Spatial Analysis Model for Population Distribution

Tenzin N.Y.[1][1], Jayasinghe.A.B[2]

[12]Department of Town and Country Planning, University of Moratuwa, Sri Lanka

Abstract

Population growth is a driver of resource overexploitation, environmental degradation, loss of biodiversity, and other environmental challenges (Yu, Liu, & Zhang, 2015). Understanding the spatial Distribution of population is important as these structures determine the urban economic efficiency, the expenditure on new infrastructure, the transport costs and consequent urban pressures on the environment. Therefore, simulating the future population distribution and their changes over time makes it essential for the planners to investigate the appropriate plans and policies to manage and shape the urban settlement activities thus leading to a sustainable development for the entire region. This study develops a model that incorporates road network centrality measures and the residential ratio of an area to predict the population density. The model will enable the estimation of population distribution based on the changes in the urban form induced by the changes in the road network and their centralities. The model can also be used to determine the road network improvements and land use changes necessary to achieve the target population in an area.

Keywords: Population distribution, Clark's model, Spatial planning, Network Centrality Analysis.

1. Introduction

The current world population of 7.6 billion is expected to reach 8.6 billion in 2030 and 9.8 billion in 2050. And by 2030, 60% of total population is predicted to in urban areas (UN, 2017). With the increasing population comes the growth of unregulated slums, unmanaged waste and Sewage disposals, inadequate water supplies, housing & transport infrastructure. Population growth is a driver of resource overexploitation, environmental degradation, loss of biodiversity, and other environmental challenges (Yu, Liu, & Zhang, 2015). In managing these issues, the first step is to visualize the distribution and variation of population across the space. The rapid urban growth have outpaced the environmental and urban planning attempt to manage them (Decker, Kerkhoff, & Moses, 2007).

Understanding the spatial Distribution of population is important as these structures determine the urban economic efficiency, the expenditure on new infrastructure, the transport costs and consequent urban pressures on the environment. Simulating the future population distribution and their changes over time makes it essential for the planners to investigate the appropriate plans and policies to manage and shape the urban settlement activities leading to a sustainable development.

1.1. Research needs

Various models such as Clarks model (Clark, 1951), Fractal based model (Chen & Feng, Fractal- Based Exponential Distribution of Urban Density And Self-Affine Fractal Forms of Cities, 2012), and city size distribution models based on Zipf's law (Arshad, Hu, & Ashraf, 2018), City Local Clustering Algorithms (Oliveira, Furtado, Andrade, & Makse, 2018) have been proposed for spatially representing the population distribution but each comes with its own shortcomings and potentials.

Clark's model and subsequent improvements model the population distribution as a function of Central density and distance from center (Martori & Surinach, 2001). Although the spatial patterns of population and population densities are generally concentric and are best captured by an exponential function (Wang, Anzhelika, & Porta, 2011), there are lots of shortcomings in the model. It fails to capture the distribution in polycentric cities and the effects from the sub centres.

[1] Corresponding Author: Tenzin N.Y.
ORCID:
Email address:nimaytenzin@gmail.com
DOI:

Power law equations has also been used to model population distribution. Given the total population in a region and the hierarchy of the centres in the region, the population in all the centres can be distributed via Zipfs law (Arshad, Hu, & Ashraf, 2018). However this model fails to distribute cities of lower order and the ambiguity of boundary delineation creates error for this distribution. Although it is validated for US and European Cities, it needs validation in Asian Subcontinents (Arshad, Hu, & Ashraf, 2018).

Population and its distribution play an important role in regional development when growing population and economy lead to increased occurrences of urban expansion, placing pressure on the natural environment, the infrastructure supply and transportation. The spatial distribution of the future population and their changes over time are important information for planning the pattern of growth in a region. (Li, 2010) (Bajat, Krunic, Kilibarda, & Petrovic Samardzic, 2011) The ability to make accurate spatial forecasts for the population using valuable information for guiding urban planning, policy making and development programs for local areas.

In order to fulfill this need and to overcome the above shortcomings this research will develop a method to effectively simulate the spatial distribution of population.

1.2. Objective

The objective of this research is to develop a method for simulating the spatial distribution of population in a region.
This research will develop a method for simulating the spatial distribution of population for any urban form using FOSS4G.

1.3. Scope of the study

The model will be developed using a case study selected in the western province of Sri Lanka. Sri Lanka, being a developing country, is a versatile-enough selection as a case study. However, the validations are limited to Sri Lankan context though the model may applicable for other countries. The research output anticipates developing a model and simulating framework that can be applied to any urban form to predict population distribution.

2. Literature Review

Popular theories and existing models on population distribution will be discussed in this section. Drawbacks of the existing models and new concepts will be discussed in this section.

2.1. Theories & Models on population distribution

In his 1798 work, An Essay on the Principle of Population, Malthus examined the relationship between population growth and human resources. Population, when unchecked, increases in a geometrical ratio while Subsistence increases only in an arithmetical ratio. The effects of these two unequal powers are kept equal through Natural and preventive checks. (Malthus , 1798) And is subject to the carrying capacity which is “The population quantity that all kinds of resources can stably supporting long term period without damaging to biosphere or without exhaustion of available non-renewable resources (Ehrlich, Holdrens, Irmi, & Clem, 1999).

The Demographic transition theory proposed in 1929 by the Warren Thompson describes the transition from high birth and death rates to lower birth and death rates as a country or region develops from a pre-industrial to an industrialized economic system. It emphasizes the role of infrastructure development and technological advancement on the settlement structure and the population. These theories explain the population growth and the factors affecting the fluctuation in population growth.

Population distribution has been modelled using various negative exponential models. Earliest attempt to model population distribution was done by Colin Clark in 1951, who developed a population distribution model based on two hypotheses that:

(i) In all cities there are densely populated areas in the center, which decrease when moving away from the center,
(ii) As time passes Density decreases in central area while it increases in Suburban Areas. (Clark, 1951)

He showed that population distribution follows a negative exponential function as follows:

$$\rho(r) = \rho_0 \exp(-\mathrm{br}), \text{ if } b = \frac{1}{r_0}$$

$$\text{Then} \quad \rho(r) = \rho_0 \exp\left(-\frac{r}{r_0}\right),$$

Where;

ρ(r) – Population density at distance r from center of city where r= 0.

ρ_0- Proportionality Constant, Central density of city at r=0.

r_0- Characteristic Radius = $\frac{1}{b}$, b is the density gradient/Co-efficient of Compactness.

Clark's model is the most popular because of its simplicity and applicability and most of the current derivations have been made from his model. Clark found out that as the residential population decreases with increase in distance from city center and that the density gradient becomes less over time. As accessibility to the center decreases the population density decreases (Clark, 1951).

This model has been criticized in such that 1) the model ignores the Density crater at the centre of city due to higher proportion of Commercial and Service land uses in the centre. 2) No provisions has been made for a polycentric city 3) in a spatially unrestricted city the accessibility varies at different points from the city and hence distribution is not uniform along the same radius (Tse, 1972).

Models of population distribution have been derived from the theory of utility maximization of individual's choice i.e. the utility maximizing model (Fahui & Zhou, 1997) and from central place theory (Christaller, 1933). These theories emphasies the importance of accessibility for distribution of market and consumer population. The factors of market interplay to reduce the cost and increase the profit for both producer and consumers and efficiently locate the market and consumer population for maximum efficiency.

Theories on population distributions also include the Power laws that show the relationship between the rank and size of the city. In city size distribution Zipf's law(Zipf's, 1949) is a popular regularity which states that in a system of cities, the largest city is roughly twice the size of second largest city, about three times the size of third largest city and so on. If the cities are ranked according to their sizes (Population) and plotted on a graph, the log of rank of cities versus log of its sizes shows a scatter diagram having regression line with slope equal to 1. (Arshad, Hu, & Ashraf, 2018) This law implies that if the total population of a region and the rank of the city centres are know, we can predict the population of all the cities in a region. Fractal geometry is another interesting concept in explaining the population distribution pattern.

2.2. Fractal Geometry of Population density and Roads

A city is a complex geographical form which is evolved and consists of scale variant, self-similar geographical entities, so "various self-organized cities are ordered cities." (Portugali, 2000). There are some attractors or order parameters that govern a self-organized system. (Portugali, 2000); explains that those parameters may be the fractals in the cities. This fractal nature of the city form is created by the socio-economic functions of the city.

City form shapes the functions of the city and functions define the shape of the city (Lu & Tang, 2004). Therefore the geometry of form and functions could be analyzed together to find a relationship between them. (Batty & Longely, 1989), (Peterson, 1996) and (Shen Q. , 2002) identified 'fractal geometry as a process of space filling'. They noted that 'When the roads are added to the city, it fractures the city more and if city is considered as a plain (2D), adding roads cover more areas of the 2D surface'.

'Transportation network is a subsystem of spatial form', which shapes the skeleton for the physical growth of the city (Elena, Dumachev, & Rodin, 2003); Shen, 1997). (Shen G. , 1997). Population distribution is an integral component of spatial form which explains its socio-economic dimension. Roads, as interactions between the elements of urban, give a very strong effect to the urban growth and population increase (Tang, 2003). Transport systems fracture the cities more and provide greater accessibility to cities, attracting more population than other locations. 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. Thus analysing and quantifying accessibility can be helpful in deriving a model for population density that incorporates accessibility as one of its variable.

2.3. Network Centrality Analysis

The concept of centrality is a powerful concept that analyses transport networks. Network centrality concepts were initially developed in social network analysis and latter applied in the fields of urban geography, spatial planning; to model, forecast, and explain the matters related to accessibility.

Centrality analysis can be defined as 'an analytical method which has been developed based on the Graph Theory and applicable in computing the level of centrality in a network by a set of measures'. There are three measures to capture the properties of networks centrality. These are Degree centrality, Closeness centrality, and Betweenness centrality.

It is a better metric than 'the distance from city centre' for measuring accessibility as it is independent of the number and hierarchy of city centres. It is calculated based on the relative accessibility of the whole network. The earlier negative exponential model lacked in explaining population distribution in complex urban form as it used distance from city centre as a measure of accessibility which is self-limited due to its inability to incorporate other sub centres.

3. Methods & Materials

This section explains the method followed in preparing the data, formulating the model and analysing the data.

3.1. Study Area & Data description

Due to the lack of complete data for the entire country, an area of 995.5Km2 is selected in western province of Sri Lanka as shown in fig. 1.

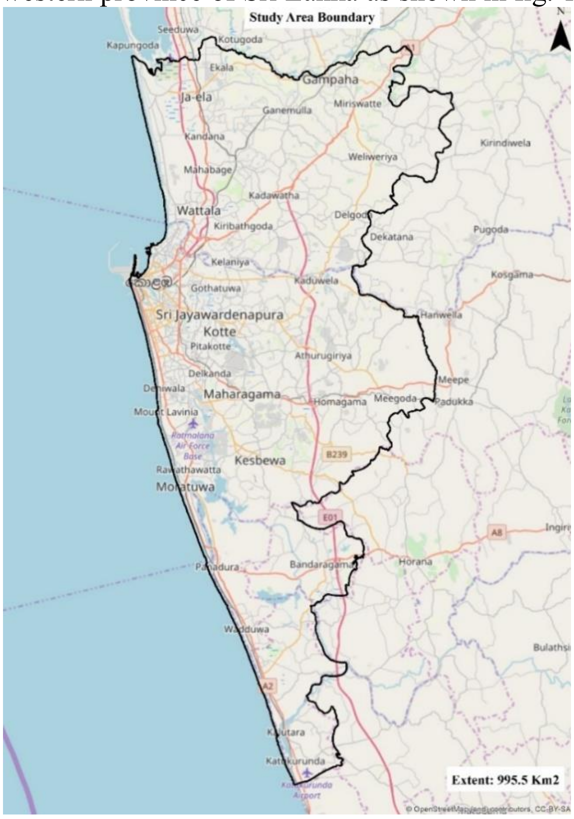


Figure 1 Study Area

The data required are summarized in the table below .The study uses the same data for calibration and validation.

Table 1 Data description

Data Type	Area	Year	Source	Description
Land Use data	Study Area	2012	2012- JICA, 2014	GIS Data: Polygons. Land use Type, Extent
Road Network Data	Study Area	2012	Open street map data	GIS Data: Polyline
Population data	Study Area	2012	Census and Statistics department	Housing and population data by GND

3.2. Study Framework

The overall method of study is given in the figure 2 below;

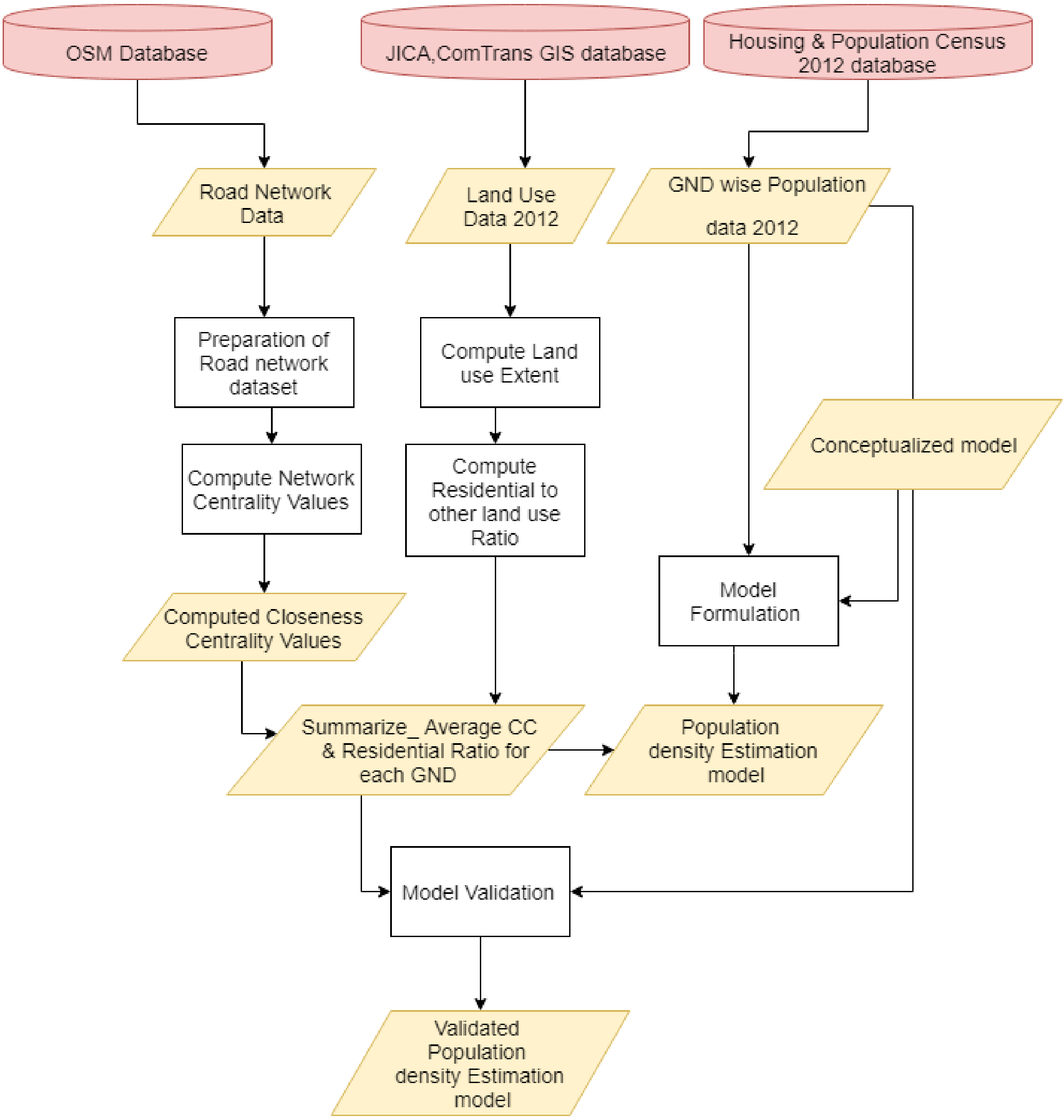


Figure 2 Study Framework

The detailed method will be discussed in sub heading 3.4 & 3.5. The first stage is the conceptualizing the model.

3.3. Model Conceptualization

Let us consider a hypothetical Region with a total extent of E_t and a total population of P_t; The population density of that region can be expressed as:

$$D_t = \frac{P_t}{E_t} \qquad (1)$$

Now if we take a small area of that region, 'x' with a population of P_x and a total extent of E_x the density of that area can be expressed as:

$$D_x = \frac{P_x}{E_x} \qquad (2)$$

Under the assumption that all the factors of residential attraction are uniformly present throughout the region;

$$\frac{D_x}{D_t} = 1 \qquad (3)$$

This means that the population is evenly distributed throughout the region and no areas of relatively high and low concentrations of population exist. However, this is possible only in a spatially unrestricted region.
In reality,

$$\frac{D_x}{D_t} \neq 1 \qquad (4)$$

the constraints and the limitations places by the need for a suitable physical morphology, accessibility, infrastructure and social construct force settlement to concentrate in favourable areas resulting in an unequal population distribution.
This density ratio can be expressed as a function of the relative residential attraction of the region 'x'

$$\frac{D_x}{D_t} = f\ Residential\ Attraction \qquad (5)$$

Factors of Residential attraction can be summarized as:

$$Residential\ Attraction = f(Accesibility,\ Land\ availability\ for\ residential\ development,\ land\ suitability, Infrastructure) \qquad (6)$$

Accessibility is one of the main factors affecting population distribution. Therefore,

$$Residential\ Attraction = f(Accesibility) \qquad (7)$$

For this model, the concept of network centrality is used to derive measure for measuring the accessibility of the place. For this study, Average Closeness centrality of all the roads in the GND will be used. Closeness centrality (CC) measures how close the location [link] to all others along the shortest path.

$$Accessibility = f(Avg.Closeness\ Centrality) \qquad (8)$$

$$CCi[r] = \frac{(N-1)}{\Sigma dij j\in N, j\neq i} \qquad (9)$$

Where,
$C\,C\,i$ = Closeness centrality of link 'i'
N = Total number of links in a network
$d\,i\,j$ = Distance between links 'i' and 'j' along the shortest path
r = Radiuses of influence system considered

Places with high accessibility has higher population density. This holds true except for central Business District (CBD) where there is a Density Crater- an area with lower population density.

The ratio of residential land use by the sum of total built up land is lower in town centres and high for an area with predominantly residential land use. Therefore another factor needs to be introduced that can capture this phenomenon of density crater that exist at the centre of all town.

Then;

$$Accessibility = f(Closeness\ Centrality_x, \frac{Rx}{Rx+Cx+Bx}) \qquad (10)$$

$$\frac{Rx}{Rx + Cx + Bx}\ is\ the\ residential\ ratio$$

$$\frac{Rx}{Rx + Cx + Bx} > 0.5 -\ high\ residential\ population$$

$$\frac{Rx}{Rx + Cx + Bx} < 0.3 - typical\ town\ center\ or\ CBD$$

Introducing this residential ratio to equation 5 we get;

$$\frac{D_x}{D_t} = f\ (Closeness\ Centrality_x, \frac{Rx}{Rx+Cx+Bx}) \qquad (11)$$

Therefore;

$$\frac{D_x}{D_t} = \boldsymbol{a}Closeness\ Centrality_x{}^{\boldsymbol{b}} . (\frac{Rx}{Rx+Cx+Bx})^c \qquad (12)$$

By taking the natural logarithm of the equation 5, we get the final linear equation that can be solved using a linear regression model.

$$Ln\frac{D_x}{D_t} = \boldsymbol{a} + \boldsymbol{b}ln(Closeness\ Centrality_x) + \boldsymbol{c}ln\ (\frac{Rx}{Rx+Cx+Bx}) \qquad (13)$$

The model requires values for three variables;

- Average Closeness centrality by GND
- Residential ratio
- Population density by GND

3.4. Data Processing

The road network file has been downloaded from http://download.geofabrik.de/asia.html. This server has data extracts from the OpenStreetMap project which are updated every day.

Figure 3 Geofabrik downloads
http://download.geofabrik.de/

The server provides the data in the format of ESRI shape files for the entire world. Road network data has been extracted from the OSM database.

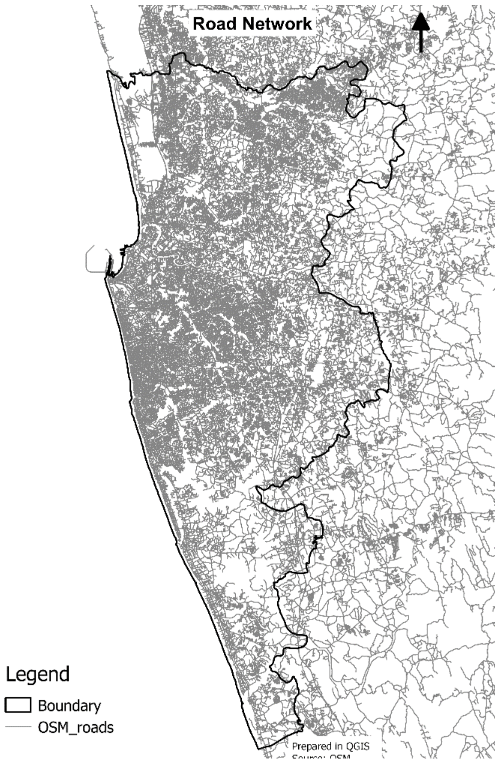


Figure 4 Road Network Map

The ComTrans GIS Database contains Features Datasets, Feature Classes and Tables use in the Urban Transport System Development Project for Colombo Metropolitan Region and Suburbs 2014. Landuse data has been obtained from the Com Trans Databse.

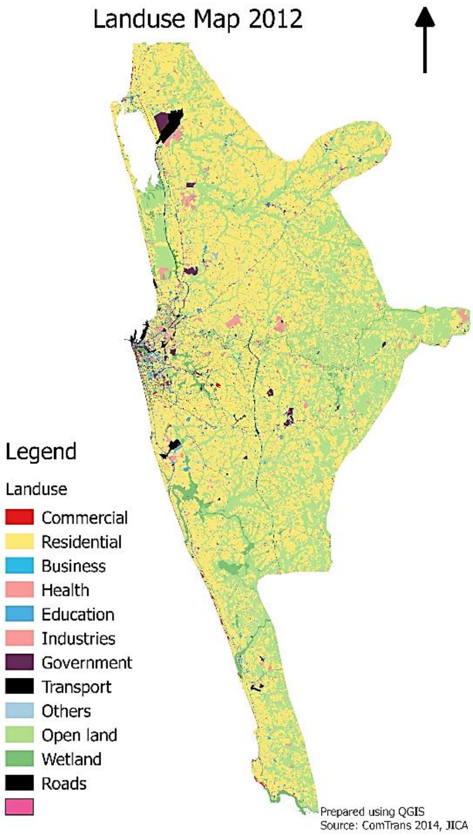


Figure 5 Land use Map

Population data for 2012 has been downloaded and processed from the department of census and statistics, sri lanka (website:http://www.statistics.gov.lk/)

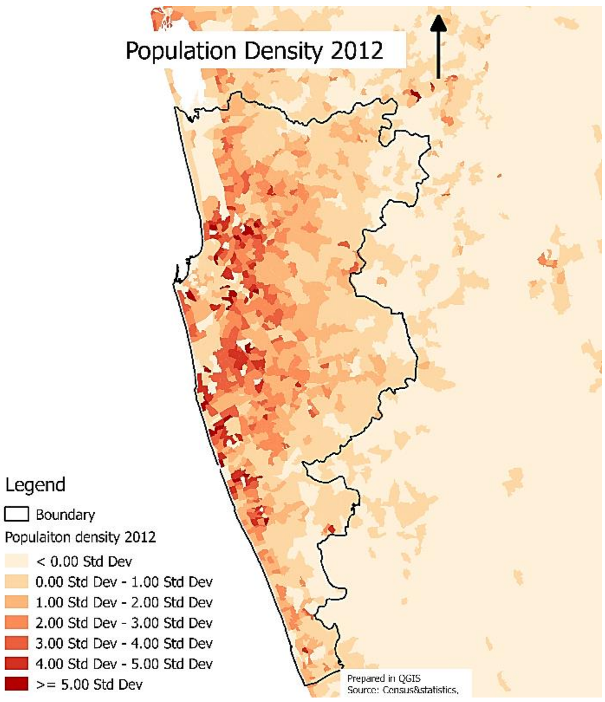


Figure 6 Population density Map

3.5. Computation of Closeness Centrality

All the process has been carried out in QGIS environment. The method is summarized in the figure below;

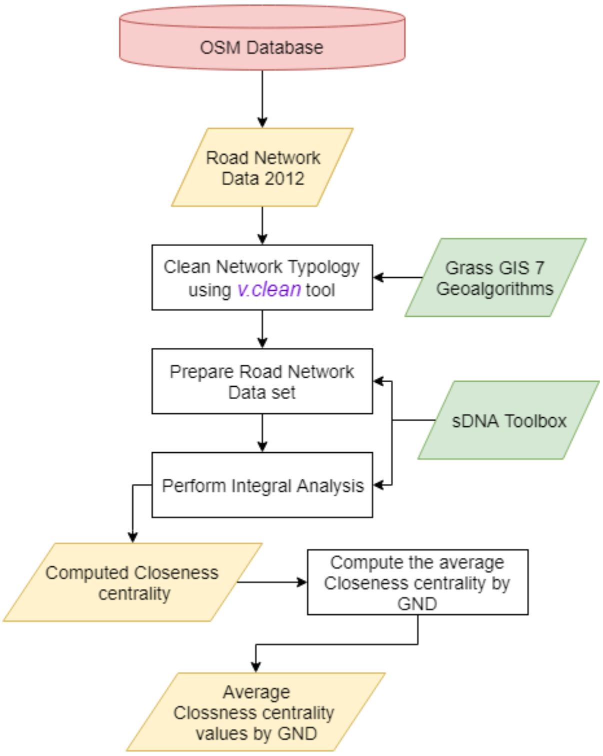


Figure 7 Computation of Closeness Centrality Values

It has been carried out in following process:

1) Cleaning the OSM road network typology using *v.clean* tool under the Grass GIS 7 Command toolbox for QGIS.

v.clean allows the user to automatically fix topology of vector maps. The *break* tool breaks lines/boundaries at intersections and it also breaks lines/boundaries forming a collapsed loop. (Gerdes, Blazek, & Landa, 2018)

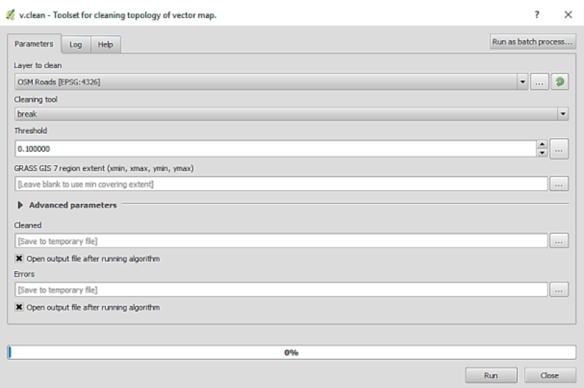


Figure 8 *v.clean* tool dialog box

Default values are used and the cleaning function is set to break. The tool corrects the typological error of the road network

2) Preparing the road network dataset using sDNA toolbox.

Spatial Design Network Analysis (sDNA) is "a is world leading spatial network analysis software, compatible with both GIS and CAD and using industry standard network representation" developed by the Cardiff University(Copper, 2016).

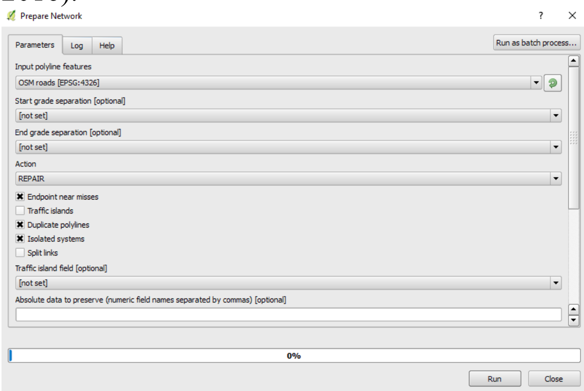


Figure 9 Prepare Network Dialog Box

Default values were used and the action set to repair. The repair action corrects errors in network that don't follow the connectivity rules.

3) Performing the Integral analysis to compute closeness centrality using sDNA toolbox.

After preparing the network and having corrected any possible typological error, Closeness centrality values is computed.

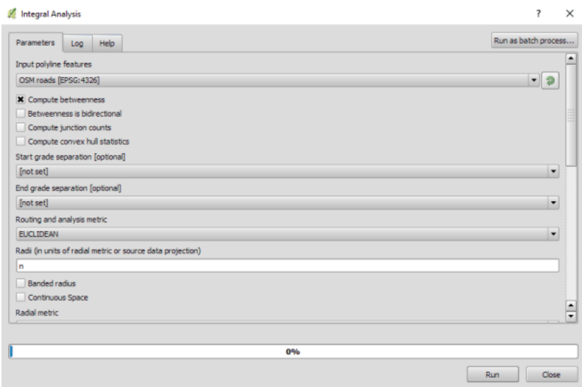


Figure 10 Integral Analysis Dialog box

Compute betweeness was checked and routing and analysis metric has been set to Euclidean to measure angular changes and radii has been set to n. After completing the analysis, we get the computed centralities in the attribute of the new shape file.

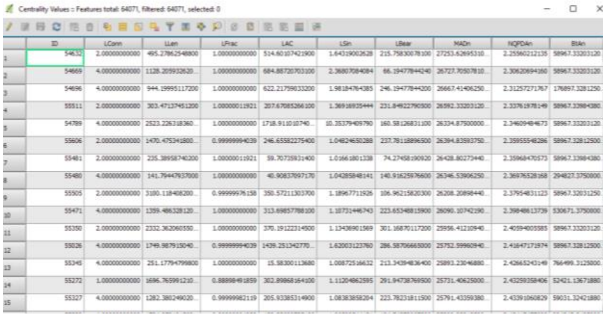


Figure 11 Attribute table of the output from the integral analysis

For this analysis NQPDA (Network Quantity Penalized by Distance in Radius Angular) has been selected as a metric for closeness centrality. NQPD is a form of closeness, commonly referred to as a gravity model, that takes into account both quantity and accessibility of network weight.

$$NQPD(x) = \sum_{y \in R_x} \frac{\left(W(y)P(y)\right)^{nqpdn}}{d_M(x,y)^{nqpdn}}$$

The set of polylines in the network radius from link x is denoted Rx
The proportion of any polyline y within the radius is denoted P(y). y∈Rx
The distance according to a metric M, along a geodesic defined by MM, between an origin polyline xx and a destination polyline y is denoted $d_M(x,y)$
Weight of a polyline yy is denoted W(y)W(y).

Then GND wise average centrality has been computed and the final output is a polygon shape file with average closeness centrality by GND.

4. Results & Findings

The study employed linear regression analysis. After checking the Multi collinearity among explanatory variables, the study utilized R2 and Median Absolute Percent Error (i.e., MdAPE) to test the goodness-of-fit. R2 and MdAPE. The study has utilized the natural logarithm values of Closeness centrality and Residential to total built-up area ratio as explanatory variables when developing the regression models. This study only utilized Closeness Centrality (CC) values and the ratio of residential to Total built up area. In the model, CC was computed at N=n. The model shows acceptable level of accuracy with R^2=0.8 and MdAPE of 25.6 % at 80% random sample rate.

Table 2 Calibration Results

Specifications		**Co-efficient values**	**Value**	**t-value**	**P-value**
Variables[a]	Constant	-5.827		-85.369	0.000
	Ln_Avg_CCn	1.854	0.938[b]	86.545	0.000
	Ln_ Residential Ratio	0.184	0.038[b]	3.479	0.000
F-value			3931.981		
Presence of Multicolinearity					
Tolerance			0.974		
VIF			1.026		
Goodness of Fit					
Calibration[c]	R^2		0.870		
	Adjusted R^2		0.870		
	MdAPE		25.69%		
Validation[d]	R^2		0.877		
	MdAPE		27.39%		
Note: a Predictor Variables; Ln_Avg_CCn, Ln_Residential Ratio b: beta values c: random 80 % of the sample gnd (n=1228) d: random 20% of the sample(n= 307)					

Model Calibration and validation at different sample percentages. The model shows a high accuracy for even low sample rates.

Table 3 Accuracy at various sample rate

% of Calibration Sample			80%	60%	40%	20%	10%
Coefficient Value		Constant	-5.827	-5.849	-5.847	-5.906	-5.698
		Ln_Avg_CCn	1.854	1.866	1.864	1.883	1.831
		Ln__Residential Ratio	0.184	0.196	1.149	0.584	0.608
F -Value			3931.9	3002.89	1906.68	939.33	493.98
VIF			1.026	1.026	1.013	1.024	1.111
Goodness of fit	Calibration	N	1228	852	564	300	130
		MdAPE	25.69%	18.96%	12.56%	18.78%	7.25%
		R2	0.865	0.912	0.866	0.862	0.877
		Adjusted R2	0.865	0.876	0.866	0.863	0.863
	Validation	MdAPE	27.39%	25.61%	25.00%	47.95%	24.84%
		R2	0.877	0.858	0.870	0.929	0.928

The error distribution shows that the error is higher at the lower population density i.e. fringes.

Table 4 Error Distribution

Density Person/Km^2	Average MdAPE	GND Count
> 50,000	7.90%	1
10,000 – 25,000	18.57%	82
5,000 – 10,000	29.80%	236
2,500 – 5,000	64.19%	373
< 2,500	160.31%	336

5. Discussion & conclusion

This research has been completed using QGIS software, sDNA toolbox for QGIS & Grass GIS Geo-algorithms. SPSS has been used for the solving the linear regression model.

5.1 Key findings

- Population density is a function of the relative residential attraction of an area. The study proposes that the Relative residential attraction is a function of the relative accessibility of that area. Network centrality measures the relative accessibility of a link using closeness centrality and between-ness centrality. Residential attraction will be modeled using the closeness centrality value and residential land use ratio.
- The proposed models for simulating population density by utilizing Closeness Centrality values and residential land use ratio as endogenous variables recorded an accepted level of predictability and accuracy (R^2= 0.870 and MdAPE < 30%) .
- The model maintains a high accuracy for Low calibration sample (MdAPE<30%, R^2=0.866 for 40% random sample for Calibration.)

5.2 Recommendations

The Population distribution model can be used in physical planning.

- It can be used to predict the changes in population based on the changes in land use and road network improvements. It can be used to predict the population of identified centers. It can also be used to predict population distribution along a new link or the overall changes a new road link brings to the overall urban form.
- It can be also used in reverse- to determine the road network improvements and land use changes necessary to achieve the target population in an area.

This method is highly recommended for assignments to be carried out in developing countries due to the following key merits:

- It uses fewer variables. The distribution model requires the centrality values of the road network and the land use data. The growth model requires the reproductive rates and the centrality growth rates.

- Both the models are highly accurate for even at low calibration sample rate with MdAPE less than 30%.

Though this study has been completed by successfully achieving the desired objectives, it opens a path for further studies on population distribution studies. Few of the future research areas may include, but not limited to the followings.

- Validating the Model for other city centers and including multiple scales of study area.
- Incorporating Fractal dimension into the Equations of Population distribution model.
- Combining the Distribution model with the Power law equations.

6. Acknowledgement

I would like to first of all thank my principal Supervisor Dr. Amila Jayasingle for his remarkable guidance and supervision and his effort in making this a successful research. I am indebted to his constant guidance, feedback, corrections and motivation.

I would also like to thank My Special thanks also go to the Head of the Department, Mr Rangajeewa Rathnayke for his support and guidance.

And also to my parents and well-wishers who wished me success all along. I am forever indebted to them.

1. References

Arshad, S., Hu, S., & Ashraf, B. N. (2018). Zipf's law and city size distribution: A survey of literature and future research agenda. *Physica A 492*, 75-92.

Batty, M. (2017). Space Syntax and Spatial Interaction: Comparisons, Integrations, Applications. *UCL working Papers Series*, pp. 1-34.

Batty, M., & Longely, P. (1989). *Fractal Cities(A Geometry of Forms and Functions).*

Cabell, J. F., & Oelofse, M. (2012). An indicator framework for assessing agroecosystem resilience. *Ecology and Society, 17*(1), 18.

Chen, Y., & Feng, J. (2012). *Fractal- Based Exponential Distribution of Urban Density And Self-Affine Fractal Forms of Cities.*

Christaller, W. (1933). *Central Place theory.*

Clark, C. (1951). *Urban Population Density.*

Copper, C. (2016). *Spatial Design Network Analysis (sDNA) version 3.4 Manual.* Retrieved from https://www.cardiff.ac.uk/sdna/software/documentation/

Decker, E., Kerkhoff, A., & Moses, M. (2007). Global Patterns of City Size Distributions and Their fundamental drivers. *PLoS ONE.*

Deole, S. (2013). *Population density, Optimal Infrastructure and economic growth.*

Ehrlich, Holdrens, Irmi, & Clem. (1999). Carrying capacity reconsidered: from Malthus' population. (R. Howarth, Ed.) *International Society for Ecological Economics (ISEE)*, 14.

Elena, R., Dumachev, V., & Rodin, V. (2003). Methods and principles of police deployment within the "chaotic" urban structure.

Fahui, W., & Zhou, Y. (1997). Modelling Urban Population Densities in Beijing 1982-1990: Suburbanisation and its Causes. *Urban Studies, Vol 36.*

Francis, R., & Bekera, B. (2014, January). A metric and frameworks for resilience analysis of engineered and infrastructure systems. *Reliability Engineering & System Safety, 121*, 90–103. doi:http://dx.doi.org/10.1016/j.ress.2013.07.004

Gerdes, D., Blazek, R., & Landa, M. (2018, November 1). *GRASS GIS Manual: v.clean*. Retrieved from GRASS GIS 7.4.3svn Reference Manual: https://grass.osgeo.org/grass64/manuals/v.clean.html

LaGro Jr, J. (2013). *Site Analysis* (3rd ed.). Hoboken: Wiley & Sons.

Lu, Y., & Tang, J. (2004). Fractal dimension of a transportation network and its relationship with urban growth: a study of the Dallas-Fort Worth area. *Environment and Planning B;PLanning and Design*, 895-911.

Malthus , T. (1798). *Essay on the Principle of Population.* London: Printed for J. Johnson, in St. Paul's Church-Yard.

Munasinghe, J., & Bandara, A. (n.d.). Evolution of a City: A Space Syntax Approach to Explain the Spatial Dynamics of Colombo. *Asian Planning School Association*.

Peterson, I. (1996). The shapes of cities: Mapping out fractal models of urban growth.

Portugali, J. (2000). *Self-Organization and the City.* Springer-Verlag Berlin Heidelberg.

Quigley, J., & Rosenthal , L. (2005). The Effects of Land Use Regulation on the price of housing: What do we Know? What can we learn? *Cityscape: A Journal of Policy Development and Research*, 69-137.

Ritung, S., Agus, F., Wahyunto, & Hidayat, H. (2007). *Land Suitability Evaluation with a case map of Aceh Barat DIstrict.* Indonesia.

Shen, G. (1997). A fractal dimension analysis or urban transportation networks.

Shen, Q. (2002). Fractal dimension and fractal growth of urbanized areas. *International Journal of information Science*, 419-437.

Straszheim, M. (1975). The Demand for Housing Attributes and the Choice of Neighborhood. *An Econometric Analysis of the Urban Housing Market*, 78-115.

Tang, J. (2003). Evaluating the relationship between urban road pattern and population using fractal geometry.

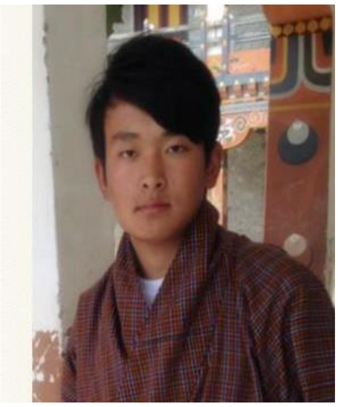
Transportation Research Board: National Research Council. (1999). *TCRP Report 47 : A Handbook for Measuring Customer Satisfaction and Service Quality*. Washington, D.C.: National Acdamy Press.

Yu, M., Liu, S., & Zhang, S. (2015). A dynamic model for populaiton mapping: a methodology integrating a MOnte Carlo simulation with vegetation-adjusted night-time light images. *International Journal of Remote Sensing*, 4054-4068.

Author/s Biography

Tenzin N.Y.[1][2], Jayasinghe.A.B[2]

[1,2] Department of Town & Country Planning, University of Moratuwa 10400, Sri Lanka
[1]*nimaytenzin@gmail.com*, [2]*amilabj@uom.lk*,



Tenzin is an undergraduate in Department of Town & Country Planning, University of Moratuwa from Bhutan. His main research interests are Network analysis, Urban Modelling and GIS applications for urban & regional planning.

Amila Buddhika Jayasinghe is a senior lecturer at the Department of Town & Country Planning, University of Moratuwa, Sri Lanka. He has earned a doctorate degree from the Nagaoka University of Technology in 2017 and the masters Degree in Infrastructure Planning from CEPT University, India in 2011. His research works are focused on urban simulation, open source GIS applications, transport network analysis and public transportation in developing countries. Dr. Jayasinghe is a charted town planner.

[2] Corresponding Author: Tenzin N.Y.
ORCID:
Email address:nimaytenzin@gmail.com
DOI: