A	A	A	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	A
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A	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	A	A	F	F
F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
F	S	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F

(A=Agriculture, F=Forest, S=Settlement, W=waste land, AS= co-occupied by agriculture and settlement)

Figure 1. Landscape cover types for two sample units in raster format (pixel 20 × 20)

Fractal dimension is measured through area perimeter relationship

$$\left.\begin{array}{l} P \alpha A^{D/2} \\ \therefore\ P = kA^{D/2} \end{array}\right\} k \text{ is constsnt} \qquad (4)$$

Where A is area of the patch and P is the perimeter, and D is the fractal dimension.

Percolation pattern is derived from percolation cluster of cover types (i).

3. Result and Discussion

From the equations (1), (2) and (3) the obtained values of spatial entropy (H), dominance index (H´) and contagion index (H´´) of the two landscape mosaic of the north western parts of Orissa, are presented in Table 1.

Table 1. Entropy (H), Dominance index (H´) and Contagion index (H´´)

Landscape	Entropy(H)	Dominance index(H´)	Contagion (H´´)
I	1.17	0.41	117.12
II	1.17	0.41	122.48

Analysis of the Table 1 revealed that in both the landscape spatial entropy (H) value (1.17) is indicative of heterogeneous pattern of landscape elements. Disorder is the prevailing condition in both the landscapes. This disorder might have resulted due to heavy anthropogenic pressure prevailing in the landscapes. The low value (0.41) of dominance index (H´) further supports the findings that the absence of any dominant covers type while the large positive value (117.12 and 122.48) of contagion index (H´´) have resulted due to the existence of large and pure clumping patch sizes. The Kullback ratio for the two landscapes (1.01 > 1) indicates the distribution of cover types are similar.

Fractal dimension of the landscapes are obtained from equation (4). The results of fractal dimension of the two landscapes are presented in Table 2. Analysis of the Table 2 revealed that the low values of fractal dimensions for cover types forest (1.17 and 1.15) and agriculture (1.21 and 1.23) indicate less patchiness in their boundary condition. Landscape boundaries for the cover types forest and agriculture have not resulted from natural processes. The boundary patterns of the patches have originated due to anthropogenic pressure. Similar result have also been reported from some parts of USA (Krummel et al 1987 and Tuirner and Ruscher 1988).

Table 2. Fractal dimensions of landscape cover types

Landscape	Forest	Agriculture	Settlement
I	1.17	1.21	1.42
II	1.15	1.23	1.41

Topographic patterns are generated by diffusion process that produce fractal dimension greater than 1.5 (Mandelbrot 1977). The fractal dimension of the two sample landscape types have not generated by diffusion processes. Fractal dimension of two cover types for two landscapes have largely been alter by human activities while the current spatial pattern of the forest patches reflect the overlapping of many small scale anthropogenic disturbances affecting large scale successional pattern of natural vegetation.

Disturbance across the landscape is an important ecological process and influenced by spatial heterogeneity. The percolation theory is still the basis for understanding interaction of ecological flow with landscape structure (cover types).

Percolation pattern of cover types across two sample landscape is presented in Figure 2a, Figure 2b, Figure 2c and Figure 2d.

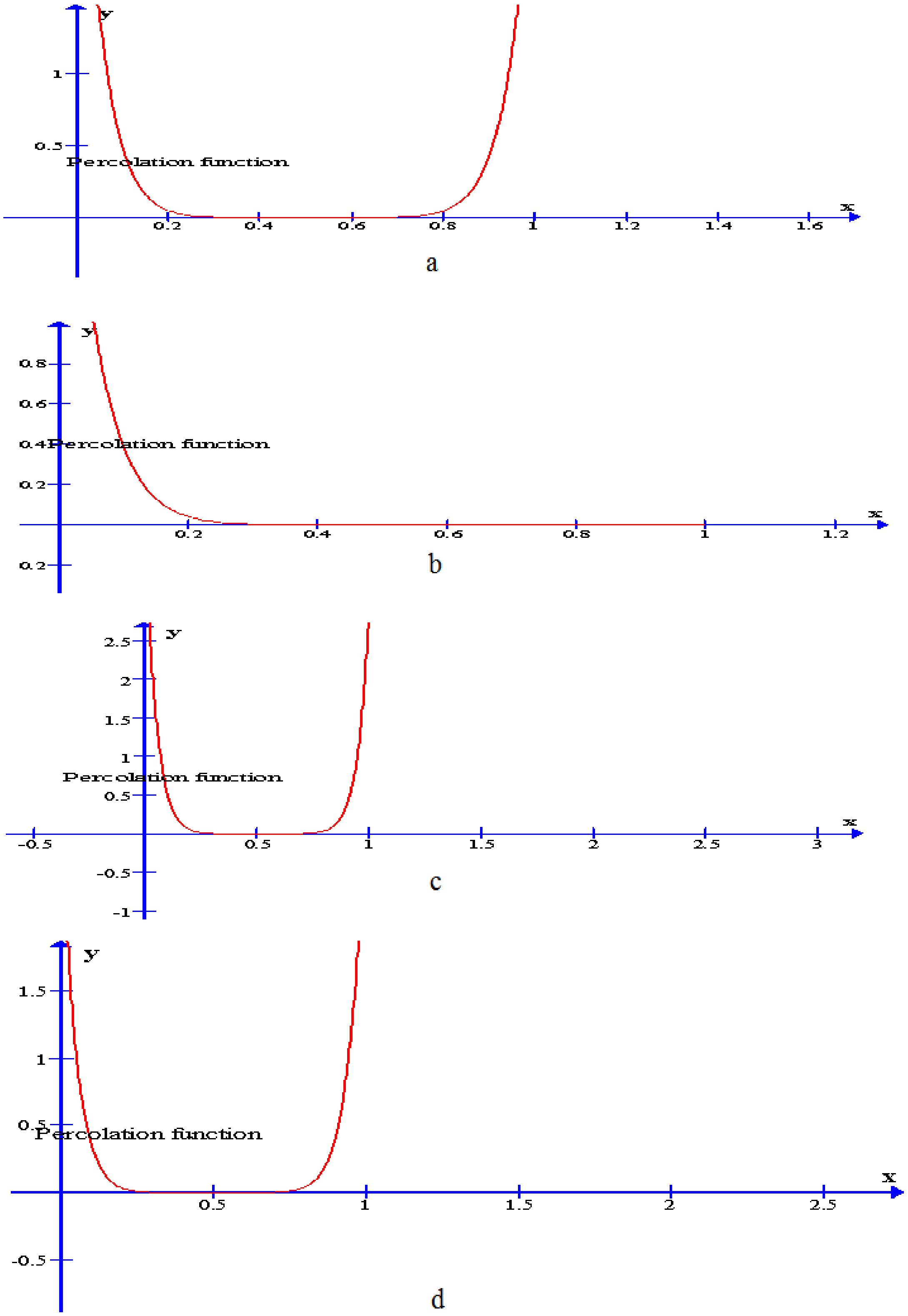

Figure 2. a Percolation pattern for Forest in Landscape type I, **b** Percolation pattern for Agriculture in Landscape type I, **c** Percolation pattern for Forest in Landscape type II, **d** Percolation pattern for Agriculture in Landscape type II

Analysis of the Figure 2a to Figure 2d indicates there exists an infinite flow path in landscape-I for any kind of ecological flow. Cover type occupying less than the threshold value (0.5928) tend to be fragmented, with numerous small patches and low connectivity. The spread of ecological flow is constrained by this fragmented spatial pattern. This is evident from cover types in landscape-II.

Neutral model development from percolation theory is used as a null model to explore ecological processes operating in heterogeneous environment in the absence of any specific landscape pattern. Cover types in the sample landscape occupying the threshold value (0.5928) tend to be highly connected forming infinite cluster (Figure 2a).

Mathematical indices obtained from the two sample landscape however revealed that in the absence of diffusion processes spatial pattern development is largely controlled by anthropogenic disturbances.

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