Spatial Analysis Approach for Identification of Urban Sprawl Pattern: A Case Study of Matara DS Division

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Abstract*:In this study the urban sprawl of Matara DS Division was analyzed from 1990 to 2020. Landsat satellite imageries were used in this study to extract the built-up area. Shannon's Entropy method and Fractal Dimension of Box Counting method were used to analyze urban sprawl. NDBI was used to extract build up area from Landsat TM/ETM+/TIR satellite imageries which are necessary to calculation of both methods and number of grids coincide with built-up vector layer had used to calculate fractal dimension. The accuracy assessment shows more than expected (above 80%). As well as built up area has changed with huge number.1.097km^2 area is showed in year1990 and when it comes to year 2020, it showed as 11.669km$^{2.}$ Shannon's Entropy was increased 1990 to 2020 with 1.23 to 1.67 and year 2000 showed from 1.46 and year 2010 shows 1.52. It has increased gradually and reach to error range (>1.5). Fractal Dimension also was increased 1990 to 2020 with 1.24 to 1.65 and year 2000 showed 1.498 and year 2010 showed 1.520. It's also reached to error range (>1.5). Hence these results proved that urban sprawl has increased in the study area and the Shannon's entropy calculation categorized as high sprawl, sprawl and no sprawl. Isadeen town, Kadawediya east, Kadawediya west, Kotuwegoda North, Kotuwegoda South, Mathotagama, Noope, Uyanwatta, Uyanwatta North, Welegoda east, Welegoda west, Weliweriya east, Weliweriya west GN Divisions have identified as high sprawl GN Divisions. and there is a close relationship between Shannon's Entropy and Fractal dimension method as revealed by the graphical representation. Finally, this study was identified the pattern of urban sprawl such as low-density development, commercial strip development, scattered and dispersed developments in the study area. The result revealed that, in year 1990 only scattered development happened in the study area. But when it came to 2020, it shows three development patterns of urban sprawl and didn't show leapfrog development.*

Keywords: *Urban Sprawl, Dimension, Shannon's Entropy, Landsat*

1. Introduction

Urban sprawl is one of the most important problems in urban development due to its impacts on environmentally, socially and economically. Understanding urban sprawl and analyzing urban sprawl pattern are useful for determining current and future needs. It is essential, especially for the management of natural resources and the construction of infrastructure. Some of the causes of the sprawl include; population growth construction work, economy and proximity to resources and basic amenities and also often encourage the regional development which eventually lead to urbanization. Urban sprawl led to serious problem in both short- and long-term infrastructure planning. Developing countries are experiencing the urban sprawl phenomenon. Because there are so many urban development activities in developing country.

Urban sprawl is one of the key challenges facing Sri Lanka's today. Sri Lanka is a developing country with high population density. It is experiencing rapid urbanization by converting agriculture and natural lands in to build up area. Due to this, there are lot of issues occurred and

badly effected to the human life and environmentally (Amarawickrama, Singhapathirana and Rajapaksha, 2015). Matara is the one of most important commercial cities in Sri Lanka. It is located in Matara DS Division area. It is highly accompanied by residential and commercial development Considering the existing situation in the Matara DS Division, many ongoing urban development projects have been carried out within last few decades. Some studies have examined the urban land use changes in this area and these studies provide an insight into why this area necessary for studying sprawl pattern (Serasinghe Pathiranage, Kantakumar and Sundaramoorthy, 2018). Identification of the patterns of sprawl and analysis of spatial changes would help immensely in the planning for proper infrastructure facilities. Pattern of sprawl and analysis of spatial changes could be done cost effectively and efficiently with the help of spatial technologies such as Geographical Information System (GIS) and Remote Sensing.

Urban sprawl in this region was analyzed by integrating Remote sensing and GIS. Remote sensing is the science of acquiring information about an object or phenomenon by measuring emitted or reflected radiation. Satellite remote sensing provides an important source of spatial data. GIS is a system designed to capture store, manage, analyze, manipulate and present spatial data. Integrated analysis will help to urban planners to in their decisions making process. Shannon's Entropy and Fractal analysis carried out with integrating RS and GIS technologies. In here build up area were extracted by using NDBI (Normalize difference build up index) and create fishnet tool on ArcMap were utilized to create different scale grid box. Hence, this study will help to understand relationship among Shannon's Entropy and Fractal Dimension.

Nowadays, urban sprawl phenomenon has been seen in many of cities in the developing and developed countries. More than half of the world's population currently lives in metropolitan regions. Therefore, on a global scale, all potential population rises will be focused more in towns and cities. This massive increment in the urban population, together with an unprecedent rate of urbanization, many cause unplanned, uncontrolled or unrestricted growth of urban areas into the peripheries may be recognized as urban sprawl (Derya *et al*, 2016). There is no unique definition for urban sprawl. However a widely accepted definition is uncontrolled ,unlawful ,unplanned ,and uncoordinated low- density single use development facilitates that does not provide for a functional and appealing combination of land use mixes and /or and is not functionally connected to neighboring land use and which variously appears as leapfrog, or isolated development ,ribbon or strip with scattered residential neighborhood and commercial strip development ,with auto mobile dominance which are aesthetically displeasing in nature (Nelson *et al*,1995,Hiller *et al*,2013).

More than half of the world's population currently live in around the urban cities and can see massive increment of world population day by day. So, land has become a scares resource. But this scares resource has built up with focusing well developed /established cities. Urban area is increasing faster than the urban population itself. Urbanization is the most dramatic form of irreversible land transformation of agricultural and prolific lands to urban areas affecting landscapes and people who live in and around cities. There are so many countries have been reached their maximum level of urban sprawl and they have identified effects of urban sprawl such as impacts on society, impacts on housing, impacts on jobs, fiscal impacts, political impacts, impacts on transport, impacts on agriculture, open space (Neslihan Serdarogle Sag, 2021). So, in global scale, have arranged so many systems to minimize and manage the urban sprawl. Urban sprawl is a worldwide problem. So, most studies have been focused on effects of urban sprawl in global scale (Kriti Rastogi *et al*, 2018).

Sri Lanka is the one of developing country in the world and it has rapid urbanization. Sri Lanka is experiencing speedy urbanization by converting the agriculture land and other natural land cover into built-up land. The rapid growth in urban population and urban areas in Sri Lanka may cause urban sprawl. This rapid growth in urban Population, may create serious sprawl disparities which are hard to fix. Sri Lanka is experiencing a speedy urbanization over the last three decades. Today, nearly 40% of the Sri Lankan population live in urban areas and it is expected that 65%of the population will live in urban areas by 2030. This will make cities grow both in number and in physical size than experienced in the past, aggravating urban sprawl-related problems in the future (Serasinghe Pathiranage, Kantakumar and Sundaramoorthy, 2018).

A. Study Area

The Matara DS Division is located in the southern coast of Sri Lanka. The Matara DS Division is 21.2 km2 (8.2 sq mi) in area. The average elevation above sea level is 16 m (52 ft). It is the administrative capital of Matara district and one of the main commercial centers in Sri Lanka (Serasinghe Pathiranage, Kantakumar and Sundaramoorthy, 2018). It has massive population increment in the last few decades. Thus, UDA initiated major infrastructure development projects, such as the construction of Southern expressway with four lanes from Kottawa to Matara and Matara to Mattala & railway track from Matara to Beliatta. This development led to population growth and urban sprawl in the suburbs of the study area. So Matara DS Division area is chosen as the study area.

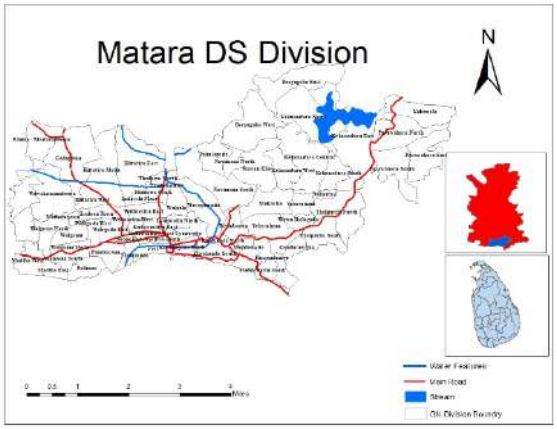

Figure 1: Matara DS Division Area

2. Data and Methodology

Satellite images were downloaded free of charge from USGS Earth Explorer and Matara district, Matara DS division and GN Division shapefile, road shapefile and stream shapefile were also downloaded from website of the Survey Department of Sri Lanka.

Table 1: Detail of Acquired Satellite Image

Year of the image	Resolution	Sensor	Band Used	Scene Cloud Cover
1990	30m	TM	Band 4 Band 5	30%
2000	30m	ETM+	Band 4 Band 5	20%
2010	30m	TM	Band 4 Band 5	20%
2020	30m	TIR	Band 5 Band 6	25%

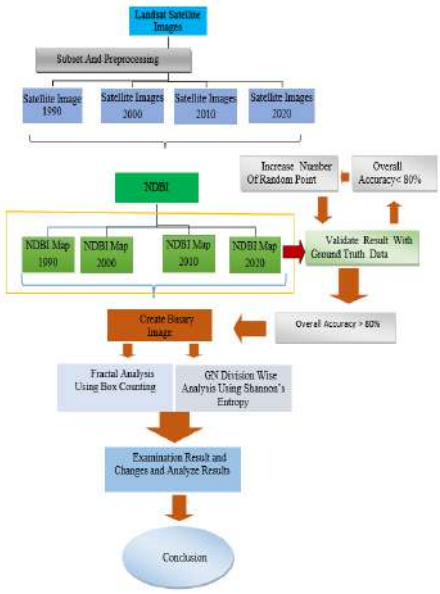

Figure 2: Flow Diagram of Methodology

The downloaded satellite images were subset using study area shape file to extract built-up area. Then preprocessing part has done. Then NDBI has applied to extract built-up area. The built-up area maps have validated with ground truth data. After accuracy assessment test the maps converted in to binary image. Then the Shannon's entropy and fractal dimension was calculated. Then the results and changes were analyzed and conclusion also done.

B. Built-Up Area Extraction

Urban sprawl is mainly defended on built up area. Due to uncontrolled population density growth the built-up areas expanded without any control. This built-up area expansion considered as most influential driver of urban sprawl and most effective in urban sprawl analysis.

Image subset were continued to extract the Matara Ds Division area for each satellite image. Then NDBI (Normalize Difference Build Up Index) were used to extract build - up area.

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)}$$

Source: (Aswal, Saini and Tanzeem, 2018)

Above equation is the equation which was used for extraction of build-up area from other areas. when it comes to Landsat 8 satellite imagery it used Band 6 as SWIR and Band 5 as NIR. But, when it comes to Landsat 7 and Landsat 5, it is asked Band 5 as SWIR and Band 4 as NIR. Add the related band to ArcMap and open the raster calculator window to write the formula of NDBI.

Threshold values were calculated for each year to categorized area as Build-Up and Non-Buildup. The accuracy assessment was continued to validate data which have used. It compares the classified image to another data source that is considered to be accurate or ground truth data. Ground truth data were collected by using Google Earth Pro which was maintained with high resolution. It compares with a classified map with real world.

C. Urban Sprawl Patterens

Urban sprawl characteristics, which are low density development, leapfrog developments, commercial strip or ribbon developments, scattered and dispersed developments were mainly identified in the many developing countries (Seevarethnam *et al.*, 2021) .

[2] Low density development(a)
[3] Leapfrog Development(b)
[4] Commercial Strip Development(c)
[5] Scattered Development(d)

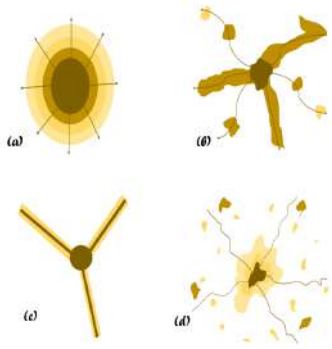

Figure 3: Development Patterns

Source: (Seevarethnam *et al.*, 2021)

D. Shannon's Entropy

Shannon (1948) employed the concept of entropy to measure the uncertainty of a variable like urban form. This uncertainty is expressed as the average expected value of information continued in a study. The Shannon's entropy has potential to measure the uncertainty of random process. Shannon's entropy method is used to determine whether the growth of urban areas was divergent or compact. Urban sprawl identified as the scatteredness of an urban area or urban development (Quezada et al,2009). Urban sprawl can be analyzed by using Shannon's entropy method and it was identified as an effective method.

$$Hi = -\sum_{j=1}^{m} Pj \log_e(Pj)$$

Source: (Mohammady and Delavar, 2016)

The Shannon entropy values range have had identified from 0 to loge(n), values closer to 0(smaller values) indicate very compacted distribution and the value closer to $\log_e(n)$ (larger value) indicates that the distribution is much dispersed in urban form (Mohammady and Delavar, 2016)

E. Fractal Dimension

The notion of "fractal" was introduced by Mandelbrot (1983) and came from the Latin term "fractus", meaning is irregular and fragmented. One of the methods of determining the fractal dimension is identified as box counting method. Box counting method consisting another two sub methods called the vector method and the grid method. Fractal dimension of region can be calculate using both methods and Grid method is more effective.

The fractal dimension value has a value between 1 and 2. Value close to one indicate more compact and sustainable urban area. Value close to 2 indicate less compact or more sprawling and disperse situation (Torrens, Alberti 2000).

Two ways have had identified to realize the box counting method. The Vector method and the grid method are the identified methods (Ge and Lin, 2009).To calculate the fractal dimension values for each years following formula is used.

$$D = \frac{\ln N(X)}{\ln (1/X)}$$

Source: (Rastogi and Jain, 2018)

N(X)= Number of boxes intersecting with Built-up area

X=Side Length of Box

D= Fractal Dimension

Vector maps were created by using raster maps of study area which was created using NDBI. Then vector maps were reclassified built up area as 1 and non-built-up area as 0. Then built-up areas were extracted for each map. Grids were created using fishnet tool and respect to the eight scale. After those grids and extracted vector areas were overlapped. Finally calculated number of non-empty grids for each maps respect to the eight scale grids. The fractal dimension is given by slope of the straight line which is formed by plotting lnN(X) and ln(1/X) (Rastogi and Jain, 2018).

3. Results and Discussion

A. Built-Up Area And Urban Growth

Built up area maps are very important because of its influence on urban sprawl analysis. Both Shannon's Entropy and Fractal Dimension methods are based on built up area and all calculation parts expected built up areas.

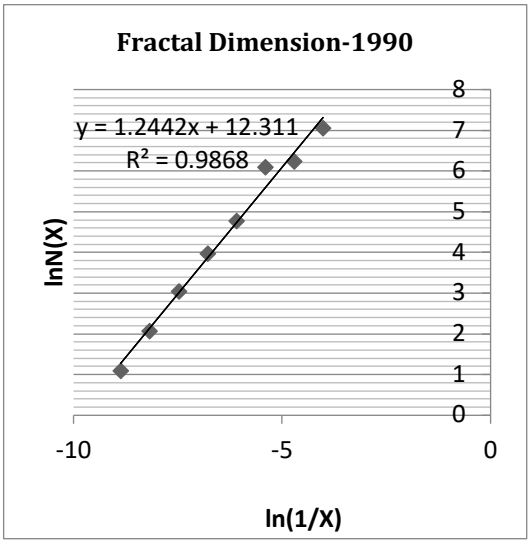

Figure 4: The Ln -Ln Plot on Fractal Dimension of the Build-Up Area of Matara DS Division 1990

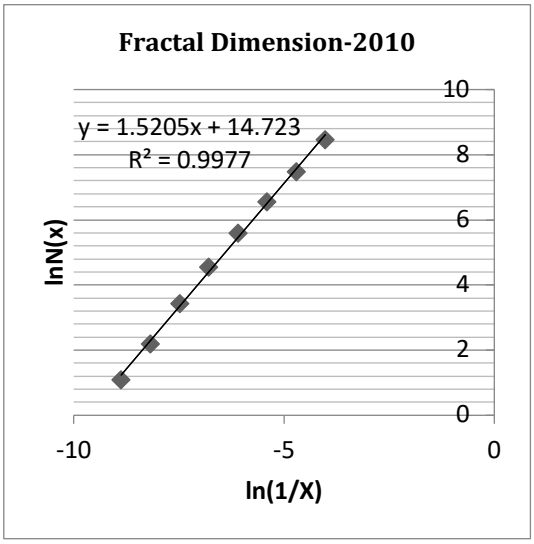

Figure 6: The Ln -Ln Plot on Fractal Dimension of The Build-Up Area of Matara DS Division 2010

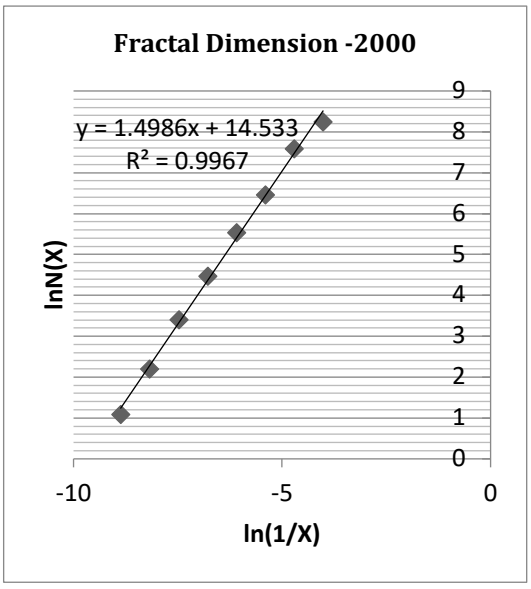

Figure 5: The Ln -Ln Plot on Fractal Dimension of The Build-Up Area of Matara DS Division 2000

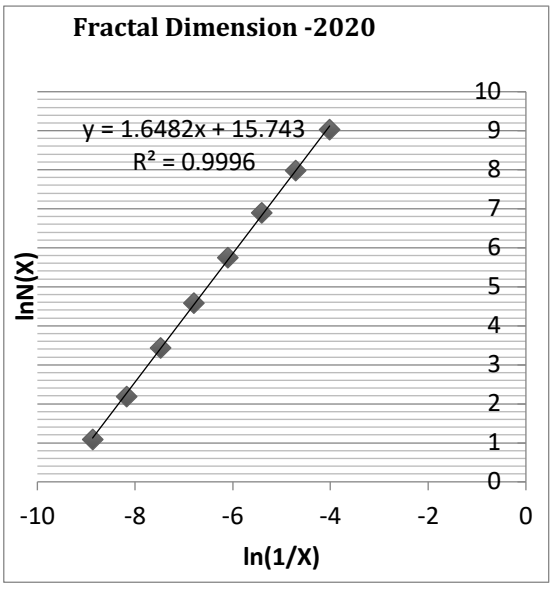

Figure 7: The Ln -Ln Plot on Fractal Dimension of The Build-Up Area of Matara DS Division 2020

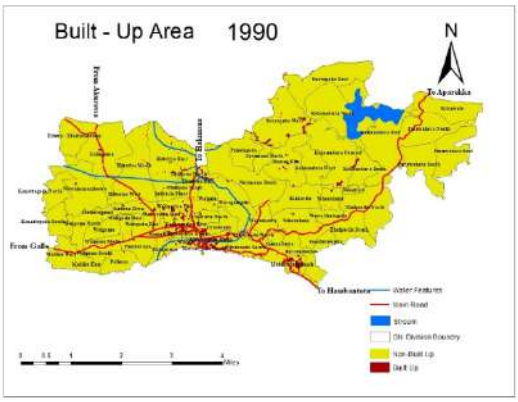

Figure 8:Build-Up Map of Matara DS Division 1990

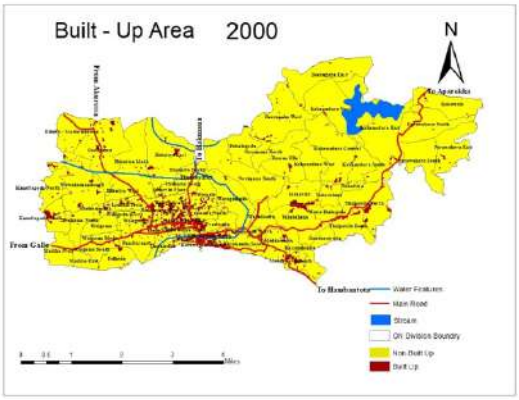

Figure 9:Build-Up Map of Matara DS Division 2000

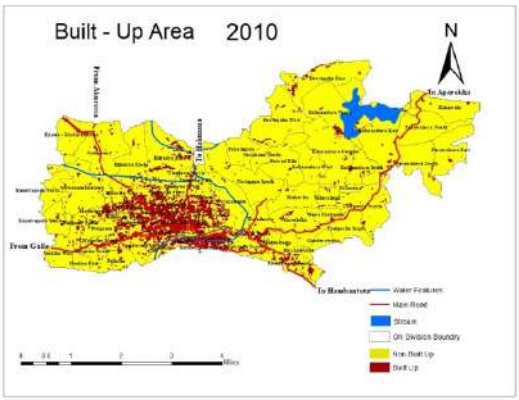

Figure 10:Build-Up Map of Matara DS Division 2010

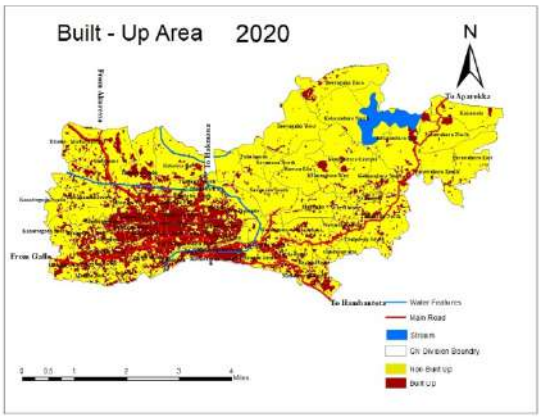

Figure 11:Build-Up Map of Matara DS Division 2020

Table 2:Built-Up Area Changes

Year	1990	2000	2010	2020
Built-Up Area (km^2)	1.097 km^2	2.971 km^2	6.635 km^2	11.669 km^2

Based on above Table 2 a rapid increase in built-Up growth rate was calculated for fast decades.

Table 3:Built-Up Area Changes for Each Decade

Decade	1990-2000	2000-2010	2010-2020
Built-up Changes(km^2)	1.874 km^2	3.364 km^2	6.635 km^2

B. Shannon's Entropy And Urban Sprawl

Shannon's entropy is a widely accepted urban sprawl analysis method. Shannon's entropy is an indicator of urban sprawl. It is an important tool calculating the compactness or dispersion of urban growth.

Table 4: Shannon's Entropy Values and Relative Shannon's Entropy Value for year 1990, 2000, 2010, 2020

Matara DS Division				
	1990	2000	2010	2020
Shannon's Entropy	1.23	1.46	1.53	1.67
Relative Shannon's Entropy	0.676	0.802	0.840	0.918

The Table 4 shows Shannon's Entropy Value and relative Shannon's Entropy values for year 1990,2000,2010,2020. It shows less Entropy value for year 1990 and 2000 and it shows high entropy value for year 2010 and 2020. It shows large Entropy value for year 2020 and it indicates high sprawl condition in year 2020. The Figure 12 showed GN Divisions which are high sprawl, low sprawl and no sprawl in year 2020 and this result showed respect to the Shannon's entropy method.

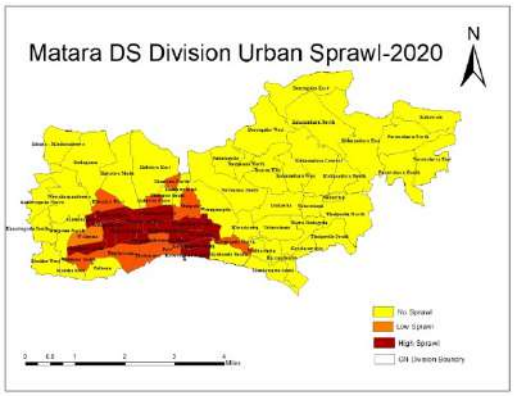

Figure 12: Urban sprawl Categories in Matara DS Division 2020

C. Fractal Dimension And Urban Sprawl

Table 5: Fractal Dimension of Matara DS Division Year 1990, 2000

Fractal Dimension - Matara DS Division				
Year	1990	2000	2010	2020
D (Fractal Dimension)	1.244	1.498	1.520	1.648

Above Table 5 shows increase of Fractal Dimension among 1990 to 2020 decade by decade. These value show that study area was not sprawl in 1990 and when it comes to 2020, it had become a sprawled because the fractal dimension value of year 2020 had reached to error range (>1.5).

D. Comparison Of Shannon's Entropy And Fractal Dimension

Graphical representation is the simplest way of the visual inspection. Its help to understand similarities and differences between the result. In this study to compare the results of Shannon's entropy and fractal dimension results, the Figure 20 has used.

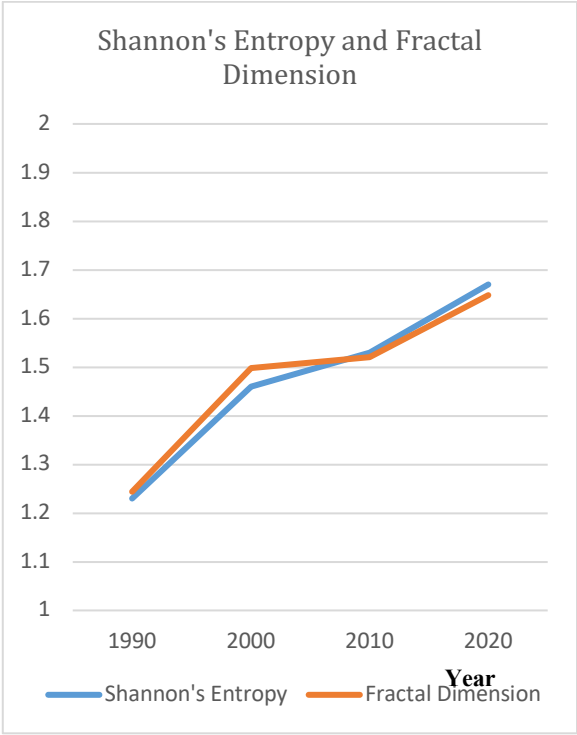

Figure 13: Fluctuation of Shannon's Entropy and Fractal Dimension Among 1990 to 2020 Decade by Decade.

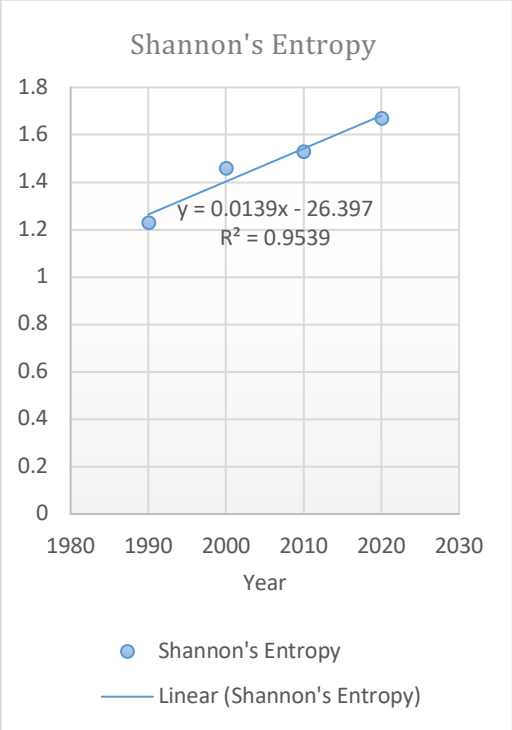

Figure 14: Linear Form of Shannon's Entropy Among 1990 To 2020

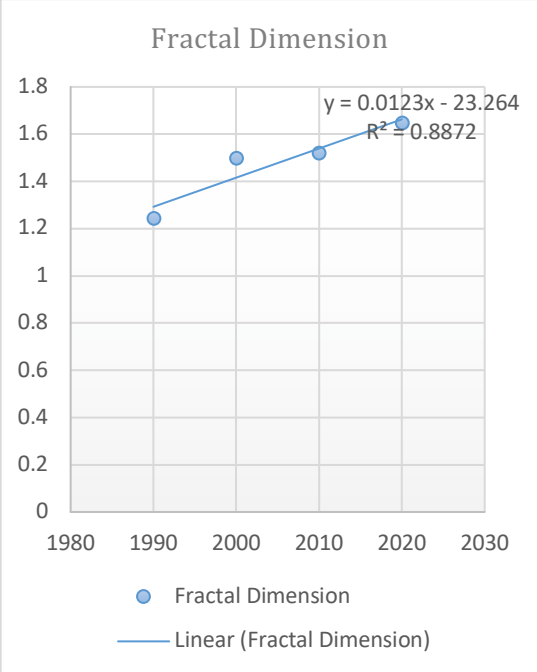

Figure 15: Linear Form of Fractal Dimension Among 1990 To 2020

Above Figure 14 and Figure 15 shows close relationship between Shannon's Entropy and Fractal Dimension. Above two graph shows approximately equal slope and it reveal that relationship among Fractal Dimension and Shannon's Entropy. R^2 is the measure of the goodness of fitness of a model. R^2 near to one means regression prediction approximates the real data points.

E. Characteristics Of Urban Sprawl

There are four characteristics identified which effected to the urban sprawl and increment of urban sprawl. Low density developments, Leapfrog developments, scattered growth, Commercial ribbon developments.

F. Low Density Development

Low density is one of the main risky phenomena which effected to the urban sprawling in urban area. It is the most generally indicated factor of urban sprawl in most, many literatures. Matara DS Division area also shows low density development in selected some years. Below Figures16 shows low density development in selected some years. It shows some GN Divisions (Isadeen town, weliweriya east, weliweriya west, kadeweediya west, Kotuwegoda South, Kotuwegoda North) with high compact urban area. Outward from other GN Divisions, built up density had decrease. This finding reveal that the study area has experience low density development.

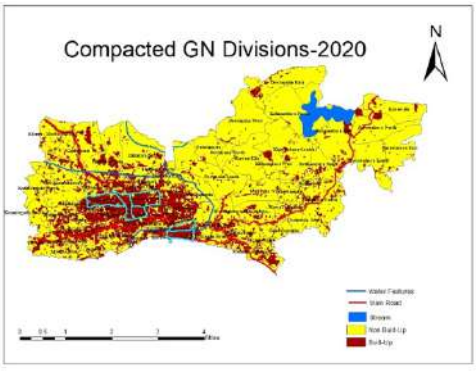

Figure 16: Compact Built-Up Area 2020

G. Scattered Development

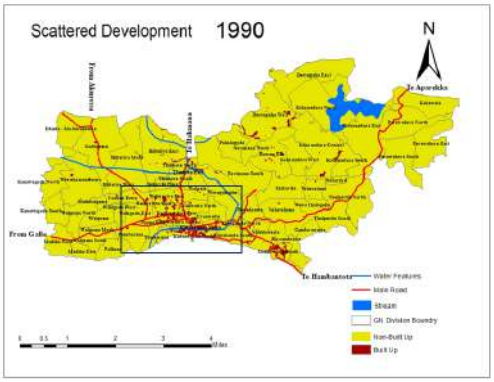

Figure 17: Scattered Development in Built-Up Area in 1990

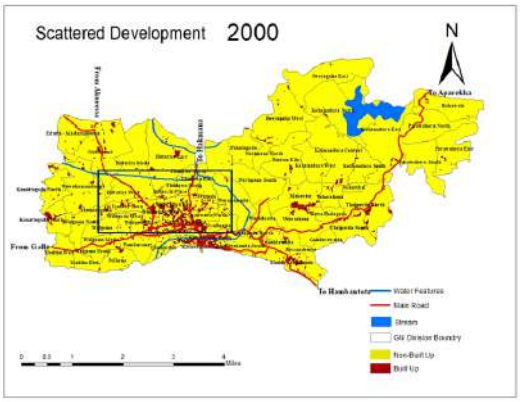

Figure 18: Scattered Development in Built-Up Area in 2000

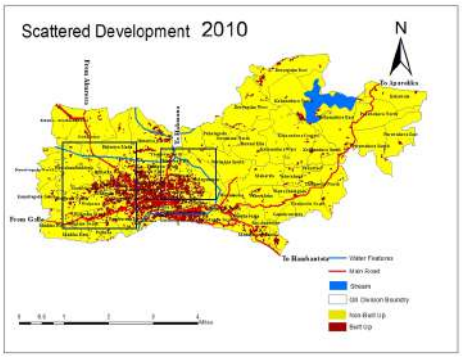

Figure 19: Scattered Development in Built-Up Area in 2010

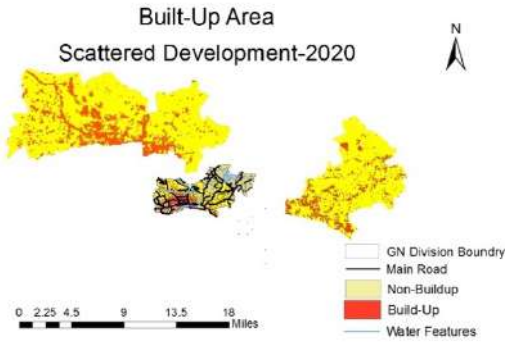

Figure 20: Scattered Development in Built-Up Area in 2020

Fractal dimension also give some idea about scattered development. If fractal Dimension closure to the 1 indicate that development is compact and if it is closure to 2 indicate that development is scattered. In Table 5, Fractal dimension value of year 1990 ,2000 ,2010 ,2020 reveal that scattered development has increased decade by decade and when it comes to 2020 high level of scattered development shows in study area. It reveals that area has treated with more sprawling characteristics.

H. Commercial Strip Development

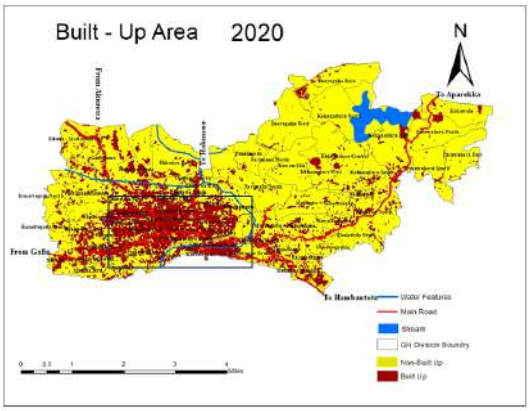

Figure 21: Commercial Strip Development in Matara DS Division 2020

The above Figure 21 highlighted area is the Matara commercial area. It contains with some road network and both sides of the road network had developed. So, it has commercial strip development and the GN Divisions are Kadawediya east, Kadawediya west,

Kadawediya south, Noope, Uyanwatta, Kotuwegoda South, Kotuwegoda North, Welegoda east, Welegoda west, Weliweriya. This commercial strip development could be cause for huge traffic problem in Matara city. Below Figure 22 and Figure 23 also shows commercial strip development in Matara DS Division.

Figure 22: Commercial Strip Development in Matara DS Division in 2020

Figure 23: Commercial Strip Development in Matara DS Division in 2020

4. Conclusion

Remote sensing and GIS prove to be are very useful tool in urban sprawl analysis. The study further shows that remotely sensed data coupled with Shannon's Entropy and Box Counting approach act as a good indicator to recognize urban sprawl. The accuracy assessment result shows accuracy of the result. It shows overall accuracy more than 80% for every year. In this study satellite imageries play a vital role in mapping and quantifying built up area. In this study, the urban sprawl in Matara DS Division was measured using Shannon's Entropy method and Box Counting method. This study reveal that urban sprawl of Matara DS Division has been increase decade by decade. Both methods confirm that urban sprawl has increased in study area because both fractal dimension and Shannon's entropy values are in error range. Because both methods show lower value in 1990(Fractal Dimension shows 1.244 and Shannon's Entropy shows 1.23). But when it comes to 2020 Fractal dimension shows as 1.648 and Shannon's entropy shows as 1.67. The findings of the study reveal that urban sprawl is a problem for Matara DS Division area. This study found that there is a close relationship between Shannon's Entropy method and Box counting method. The linear graphs of Shannon, entropy and fractal dimension, it shows same slope both methods and it talks about close relationship between both methods. Four development pattern which led to urban sprawl used to evaluate urban sprawl in study area. It shows that when it comes to 1990 there was no much sprawl characteristics and when it comes to 2020 it shows high sprawl conditions because in 1990 there were only one development pattern and in 2020 it had four development patterns. Scattered development shows in 1990 near Matara city. Other development patterns didn't show in 1990.When it comes to 2000 urban area expanded outward from the Matara city and it shows commercial strip development and scattered development. When it comes to 2010 the GN divisions around the Matara city has fully urbanized and the urban edges has expanded further more outward from the city with scattered development and near city shows commercial strip development and the GN Divisions are Kadawediya east, Kadawediya west, Kadawediya south, Noope, Uyanwatta, Kotuwgoda South, Kotuwegoda North, Welegoda east, Welegoda west, Weliweriya. when it comes to 2020, scattered development, commercial strip development and low-density development shows in study area. But leapfrog development could not be showed in study area. The commercial strip development could be cause for huge traffic problem in Matara city. The GN Divisions, Isadeen town, Kadawediya east, Kadawediya west, Kotuwegoda North, Kotuwegoda South, Mathotagama, Noope, Uyanwatta, Uyanwatta North, Welegoda east,

Welegoda west, Weliweriya east, Weliweriya west GN Divisions have identified as high sprawl GN Divisions. The development patterns also used to identify sprawl in study area and they are very effective.

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