Reading the Patterns of Transport Network and Population Distribution; Fractal Geometry Application in Kurunegala Township and its Surrounding Areas, Sri Lanka

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Abstract

The Reciprocal relationship between the population distribution and the transport network pattern has been widely discussed, for example when the population increases; demand for transport related infrastructure increases and vice versa. But the relationship between the road network pattern and population distribution has not been adequately investigated and lacks the appropriate method especially in Sri Lankan spatial and transport planning studies. In such a context, this research explores the feasibility of an emerging method called 'Fractal Geometry' to explain the relationship between road network patterns and population distributions. Thus, this study calculated the road and population distribution fractal dimensions based on the 'mass radius' fractal geometry method and analyzed the relationship between these two variables. Findings of the study have revealed a strong correlation and liner relationship between the fractal dimensions of road and population distribution. Accordingly, the study concludes fractal geometry as a useful tool in understanding the relationship between population distribution and the road network.

Keywords: fractal geometry, road networks, population distribution, spatial planning

Introduction

'Transportation network is a subsystem of spatial form', which shapes the skeleton for the physical growth of the city (Rodin and Rodina, 2000; Shen, 1997). Population distribution is an integral component of spatial form which describes its socio-economic dimension. Roads, as interactions between urban elements, give a very strong effect to urban growth and population increase (Tang, 2003). Furthermore Forman and Alexander (1998) point out that road networks alter the landscape spatial pattern; for example, people tend to live along the road for traffic convenience. Thus, road distribution and its network structure are informative urban topics. On the other hand, complex transport systems fracture cities more and provide greater accessibility into cities, attracting increased population movements over less accessible locations. Another striking feature in the urban system is its population. Population research, especially population density research, provides a potentially strong, scientific framework for socio-economic analysis of the urban form and spatial distribution (Mandelbrot 1983). Therefore the reciprocal relationship between the population distribution and the transport network pattern has been widely discussed; for example when the population increases the demand of the transport related infrastructure increases and vice versa. But the relationship between road network pattern and population distribution has not been adequately investigated, especially in Sri Lankan spatial planning and transport planning studies. This limits the spatial planner's ability to model the changes in population distribution pattern followed by the proposed transport networks as well as the transport planner's ability to plan transport networks considering future population distributions.

In such a context, this research attempted to demonstrate the applicability of 'Fractal Geometry' to explain the relationship between road network patterns and population distributions through a quantitative method. Fractal analysis (i.e. a method developed by Batty et al in 1989) is an effective approach to describe the disorder and irregularity of natural or manmade spatial forms. In fact, fractal geometry has been tested in demonstrating its ability to illustrate spatial patterns of a wide range of geographic areas.
Although the relationship between road patterns and population is clear, and fractal geometry has been identified as an effective technique, it has not yet been tested as to whether it is suitable in a Sri Lankan context. The main objective of this study is to find the applicability of this technique in a Sri Lankan context. This research was designed to test the applicability of fractal geometry in a Sri Lankan context, using Kurunegala as the initial case study area within the long-term research agenda to cover the other areas in the country. It was assumed that there is a definite relationship between road patterns and population distribution and that fractal geometry as an effective technique to study this relationship. Thus, if the technique proves that there is a strong relationship between road pattern and population distribution, it will definitely say that the technique is applicable in the Sri Lankan context.

Literature review

1. Fractal Geometry

Geometry is a concept thatevolved over centuries by considering the shape, size, relative position of figures, and the properties of space. Most of the real properties of naturedo not have simple geometric shapes such as points, lines and planes which can be described by traditional Euclidian geometry. According to Batty and Longley (1994) dimensions of any real system is fractional. Fractal geometry is one of the non Euclidean geometry methods which describe non-integer dimensions of fractal properties. Fractals are found in nature as scale in variant, self-similar objects (Hastings and Sugihara, 1993) and fractal is a term which was first coined by Mandalbrot (1967; 1977; 1982). The word fractal has been developed by the Greek word "frangere" which gives the meaning of "breaking". Fractals are created from the iteration process as such, "Fractals are of rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced copy of the whole" (Zmeskal et al, 2001).

Fractal geometry is the method to calculate and express the geometry of these fractal objects. 'Fractal geometry is a mathematical procedure for calculating the geometry of more complex natural or manmade geometric shapes which are not easy to explain using simple Euclidian geometry. So it can be used to calculate the fractal geometry of urban systems (urban morphology) or its subsystems (which create urban morphology) and to analyze their relationships' (Lu,Tang, 2004;Lia, Dub andCaixin, 2007 ;Frankhauser, 1997;Zmeskal et al, 2001)

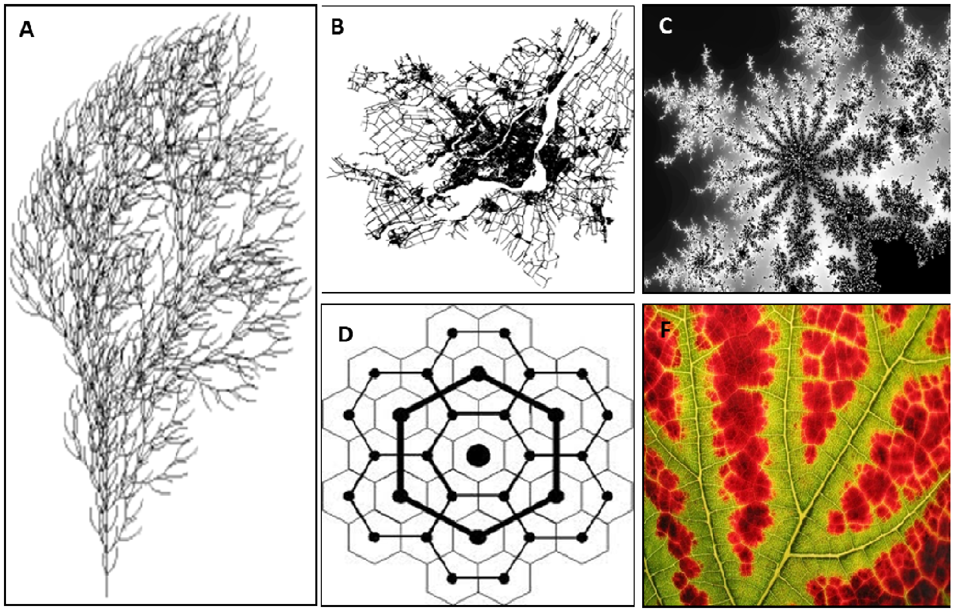

Figure 1: A; Dendritic structure of a tree that Describes fractal geometry (Source; Lindenmayer, 1968)B: A road map of a city showing fractal nature (Source;Morency C., Chapleau R. (2003), C; Art of fractals described by the mathematical concept of geometry(Source; Curious, 2010)D; Iteration process of cities(Source; Christoller, 1930)E, fractal nature of a deciduous leave (Source; Lymn*, 2010*)

2. Application of Fractal Geometry in Spatial Planning

Mandelbrot (1967) introduced fractal geometry to calculate the length of the British Coastline. He argued that the coastline has a dimension somewhere between 1 (a straight line) and 2 (a plane), for example, 1.75. This is commonly referred as fractal dimension. Later Nystuen (1990), Frankhauser (1988, 1992) and Shen (1997, 2002) discovered that 'not only natural geographical phenomena but also artificially designed and planned concrete spatial objects can be typical fractal objects'. The use of fractal geometry for spatial analysis was started with this finding. Batty et al(1989), Manrubia et al (1999), Peterson (1996), and Shen (2002) emphasized that 'cities are fractal in nature and are not Euclidian'. Christoller (1930), in his central place theory, explained that cities have been created through the iteration process. Appleby (1996), Longley et al (1991), Sambrook & Voss (2001) noted that 'both city form and the functions are also fractals which are irregular, scale in variant and self similar'.'City form shapes the functions of the city and vice versa.' (Yongmei Lu, Junmei Tang, 2004). Therefore the geometry of form and functions could be analyzed together to find a relationship between them. Batty et al (1989), Manrubia et al (1999), Peterson (1996) and Shen (2002) identified 'fractal geometry as a process of space filling'. They noted that 'When the roads are adding to the city, it fractures the city more and if the city is considered as a plain (2D), adding roads covers more areas of the 2D surface'. Tang (2003)used fractal geometry to analyze the relationship between road pattern and population distribution in quantitative figures. He concludes that 'identifying the fractal geometry of road pattern and population distribution as well as their relationship, will provide the ability of predicting both factors according to the changes done for the other factor'. Lu and Tang (2004) used fractal geometry to study urban sprawl and suggested measures to manage urban sprawl in a predetermined way.

3. Methods of Calculating Fractal Geometry

There are different methods in calculating fractal geometry. Box Counting Method is the most famous which includes two sub methods. The first sub method is the normal box counting method. The second method is the Mass-radius method. These cond method is used in this study to calculate the fractal geometry. Below Figure 2 shows how the box dimension works. Circle (a) has four unit squares, if radius of the circle is doubled (b1), the circle will meet 16 unit squares, alternatively the cell size of unit squares in (a) is reduced by a linear factor of ½ (b2), it will meet 16 unit squares as well." This is called the telescope principle and it is used in calculating the geometry of fractal properties. The first method (b1) shows the box dimension while the second method (b2) displays the mass radius method.

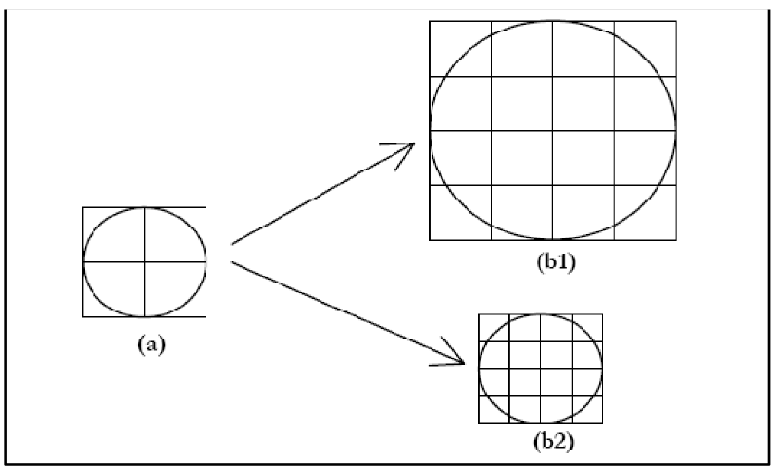

Figure 2: The box dimension. Source: Hastings and Sugihara, 1993

Morency and Chapleau (2003) defined the mass dimension as the 'relationship between the area located within a certain radius and the size of this radius (or box). This is performed for various radiuses as well as from various points of origin. The mass dimension can be estimated from the log-log plot of the area as a function of the radiuses (Lu and Tang 2004). Box counting method provides the fractal geometry of the entire city but the mass radius method can be used to measure the fractal geometry in different sizes of the city. Therefore, mass radius method provides a better spatial understanding about the changes to the fractal geometry by any development or changes adopted for any urban system or subsystem. Mass radius method has a capability to understand the growing phenomenon of the city (Lu and Tang, 2004). By considering those factors, this study uses mass radius method to analyse fractal geometry of the roads and population distribution.

Study Area

The study area (extent = 1964 km²) is the Kurunegala Township and its surrounding area (25km radius area from town centre), which is served by the city. Kurunegala is the capital of the North Western Province, Sri Lanka.

Despite of this administrative boundary, it serves a larger region as a commercial, transport and administrative hub that is located at a highly connected node of several major arteries linking to other regions of the country.

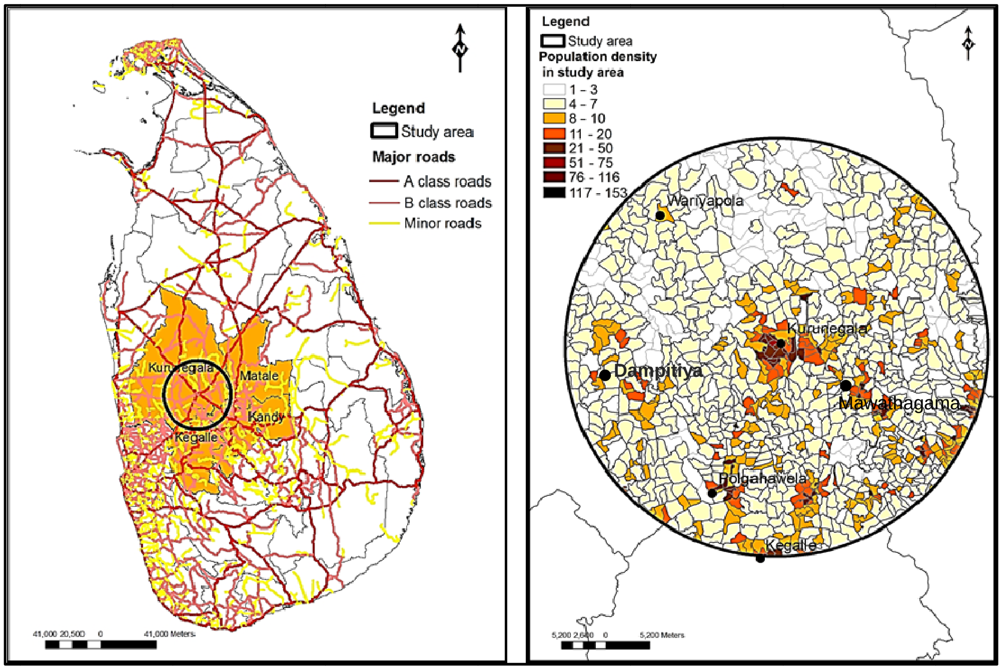

Figure 3: Location of the study area
Source: Prepared based on, 1:50000, Topographic Map, Survey Department Sri Lanka.

Kurunegala is the 1storder city according to the national physical plan-2030 prepared by National Physical Planning Department, Sri Lanka. The city of Kurunegala has been identified as a Mono centric city, which has developed around one single node. Economic and the commercial activities of the city are concentrated in the CBD (T&CP, 2010). The density of activities, buildings, infrastructure and population decreases as you move away from the city centre.For example, the main bus stand of the city is located in the centre of the city, whereas all the commercial activities are also concentrated in the centre of the city around the bus stand and are regularly dispersed.Thevisual appearance of the road pattern exhibits a pattern of equal distribution throughout the study area, though there are some variations. (Figure 4).A higher concentration of roads in the city centre is relatively significant.

The total length of the road network of the study area is about 3090 km. Of which only 637 km from them are motorable roads. This includes 116 km of ‘A’ class roads, 332 km of ‘B’ class roads and 188 km of minor roads (1:50000, Topographic Map, Survey Department Sri Lanka, 2001). The strong network of ‘A’, ‘B’ and ‘C’ class roads ensure better accessibility within the regional and local context. Population is highly concentrated in and around the Kurunegala town centre area (about 2-3km from town centre). The highest population density of 435 ppHa (Population per Ha) is recoded in GN divisions that are located near the city centre..Similarly, Polgahawela, Mawathagama and, Wariyapola town areas indicate high population density when compared with other areas.

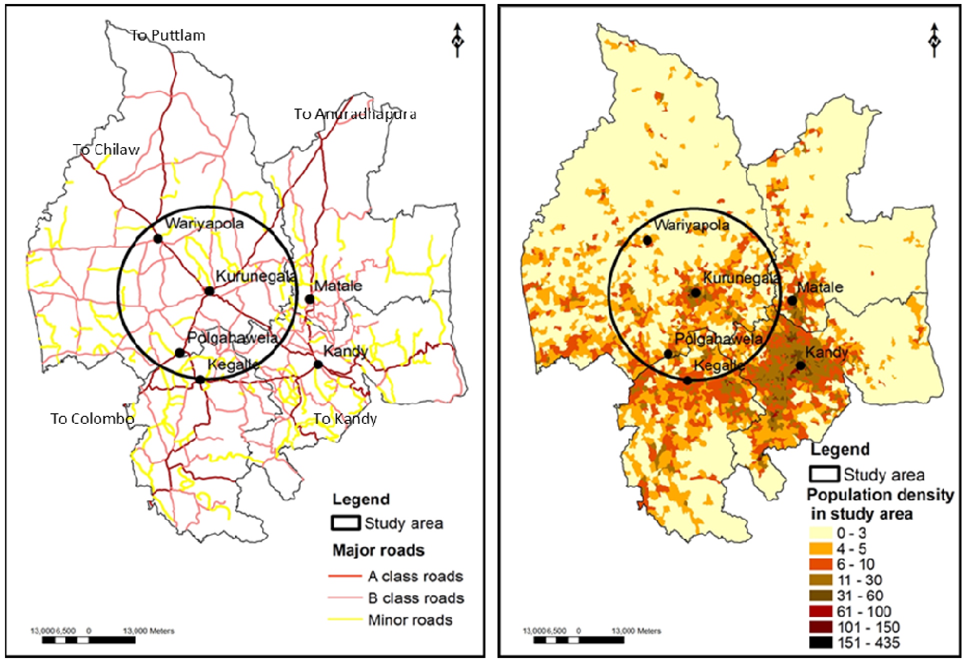

Figure 4: Road pattern and population distribution of the study area
Source: Prepared based on, 1:50000, Topographic Map, Survey Department Sri Lanka & GN level Populations Data-2001, Censuses & Statistic Department, Sri Lanka.

Method

Box counting dimension method was used to calculate the fractal dimension of the road network and population distribution. Of the main two methods in the box counting method for calculating fractal dimension, 'Mass radius' method, which covers more areas by increasing the size of radius, was selected as the appropriate method.

This method calculates the fractal dimension of black & white digitized images of fractals. Mass radius fractal dimension is based on the dependency of black and white pixels on a circle shaped plain, with varying areas. The ratio of changes in the above dependency of different sized radius is the fractal dimension. It assumes that all fractal geographical entities exhibit a dimension relationship as follows.

$$L^{1/1} \alpha S^{1/2} \alpha V^{1/3} \alpha M^{1/D} \text{........ (1)}$$

Where L is the length of geographical entity, S is the area, V is the volume and M is any dimension, and D is the fractal geometry.

1. Preparation of road pattern and population distribution maps

The road network was acquired from the Topographic Map of Sri Lanka-2001 (Survey Department Sri Lanka) as a GIS shape file. The population density was acquired from the census data of 2001 in 'Grama Niladhari' (GN) divisions from Censuses & Statistics Department, Sri Lanka. After transferring the road map and population density map from shape to coverage file in Arc GIS 9.3, the study clipped two maps into different circle areas by increasing the radius of buffer (figure 5&6).

In this research, buffers drawn around the city centre were used(i.e. most connected node by 'A' roads) by increasing the 500m radiuses for each buffer covering entire study area (i.e. up to 25km).Tang (2003) emphasized increasing 500m distance for each buffer as the best method of calculating fractal dimension in the regional context. But if the geometry is to be calculated at the local scale, it will require having a smaller scale of varying sizes of buffers.

Ri = radius at scale i
L (Ri) = length of road at scale i
Ri-1 = cell length of scale i-1
L(Ri-1) = the length of road at scale of i-1.

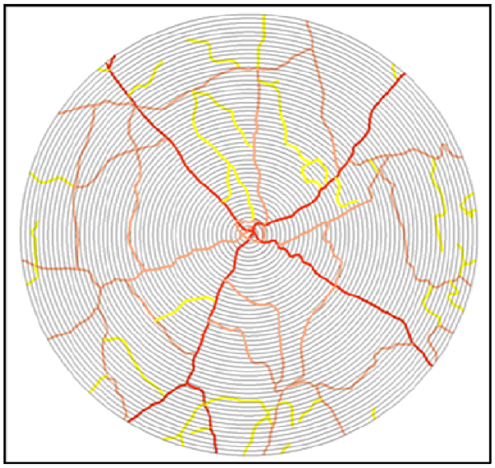

Figure 5: 50 buffers on the Road pattern distribution
Source: Prepared based on, 1:50000, Topographic Map, Survey Department

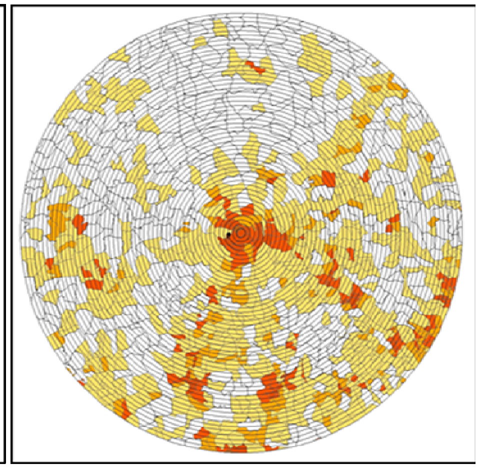

Figure 6: 50 buffers on the population distribution
Source: Prepared based on, 1:50000, Topographic Map, Survey Department

2. Calculating fractal dimension of roads

The study used a modified boxing fractal geometry method to calculate fractal dimension of roads.

Therefore the study used the road map (illustrated above) to calculate lengths of roads in each circle using Arc GIS 9.3.

Then, the following equation isused (developed by Tang, 2003) to calculate the fractal dimension of roads, which is denoted as $D(L_i)$.

$$\boldsymbol{D(Li) = \frac{Log\left[\frac{L(R_i)}{L(R_{i-1})}\right]}{Log\left(\frac{R_i}{R_{i-1}}\right)} \ldots\ldots\ldots..(2)}$$

D (Li) = fractal dimension of roads

3. Calculating fractal dimension of population distribution

In this step, the following equation (introduced by Batty and Longley, 1991) is used to calculate fractal dimension of population, denoted asD (P), in the study area. Accordingly,R is any given distance from the centre, and the fractal dimension of population distribution D (P) is calculated from following equation:

$$\boldsymbol{D(P_i) = 2 + \frac{Log\ P(R_i)}{Log(R_i)} \ldots\ldots\ldots..(3)}$$

D (P_i) = fractal dimension of population distribution at scale i
Ri = radius at scale i
P(R) = population density at scale i

I	Road Length	Cum Road Length	R	Log (R)	Log(LR)	D(Li)	I	Road Length	Cum Road Length	R	Log (R)	Log (LR)	D(Li)
1	8460	8460	0.50	-0.30	3.93		26	53363	1176524	13.00	1.11	6.07	1.1835
2	23216	31676	1.00	0.00	4.50	1.9047	27	54018	1230542	13.50	1.13	6.09	1.1895
3	31256	62932	1.50	0.18	4.80	1.6931	28	58395	1288937	14.00	1.15	6.11	1.2748
4	39295	102227	2.00	0.30	5.01	1.6864	29	60225	1349162	14.50	1.16	6.13	1.3013
5	41670	143897	2.50	0.40	5.16	1.5322	30	60161	1409323	15.00	1.18	6.15	1.2868
6	40415	184312	3.00	0.48	5.27	1.3577	31	62151	1471474	15.50	1.19	6.17	1.3161
7	45969	230281	3.50	0.54	5.36	1.4445	32	60707	1532181	16.00	1.20	6.19	1.2734
8	41700	271981	4.00	0.60	5.43	1.2464	33	54899	1587080	16.50	1.22	6.20	1.1440
9	42366	314347	4.50	0.65	5.50	1.2291	34	54165	1641245	17.00	1.23	6.22	1.1242
10	46497	360844	5.00	0.70	5.56	1.3093	35	58770	1700015	17.50	1.24	6.23	1.2137
11	42649	403493	5.50	0.74	5.61	1.1721	36	61665	1761680	18.00	1.26	6.25	1.2648
12	40653	444146	6.00	0.78	5.65	1.1032	37	61530	1823210	18.50	1.27	6.26	1.2530
13	44783	488929	6.50	0.81	5.69	1.2002	38	62721	1885931	19.00	1.28	6.28	1.2683
14	53803	542732	7.00	0.85	5.73	1.4087	39	62362	1948293	19.50	1.29	6.29	1.2524
15	53770	596502	7.50	0.88	5.78	1.3692	40	62934	2011227	20.00	1.30	6.30	1.2557
16	49998	646500	8.00	0.90	5.81	1.2472	41	62926	2074153	20.50	1.31	6.32	1.2477
17	49192	695692	8.50	0.93	5.84	1.2096	42	66889	2141042	21.00	1.32	6.33	1.3171
18	48450	744142	9.00	0.95	5.87	1.1779	43	66443	2207485	21.50	1.33	6.34	1.2988
19	48380	792522	9.50	0.98	5.90	1.1650	44	66870	2274355	22.00	1.34	6.36	1.2981
20	49917	842439	10.00	1.00	5.93	1.1908	45	67217	2341572	22.50	1.35	6.37	1.2961
21	51851	894290	10.50	1.02	5.95	1.2242	46	66028	2407600	23.00	1.36	6.38	1.2652
22	56794	951084	11.00	1.04	5.98	1.3236	47	66826	2474426	23.50	1.37	6.39	1.2730
23	58633	1009717	11.50	1.06	6.00	1.3458	48	64208	2538634	24.00	1.38	6.40	1.2168
24	58082	1067799	12.00	1.08	6.03	1.3141	49	63774	2602408	24.50	1.39	6.42	1.2033
25	55362	1123161	12.50	1.10	6.05	1.2382	50	65736	2668144	25.00	1.40	6.43	1.2348

Table 1: Result of road fractal analysis. Source: Prepared by Authors

Results and Analysis

1. *Road pattern* fractal analysis

The above table (table 1) summarizes the results of road fractal analysis. It indicates the road lengths, radius (R), their log values and the fractal dimension D (Li) of roads within the study area.

According to the graph, road lengths increase with the increasing radius. As indicated in the above graph, there is a very high gradient from city centre to 2.5km, high gradient from 2.5km to 7.5km and moderate gradient from 7.5km to boundary of the study area. It indicates that there is a very high concentration of road within the city centre area while that concentration reduces towards the periphery of the study area. This pattern is characteristic a Monocentric city form. Until the end of the city there is a smooth flow that is increasing rather than some fluctuations. It is generally understood that Monocentric cities have the above characteristics of increasing road lengths with the growing city size as roads are concentrated into one single node that then disperse their density outward.

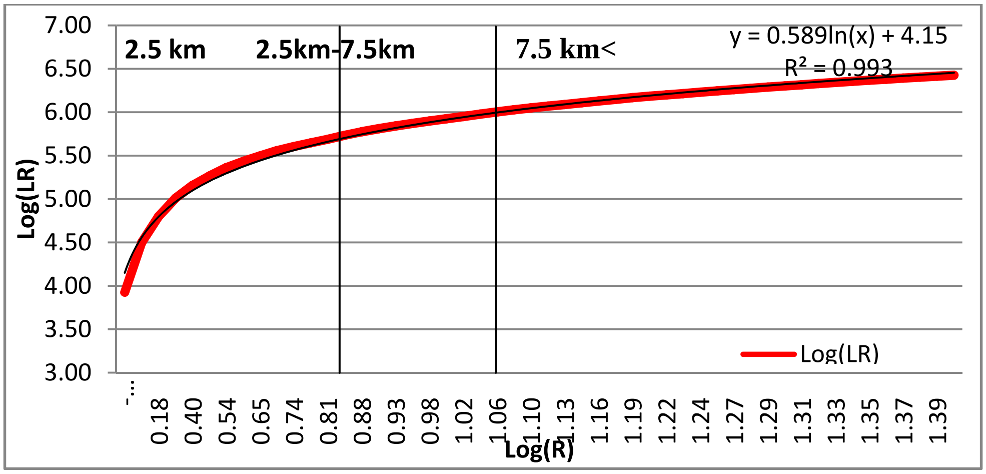

Figure 7: log likelihood ratio curve of roads
Source: Prepared by Authors

But these values of increasing length with city size does not provide an idea as to how the changes in the filled space of city (with roads) may change as new buffers are added to the expanding city limits. Lengths of roads increase when new areas with increasing radius are added. Evaluating this is possible with the fractal dimension of the roads. Figure 6 shows how fractal dimension varies from the growing size of city by 500 m buffers till the boundary.

When considering the gradients of the graph, the Monocentric form of city can be predictable. The centre of the city having higher fractal dimension of roads means that the first few buffers are mostly filled with the road network. When moving away from the city, the dimension is reduced. But still there are some small fluctuations of the dimension that model the uneven distribution of the road network. There are no peaks or troughs of the graph that indicates that the city still servesas the major transport and commercial hub and that there are no emerging centres within the surrounding area.

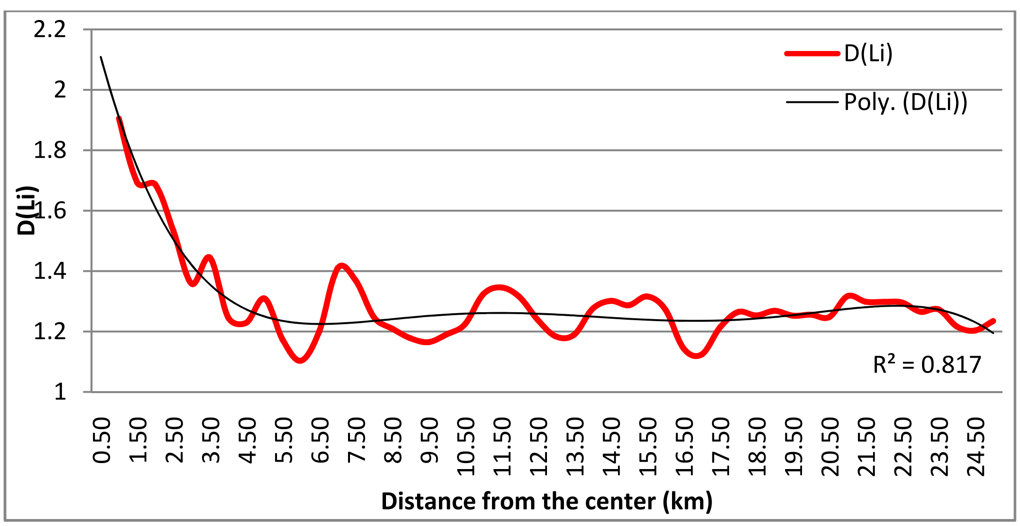

Figure 8: Fractal dimension of the road pattern
Source: Prepared by Authors

As depicted in the histogram, the mean fractal dimension value of the road pattern within the buffers is 1.28. The left skewness (Std. Dev 0.117) indicates that a large number of buffers have low fractal dimension. But the distribution shows that there are more middle level values (the high number of fractal values distributed in the range of 1.2 and 1.4) as well. According to the distribution, only 18% of buffers have fractal dimension values less than 1.2.About 4% of all 50 buffers have higher fractal values (More than 1.6). When the fractal values are getting closer to 2, it means that more land areas are filled up by the road network.

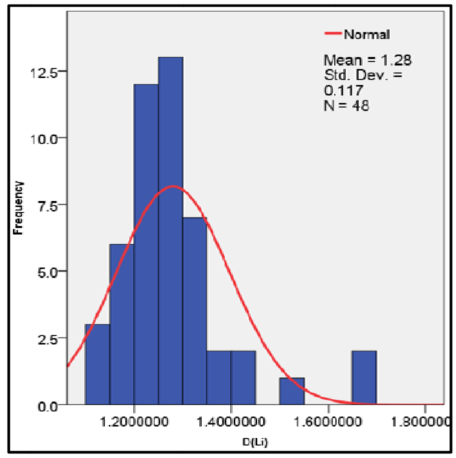

Figure 9: Distribution of fractal dimension of the road pattern. Source: Prepared by Authors

2. Population distribution fractal analysis

The table below summarizes the result of the population distribution fractal analysis. It indicates the population (pop), cumulative population (Cum pop), population density (pop den), radius (R), log value of R and fractal dimension D (Pi) of population density in the study area.

I	pop	Cum pop	pop den	R	Log (R)	D(Pi)	I	pop	Cum pop	pop den	R	Log (R)	D(Pi)
1	2587	2587	32.95	500	2.699		26	281715	3395784	3.68	13000	4.114	2.14
2	10895	13482	35.26	1000	3.000	2.52	27	297460	3693244	3.78	13500	4.130	2.14
3	21721	35203	27.57	1500	3.176	2.45	28	314704	4007948	3.99	14000	4.146	2.14
4	32989	68192	20.50	2000	3.301	2.40	29	332778	4340726	4.04	14500	4.161	2.15
5	43534	111726	14.92	2500	3.398	2.35	30	351331	4692057	4.00	15000	4.176	2.14
6	53464	165190	11.49	3000	3.477	2.30	31	369159	5061216	3.72	15500	4.190	2.14
7	63639	228829	9.97	3500	3.544	2.28	32	386084	5447300	3.42	16000	4.204	2.13
8	72593	301422	7.60	4000	3.602	2.24	33	403463	5850763	3.40	16500	4.217	2.13
9	80831	382253	6.17	4500	3.653	2.22	34	423832	6274595	3.87	17000	4.230	2.14
10	90140	472393	6.24	5000	3.699	2.21	35	446401	6720996	4.16	17500	4.243	2.15
11	99315	571708	5.56	5500	3.740	2.20	36	471979	7192975	4.59	18000	4.255	2.16
12	107983	679691	4.80	6000	3.778	2.18	37	498950	7691925	4.70	18500	4.267	2.16
13	117217	796908	4.70	6500	3.813	2.18	38	525366	8217291	4.48	19000	4.279	2.15
14	128559	925467	5.35	7000	3.845	2.19	39	549715	8767006	4.03	19500	4.290	2.14
15	140615	1066082	5.29	7500	3.875	2.19	40	573559	9340565	3.84	20000	4.301	2.14
16	151667	1217749	4.54	8000	3.903	2.17	41	599284	9939849	4.04	20500	4.312	2.14
17	161721	1379470	3.88	8500	3.929	2.15	42	626645	10566494	4.20	21000	4.322	2.14
18	171546	1551016	3.57	9000	3.954	2.14	43	654657	11221151	4.20	21500	4.332	2.14
19	182164	1733180	3.65	9500	3.978	2.14	44	683496	11904647	4.22	22000	4.342	2.14
20	194022	1927202	3.87	10000	4.000	2.15	45	711310	12615957	3.98	22500	4.352	2.14
21	207600	2134802	4.22	10500	4.021	2.16	46	739473	13355430	3.94	23000	4.362	2.14
22	222200	2357002	4.32	11000	4.041	2.16	47	769230	14124660	4.07	23500	4.371	2.14
23	237726	2594728	4.39	11500	4.061	2.16	48	800813	14925473	4.23	24000	4.380	2.14
24	252352	2847080	3.96	12000	4.079	2.15	49	833201	15758674	4.25	24500	4.389	2.14
25	266989	3114069	3.80	12500	4.097	2.14	50	867446	16626120	4.40	25000	4.398	2.15

Table 2: Result of road fractal analysis
Source: Prepared by Authors

The following Graph (figure 10) indicates Log likelihood value of population distribution against radius of buffers.

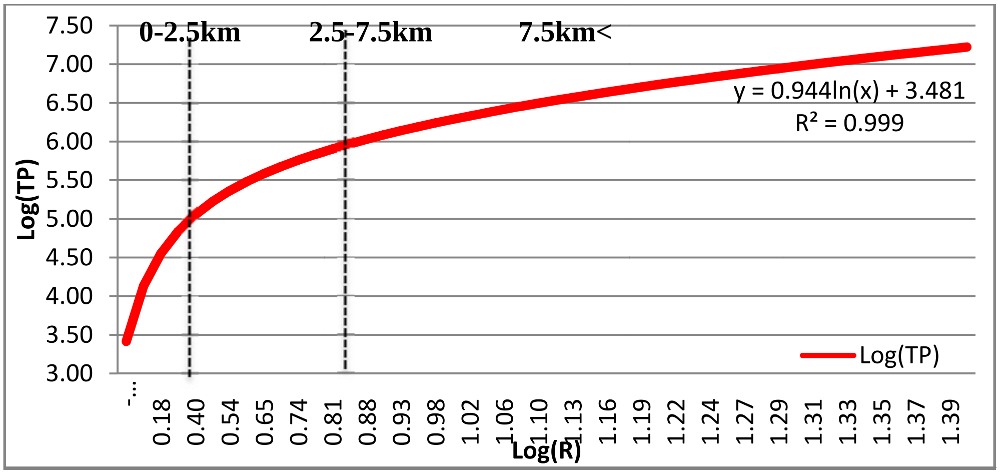

Figure 10: log likelihood ratio curve of population distribution
Source: Prepared by Authors

According to the data,population increases with the radius. As illustrated in figure 11, there is a very high gradient from the city centre to 2.5km away, a high gradient from 2.5km to 7.5km and moderate gradient from 7.5km to boundary of the study area. This indicates that there is a very high population concentration in the city centre area while reducing towards the periphery of the study area. When compared to the log likelihood ratio curve for road lengths, this curve shows a similar gradient of acceleration. (R^2 for road lengths comparison curve is 0.993, whereas $R^2$for population distribution is 0.999). The graph shows that up to 7.5km radius, the gradient of the curve is higher and it is similar to the pattern of the log likelihood curve. This similarity of the pattern explains that the interrelationship between road pattern and the population distribution may be inevitable.

The following Graph (figure 11) whichshows the distribution of fractal geometry values of population distribution D(Pi),provides a better idea as to how population distribution gets dispersed proportionally to the distance from the city centre. The fractal dimension of population distribution is decreasing at a higher rate within the first 4.5 km.

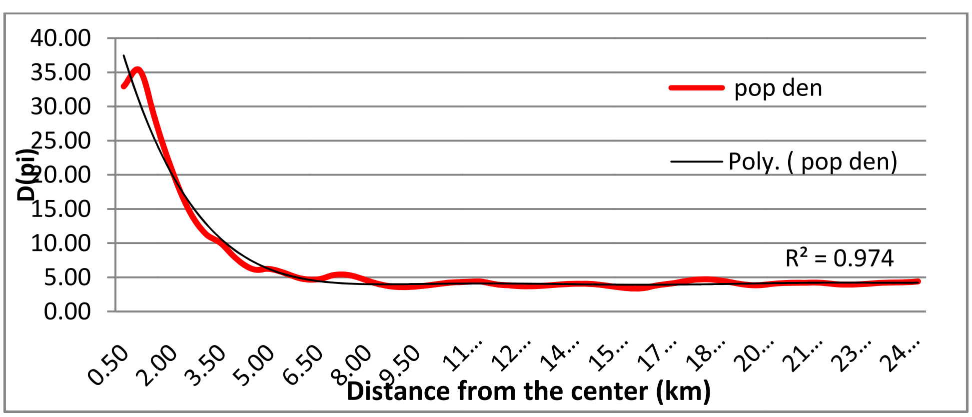

Figure 11: Fractal dimension of the population distribution
Source: Prepared by Authors

As depicted in the histogram (figure 12), the mean fractal dimension of the study area is 2.18. The left skewness (Std. Dev 0.084) indicates that large numbers of buffers have lower fractal dimensions of population distribution. According to the pattern of distribution, more than 80% of buffers have fractal dimensions less than 2.2while very few buffer areas have fractal dimensions more than 2.5 (only 1% out off 50 buffers).

3. Relationship analysis between population distribution fractal dimension and the road pattern fractal dimension

Table 3 presents the results of the fractal dimensions of road and population density in every scale (buffer), computed by equation (2) and equation (3) respectively. In general, the bigger the radius,, the smaller the fractal dimensions of road and population density.

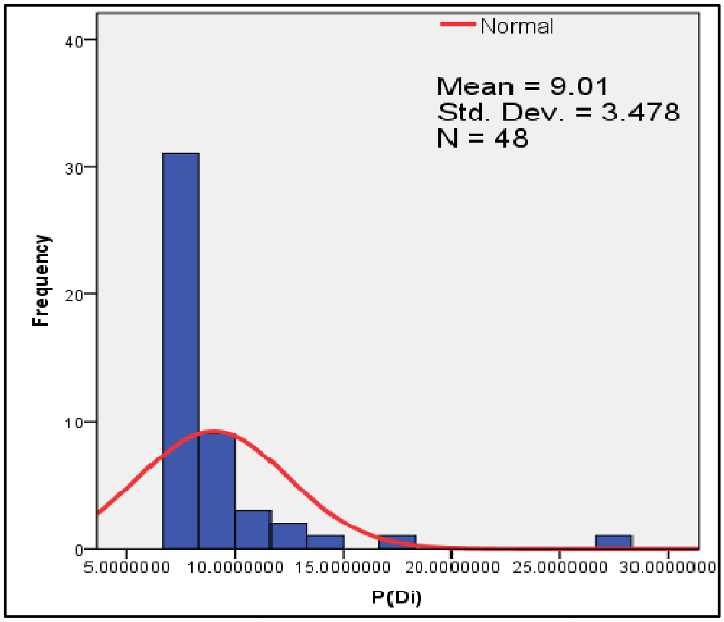

Figure 12: Distribution of fractal dimension of the population distribution

This indicates that the population has transparently spread over the study area. While few areas have a higher level of concentration (i.e. at the city centre), all the buffers, which have fractal dimensions more than 2.2, are located within the first 4.5km from the city centre. This is the nature of a Monocentric city. Monocentric cities have a higher concentration of the population at the centre that disperses towards the periphery.

The range of dimensions of road computed from equation (3) indicates that the dimensions of all roads are less than 2 and ranges from 1.9 to 1.18, which suggests that roads do not fill in the entire two-dimensional space. This trend is especially clear in the dimension of population density, which decreases gradually. We can see that the highest dimension of population density is 2.52 (when R = 1.0 kilometers), which means that people have filled in this centre area greatly. Though the dimensions of population density fall within the range 2.52~2.13.

I	1(0.5)	2(1.0)	3(1.5)	4(2.0)	5(2.5)	6(3.0)	7(3.5)	8(4)
D(Li)		1.90	1.69	1.69	1.53	1.36	1.44	1.25
D(Pi)		2.52	2.45	2.40	2.35	2.30	2.28	2.24
I	9(4.5)	10(5)	11(5.5)	12(6.0)	13(6.5)	14(7.0)	15(7.5)	16(8.0)
D(Li)	1.23	1.31	1.17	1.10	1.20	1.41	1.37	1.25
D(Pi)	2.22	2.21	2.20	2.18	2.18	2.19	2.19	2.17
I	17(8.5)	18(9.0)	19(9.5)	20(10.0)	21(10.5)	22(11.0)	23(11.5)	24(12.0)
D(Li)	1.21	1.18	1.17	1.19	1.22	1.32	1.35	1.31
D(Pi)	2.15	2.14	2.14	2.15	2.16	2.16	2.16	2.15
I	25(12.5)	26(13.0)	27(13.5)	28(14.0)	29(14.5)	30(15.0)	31(15.5)	32(16.0)
D(Li)	1.24	1.18	1.19	1.27	1.30	1.29	1.32	1.27
D(Pi)	2.14	2.14	2.14	2.14	2.15	2.14	2.14	2.13
I	33(16.5)	34(17.0)	35(17.5)	36(18.0)	37(18.5)	38(19.0)	39(19.5)	40(20.0)
D(Li)	1.14	1.12	1.21	1.26	1.25	1.27	1.25	1.26
D(Pi)	2.13	2.14	2.15	2.16	2.16	2.15	2.14	2.14
I	41(20.5)	42(21.0)	43(21.5)	44(22.0)	45(22.5)	46(23.0)	47(23.5)	48(24.0)
D(Li)	1.25	1.32	1.30	1.30	1.30	1.27	1.27	1.22
D(Pi)	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14
I	49(24.5)	50(25.0)			Mean	Std. Deviation		N
D(Li)	1.20	1.23			2.1835	.08437		49
D(Pi)	2.14	2.15			1.2927	.14633		

Table 3: Dimensions of road and population density
Source: Prepared by Author

Though a similar pattern of fractal dimensions of road and population distribution can be identified using the above table, the graph below (figure 12) provides a better foundation for the purpose of comparison.

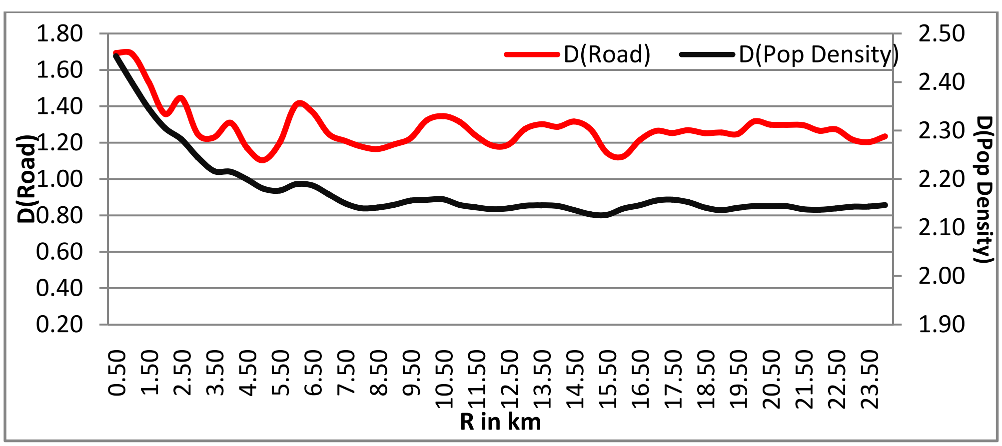

Figure 13: Distribution of fractal dimension of the road pattern and population distribution
Source: Prepared by Author

The curve representing the fractal dimensions for population distribution is smoother than the curve representing the fractal dimension of road pattern. The gradual decrease of fractal dimensions of population can be observed up to 3.5 km which is illustrated by the higher gradient of the graph. The level of higher fractal dimensions for roads can be seen in the first 3, 4 buffers. Road dimensions show variations in different buffers and this indicates that there are emerging potential areas within the city with higher accessibility. As an example there is a higher fractal dimension in the 7^{th} buffer. But the smooth flow of fractal dimensions of population distribution indicates that the very low geographical restrictions on population distribution has caused there to be a more or less equal population distribution.

4. Correlation and regression analysis between population distribution fractal dimension and the road pattern fractal dimension

Correlation and regression analysis between the two curves in figure 13 was carried out to find the relationship between the road pattern and population distribution pattern.

4.1 Results: Correlation analysis

The coefficient correlation value between population distribution fractal dimension and the road pattern fractal dimension is 0.877 (significant at the 0.01 level). The plus value of the correlation indicates that these two variables have a positive relationship. Since the value is much closer to the 1, it says that there is a very strong positive relationship between the two variables. The Reciprocal relationship which was identified earlier between the population distribution fractal dimension and the road pattern fractal dimension can be proven with this coefficient value. When the roads fill more area of the buffer, population fractal dimension of the buffer also tends to increase, and vice versa.

Model	**R**	**R square**	**Adjusted R Square**	**Std. Error of the estimates**
1	0.875	0.765	0.760	.0414

Table 5: Results Correlation analysis
Source: Prepared by Authors

		D(Pi)
D(Li)	Pearson Correlation	.877**
	Sig. (2-tailed)	.000
	N	50
**. Correlation is significant at the 0.01 level (2-tailed).		

Table 6: Results Regression analysis – Model Summary
Source: Prepared by Authors

4.2 Results: Regression analysis

The regression analysis between population distribution fractal dimension and road pattern fractal dimension provides interesting results.R^2 of the two variables is 0.765. This value illustrates that there is a strong relationship between these two variables. As such there is a 76% possibility of predicting one variable according to the other variable.

Coefficients						
Model		Un standardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.531	.053		28.836	.000
	D(Li)	.505	.041	.875	12.361	.000
a. Dependent Variable: D(Pi)						

Table 7: Results Regression analysis – Coefficients Values
Source: Prepared by Authors

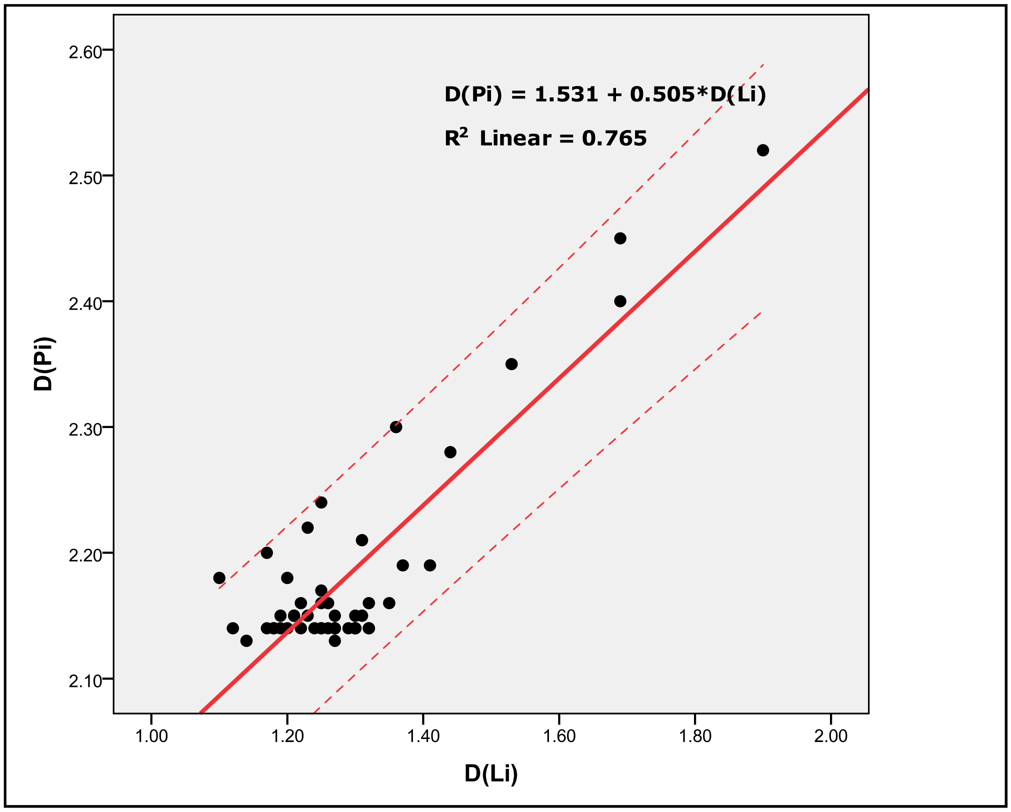

Figure 14: Relationship between fractal dimension of the road pattern and population distribution
Source: Prepared by Authors

Conclusion

As stated at the beginning, what is presented in this paper is only the preliminary findings of the initial stage of a long term project, aimed at exploring the feasibility of 'Fractal Geometry' in modeling the relationship between road network patterns and population distributions. The main finding here is that the areas with higher road fractal dimension were the ones with higher population fractal dimension and vice versa. In other words, there is a non-trivial correlation (correlation coefficient is 0.877 and significant at the 0.01 level) between the road fractal dimension and population fractal dimension and the strong linear relationship (R^2 = 0.76) between those two variables. There are different types of roads which have different impacts, and major roads have a higher impact on urban population size. For example, highways are more effective than village roads in its effect to increase urban population. However, in this research they are treated as having the same impact instead of classifying them first. Therefore, this generalization may have impacted the overall result to a degree.

The results indicate the competence of fractal dimension analysis as a technique to model the relationship between road and population density. Spatial planners may find a strategic importance in this finding for two directions of interference with the region: the first requires a more passive involvement, where planners can identify and predict the population distribution trends throughout the region in question, and devise suitable policy strategies to enhance the ongoing trends. The second is the active interference, where the whole region can be re-modeled with a few carefully identified strategic projects and steer the population distribution trends in the region towards more desirable directions, deviating from ongoing trends. Further, it will enable transport planners' ability to plan transport networks considering future population distributions. However, it should be noted that in the above scenarios, road the network is only one factor in determining population distribution, yet it is an important aspect of promoting a location for population distribution. The study presented here may have some inbuilt limitations that need to be strengthened with further investigations. Yet, the initial findings shows favourable results to endeavour a wide scale research to analyze the population distribution and road patterns of different regions in Sri Lanka and to indicate situations where planned action is needed. Further, fractal values of the different cities are inbuilt and those values must be studied differently to identify the relationship between fractuality of roads and population in those different cities. Studies on the changes of fractal values in different years may provide a better understanding of how the fractuality of population and road pattern have changed according to the each other over time.

Finally it can be concluded that fractal analysis is a suitable method to read the patterns of Transport Network and Population Distribution and it will be a useful tool for spatial and transport planning application in the Sri Lankan context.

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