A TIME SERIES SPATIAL ANALYSIS ON URBAN RESILIENCE

P.A.K.R. Lakshani[1] and D.R. Welikanna[2]
[1]Department of Remote Sensing and GIS, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka, Belihuloya, Sri Lanka.
Email: kalanirandima3@gmail.com
[2]Department of Surveying and Geodesy, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka, Belihuloya, Sri Lanka.
Email: dre@geo.sab.ac.lk

KEY WORDS: Urban area, Resilience, Linear Unmixing, Adaptive capacity, Vulnerability

ABSTRACT: Investigating naturally occurring phenomena spatially using a single time frame is a task that lacks true potentials. This lack of promise in the whole modeling process is promoted by the nature of the natural phenomena (ex, Cyclones, Landslide, Rainfall) to be analyzed and its temporal frequency. One significant global parameter that estimates the ability of structural entities to withstand against the damages is known as the resilience. This is mainly a function of vulnerability and adaptive capacity. The main aim of this study is to analyze the urban resilience of Rathnapura within a time span of eleven years starting from 2003 to 2014. More concern in the study was given to the years 2003, 2008 and 2014, because flood vulnerability in the Ratnapura Municipal Council area had significant fluctuations during these years. The evaluated resilience showed there is an increment with the shrinking effect in the presence of floods when compared to the early stages. So the highlighted fact is the boost of the flood resilience in Rathnapura urban area with the time. Further the experiments were extended to see whether there is a correlation between resilient level change and the urbanization. Urbanization was parameterized by using impervious surface distribution, measured through Linear Unmixing of Landsat 7 and 8 Imagery. The analysis which was done using the probability density functions of the resilient levels and impervious surface values suggested that when the imperviousness is in the midrange the highest and the lowest resilience can be expected. This positive resilient level change experienced in Ratnapura was proven according to the recent major flood situation in SriLanka on May, 2016. Even though most of the cities which are vulnerable to the floods were affected, Rathnapura which was highly vulnerable had the chance to escape due to the growth in its resilience levels.

INTRODUCTION

Predictions based on optimistic and pessimistic hypothesis about the naturally occurring phenomena (floods, landslides, earth quakes...etc) is intricate due to its nature and temporal frequency. The increasing pressure on nature due to the consistent human commotions and other temporal occurrences has made the severity and the behavior of these phenomena acquire different facets. So the preparedness for the different phases of such situation like impact, response and recovery are vital to physical as well as human objects for their survival. Resilience which is a global parameter that estimates the ability of structural entities to withstand against damages is a one scale which is used to measure this ability of survival. The vulnerability and adaptive capacity are the key parameters of resilience, which were preferred to be addressed using spatial data in this study.

Investigating the timely changes of resilience spatially using a single time frame is a task that lacks true possibilities. So a time series spatial analysis is a vital consideration in understanding the behavior of resilience during different era. Urban land covers which occupy a very small percentage of the world total land cover, require the highest attention in terms of resilience due to its direct impact on human livelihoods. The main purpose of this study was to analyze the urban resilience of “Rathnapura” area in Sri Lanka which is located in the river basin of “Kalu Ganga”. This is naturally a flood plain, which is identified as a high risk zone by Disaster Management Centre, SriLanka and frequently visited by floods. The years of 2003, 2008 and 2014 were more focused in this study because of the crucial alterations of resilience in the study area during this period.

There are many studies based on assorted scopes of resilience, vulnerability, adaptive capacity, exposure and sensitivity (Barkham, 2016; Cutter, Burton and Emrich, 2010; Launch of Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, 2012; University of Moratuwa, 2012). But very few are more interested in understanding the conduct at a very local level than a big community like metropolitan areas. In understanding the heterogeneous manner of resilience, addressing the lowest administration level is conclusive so as in this research. According to the recent records, Ratnapura Municipal Council area has recorded increasing trend of resilience towards floods which was highly vulnerable once. Vulnerability and adaptive capacity which evaluate the resilience, is not proportional or inversely proportional to time for a certain urban region. Due to the composition of the urban area as well as the reasons such as the enhancement in an urban entity against disasters can show variations in resilience along time. So in evaluation and reasoning, this research has put more weight towards correlating urban composition which is time dependent with resilience. Even though the exposure is subsiding, the sensitivity is escalating due to the climatic parameters like rainfall as shown below in figure 1.

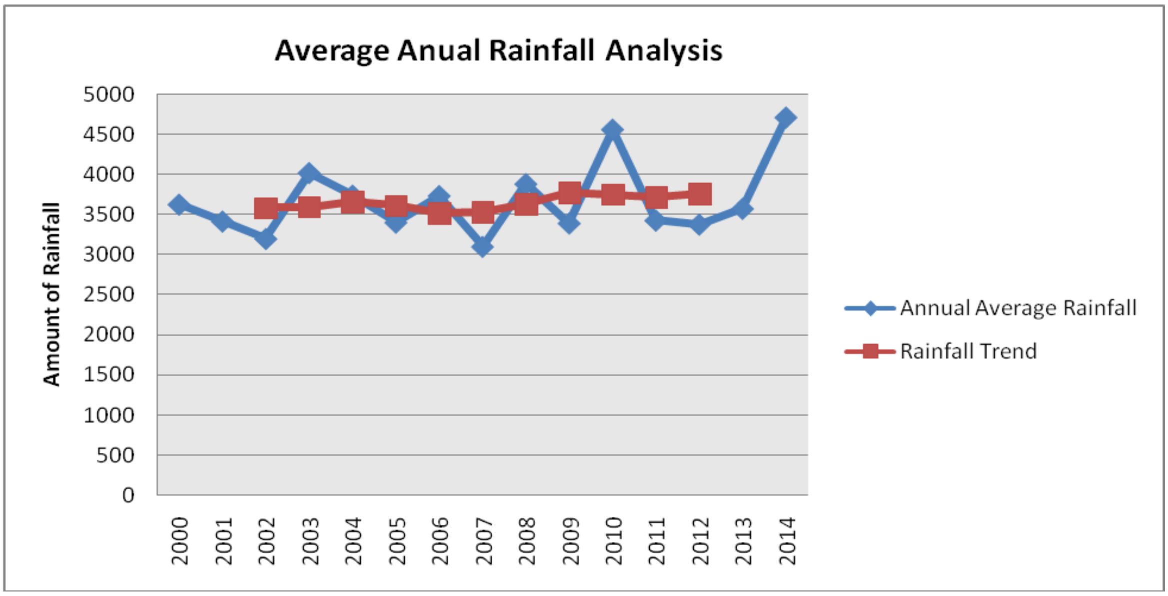


Figure 1: Average annual rainfall trend in Ratnapura area for 14 years

Hence this research experiments to see whether the urban composition of this area that has been evolved over time, has contributed to this significant change of resilience by considering the time period from the year 2003 to 2014. The outline of this paper contains introduction, study area, data, Methodology, results, conclusion and recommendations.

STUDY AREA

The focused area for this study is Ratnapura Municipal Council which is very famous for Gem mining activities. Ratnapura municipal council is the provincial capital of Sabaragamuwa province, situated 101km away from capital city along Colombo-Baticaloa high way. It is located between Northern latitudes $6^0$39' 54"- $6^0$43'30" and Eastern longitudes 80^0 22' 12"-80^0 25' 12" including a river bend of kalu Ganga at the centre of the area. Ratnapura area has become vulnerable mainly to floods due to its natural topography. The elevation of this area varies from 12m to 360m above Mean Sea Level (MSL) and it is situated in a basin surrounding a stretch of mountain ranges which triggers the starting points of the main river, streams and other water sources which flow through the area. Normally the average annual rainfall ranges between 3000mm and 4000 mm. The average annual temperature is 29.44^0C. According to Ratnapura city profile the total population of Ratnapura MC area in 2011 was 49083. Also it has a significant urban population growth rate over 1.0%. Ratnapura fosters to a diverse land use and land cover classes as shown in Table 1.

Table 1: Land use patterns of Ratnapura Municipal Council Area

Utilization	Land Extent (Hectares)	Percentage from the total land
Residential	951.2	42.9
Commercial	46.57	2.1
Industries	0.22	0.01
Administrative Institutions	88.72	4.0
High ways	117.55	5.3
Play grounds, Parks and Open Lands	22.18	1
Religious	4.43	0.2
Urban Forests / Scrubs	307.85	13.88
Cemeteries	0.22	0.01
Paddy Lands	252.85	11.4
Garden Plantations	312.73	14.1
Mixed crops / Garden Plantations	26.61	1.2
Wetlands	11.99	0.5
Water Ways	66.54	3.0
Bare Lands	8.02	0.4
Total	**2218**	**100.00**

DATA

Both spatial as well as Aspatial data were utilized in this study. Under the spatial data two Landsat satellite images were collected for the two years of 2008 and 2014. The satellite image dated 2008/11/04 was a Landsat 7 TM (Thematic Mapper) satellite image and the image dated 2015/01/08 (Figure 2) was a Landsat 8 OLI (Operational Land Imager) _TIRS (Thermal Infrared Sensor) image.

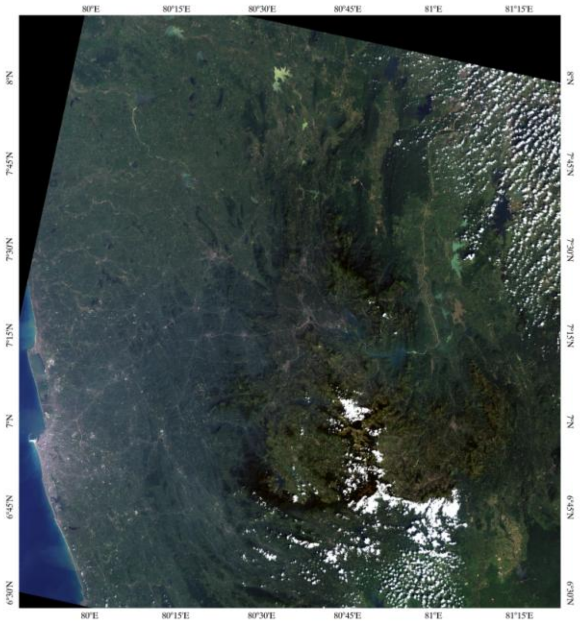


Figure 2: True Color Composite Landsat satellite image dated 2015/01/08

The secondary data was collected mainly to evaluate resilience and climatic patterns. Most of them were quantitative data. The climatic patterns were modeled by using the precipitation data and temperature data provided by the Meteorological Department, SriLanka. The main resilience parameters, exposure, sensitivity and adaptive capacity were extensively categorized on the basis of major factors affecting them. These factors are listed below in Table 2. Assigning weights for these major categories were done by considering the comments provided by the authorized officers and community.

Table 2: Major factors determining resilience

Category	**Major Factors**
Exposure	Affected number of people Affected number of families
Sensitivity	Rainfall Distance From the river Height of the area Probability of water accumulation

Adaptive Capacity	Rate of employment Percentage of houses without improvised structures Percentage of telecommunication facilities Percentage of electricity facilities Percentage of literacy percentage of safe waste disposal Quality and safety of drainage systems Percentage of permanent houses Percentage of sealed toilet facilities Percentage of pipe born water facilities Percentage of well conditioned roads

METHODOLOGY

Figure 3 below showcase the flow of the method adopted in the study. After the data collection, by using the weights evaluated for the major factors based on the Analytical Hierarchy Process (AHP) the resilience maps were generated for the three years of 2003, 2008 and 2014. Evaluation of weights using AHP was done by stressing the fact that the consistency ratio of the pair wise comparison is less than 0.1 or very close to 0.1.

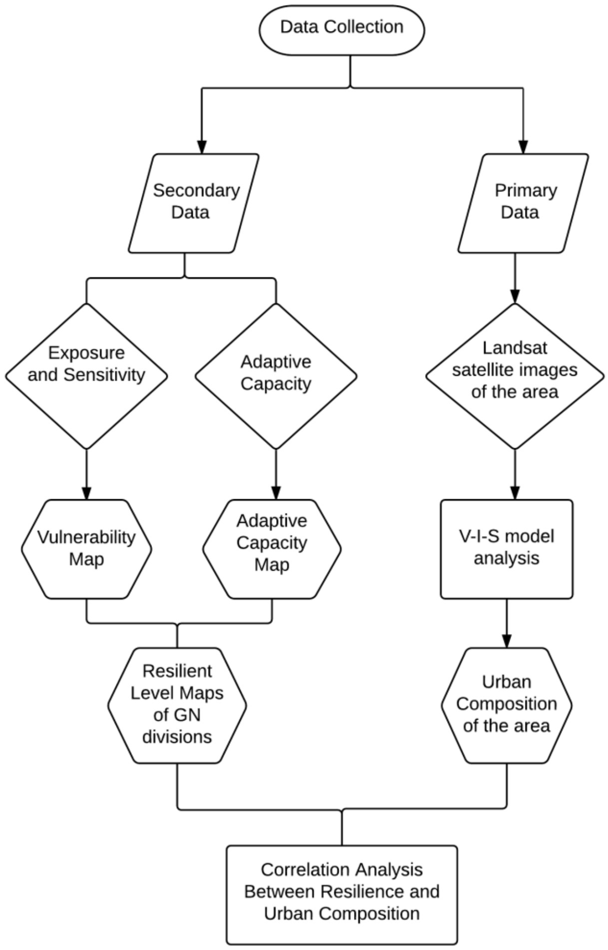


Figure 3: The adopted Methodology of the research

Table 3 shows the fundamental weighting scheme in the pair wise comparison.

Table 3: Fundamental Scale for pair wise comparisons in AHP

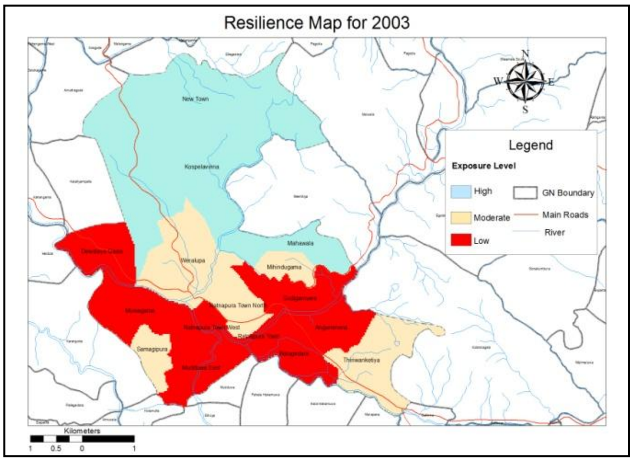
Weight/rank	Intensities
1	Equal
2	Moderately dominant
3	Strongly dominant
4	Very strongly dominant
5	Extremely dominant

In the second part of the study, remotely sensed satellite data of the study areas was used to determine the impervious surface area. Linear Unmixing Methods by using the impervious end members was used for this purpose. As the cloud coverage was a factor which hampers the accurate determination of end members it was hard to get a useful image for the year 2003. Therefore by using the images of 2008 and 2014 the impervious surface fraction along with the Vegetation and Soil fractions were determined (RIDD, 1995). Generation of distribution fittings considering the impervious surface pixel values corresponding to different resilient levels was a novel procedure in the correlation analysis between resilience and urban composition.

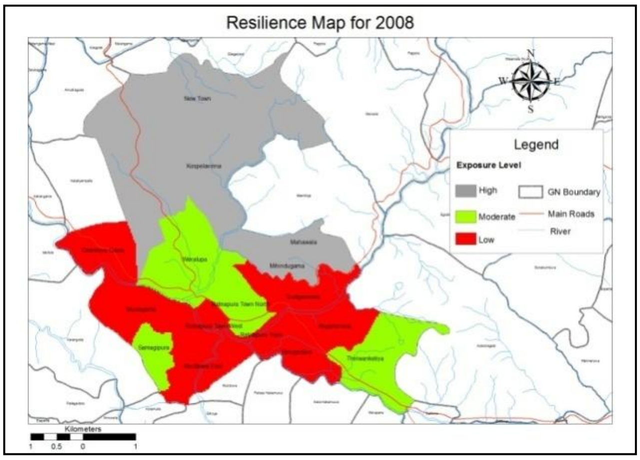
RESULTS

The main focus of analyzing the results was to derive the recent fluctuations of resilience in Ratnapura Municipal Council area and find out the relationship between resilience and urban composition. Resilient level maps of GN divisions for the years 2003, 2008 and 2014, the impervious surface abundance images and the probability density function fittings generated using the pixel values corresponding to different resilience levels were the main outcomes of this research. The resilient level maps were generated by using the vulnerability maps and adaptive capacity maps which were the key input parameters to measure resilience. This analysis was based on the presumption that a city has a strong resilience in the presence of good adaptive capacity to offset the vulnerability.

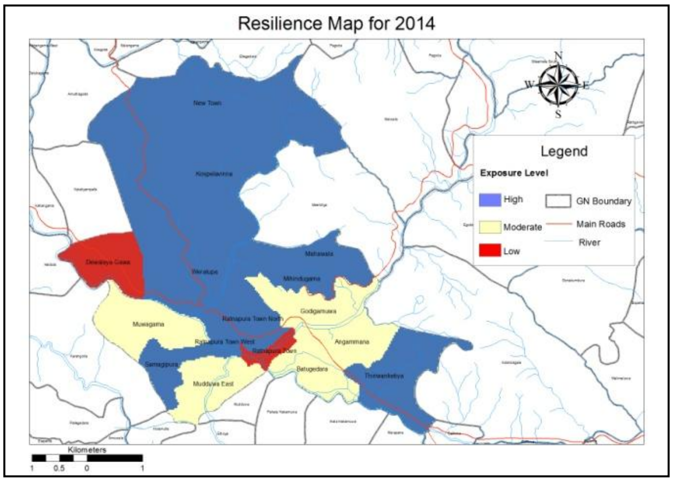
The figures (Fig.4) below represent the different resilient level maps of Ratnapura Municipal Council area for 2003, 2008 and 2014. (a) Resilience map for 2003, High Resilient areas New Town, Kospelawinna, Mahawala (b) Resilience map for 2008, High Resilient areas New Town, Kospelawinna, Mahawala, Mihindugama (c) Resilience map for 2014, High Resilient areas New Town, Kospelawinna, Mahawala, Mihindugama, Weralpa, Ratnapura North, Ratnapura West, Samagipura, Tiriwanaketiya



(a)



(b)



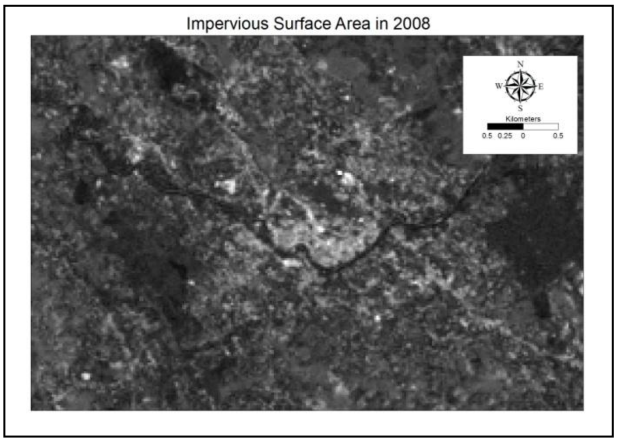
(c)

Figure 4: Resultant resilience maps for the years 2003, 2008 and 2014

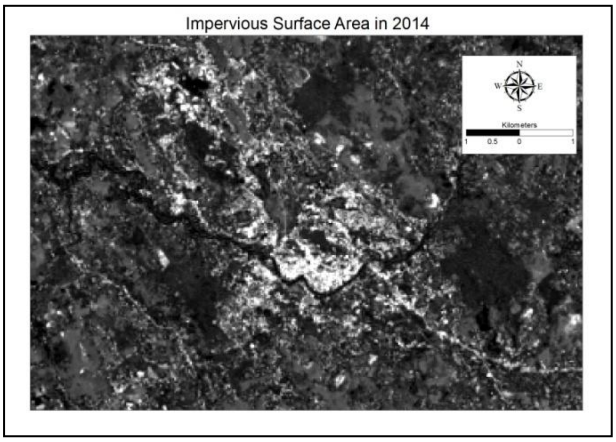
According to the resilient maps (Figure 4(a), Figure 4(b), Figure 4(c)) derived above, a complete analysis can be done for the temporal resilient level changes of the relevant areas. Here from the maps it is significant that even though there is no big disparity between the resilient levels of the year 2003 and 2008, when considering the period from 2008 to 2014, the resilience level changes have shown large variations.

New Town, Kospelawinna, Mahawala GN divisions have an explicit high resilience throughout the whole period. In addition Mihindugama, Samagipura, Weralupa, Ratnapura North and Tiriwanaketiya GN divisions have gradually increased their resilient level to high resilience. Batugedara, Godigamuwa, Angammana, Mudduwa East and Muwagama have gradually increased their resilient levels up to Moderate resilience, while Dewalayagawa and Ratnapura Town continuously maintain the low resilient level.

Most important observation here is the conversion of Ratnapura West from low resilient level to high resilient level with in a period of six years starting from the year 2008.



(d)



(e)

Figure 5: Impervious surface fraction for the years 2008 and 2014 using the Linear Unmixing of pixels

The figures (Fig. 5) above represent the impervious fractional images for Landsat satellite images in 2008 and 2014. (d) Impervious surface (Bright grey levels correspond to the imperviousness) area 2008 (e) impervious surface area 2014

In the process of generating the relationship between resilience and urban composition the impervious surface pixel value distributions corresponding to different resilience levels were analyzed graphically using the normal distribution fittings.

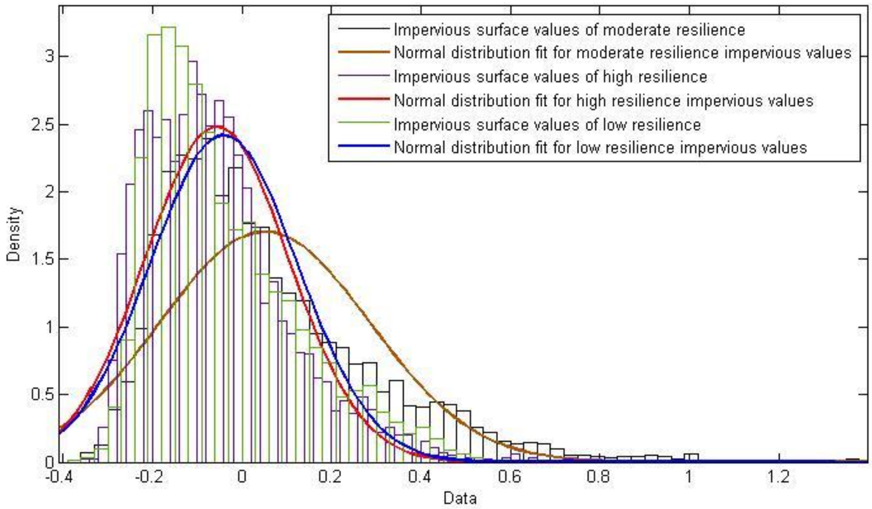


Figure 6: Normal distribution fittings for different resilience pixel values of 2008.

A detailed study about the normal distribution fittings which is denoted by figure 6 and figure 7 illustrated a set of well distributed impervious surface values with in different resilience levels. The urban expansion of Rathnapura Municipal Council area is clearly explicated in these two pixel distributions by the positive growth of the pixel distributions. Most importantly all the forms of resilience (high, moderate, low) convinced in this study occupies a majority number of impervious surface fraction in Ratnapura area.

From the plots it can be seen that when the imperviousness is in the midrange the highest and the lowest resilience can be expected. It was hard to distinguish the exact impervious value corresponding to the highest and the lowest resilience. More focused regions (resilience predicted below is for the GN divisional scale) can be analyzed further to find the exact relationship between the resilience and the urban composition.

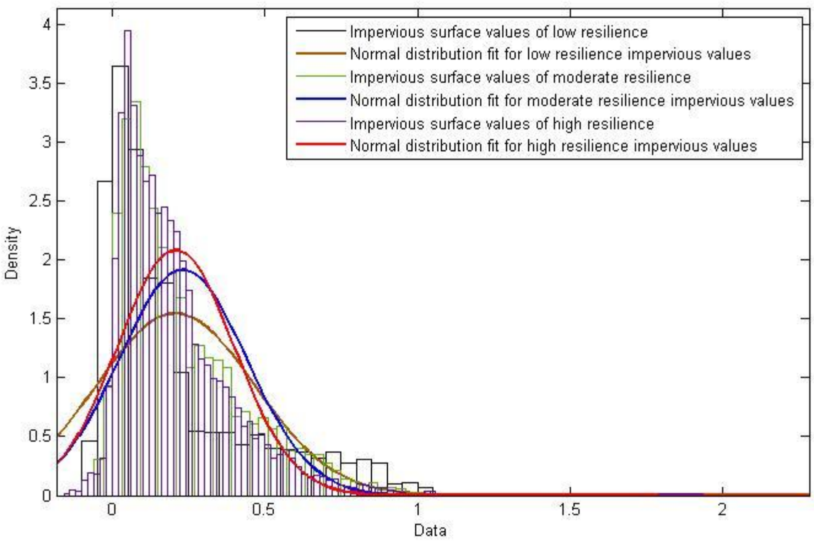


Figure 7: Normal distribution fittings for different resilience pixel values of 2014

As the findings from the secondary data suggested, the resilience has grown in the year 2014, according to the remote sensing images the number of impervious pixels has also shown a rise in the year 2014. This change in urban composition was analyzed further, based on the results from change detection using NIR, Red and SWIR bands of Landsat satellite images. The percentage of changed pixels was evaluated for three resilient levels namely high, moderate and low as shown in Table 4.

Table 4: The impervious pixel changed percentages corresponding to different resilient levels of High, Moderate and Low

	NIR (%)	Red (%)	SWIR (%)
High Resilience	1.18385902	0.191294304	2.559012488
Moderate Resilience	0.483649751	0.180466325	0.696600014
Low Resilience	0.064967877	0	0.137154407

According to the changed percentages of High, Moderate and Low resilient levels for NIR, Red and SWIR bands the highest changed percentage is recorded for high resilient level and it is gradually decreasing in the moderate and low resilient levels. This suggests that Ratnapura Municipal Council area has undergone some changes in its composition which has contributed to these significant fluctuations in the resilience.

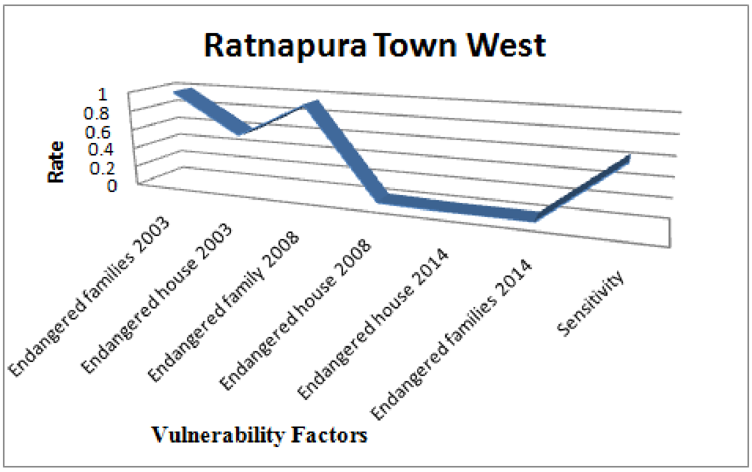


Figure 8: The rates of vulnerability factors in Ratnapura West GN division from 2003 to 2014

The Figure 8 above shows the resilient level increment of Ratnapura West GN division from 2003 to 2014 with the decrement of the rates of vulnerability factors. This situation is very similar to the other GN divisions as well. This suggests that the resilience has slight tendency to increase in the urban composition with impervious class dominance. But further studies are needed in order to suggest an accurate relationship.

CONCLUSION

Declination of resilience causes an increment of risk. According to the resilient level analysis the areas like Dewalayagawa and Ratnapura Town shows continuous low results in resilience throughout the whole period from 2003 to 2014. This means those areas have a definite risk for the future flood situations.

The resilience of the cities in Ratnapura Municipal Council area has changed like low in to moderate level, moderate in to higher level, low in to higher level while some cities are remaining in the high resilience level and low resilience level continuously throughout the period from 2003 to 2014. After finding reasons to those temporal changes in risk it was revealed that the quality and the condition of infrastructure facilities play a major role in disaster resilience.

When considering the average impervious surface values of different resilience levels (Table 5), this research shows that a country or a region will be safer if the impervious surface pixel values corresponding to high moderate and low resilience levels are biased around dominant impervious surface values. Also it would be very important if those values have less difference between each other.

Table 5: Mean impervious values for the different resilience levels of the years 2008 and 2014

	2008	2014
High Resilience	-0.0563	0.2070
Moderate Resilience	0.0511	0.2309
Low Resilience	-0.0407	0.2070

RECOMMENDATIONS

Although the resilient estimation of Ratnapura Municipal Council was done for the lowest administration unit in SriLanka, It is better if it can be improved up to the pixel level. Then all the resilience evaluation factors have to be calculated for a more focused region. In this research the exposure was calculated by using affected number of families and affected number of houses. But it is better if it can be evaluated by using social, cultural, economic and environmental damages and exposure.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude towards Municipal Council, Urban Development Authority, District Secretariat Office, Divisional Secretariat Office, Central Environmental Authority, Disaster Management Center and Grama Niladhari Officers in Ratnapura, SriLanka who provided me an appreciative courtesy in data collection and validation. Also it will not possible to complete this report without the guidance from Faculty of Geomatics, Sabaragamuwa University of Sri Lanka.

REFERENCE

Barkham, R. (2016). Resilient Cities. A Grosvernor Research Report. Grosvernor, pp.1-18.

Cutter, S., Burton, C. and Emrich, C. (2010). Disaster Resilience Indicators for Benchmarking Baseline Conditions. Journal of Homeland Security and Emergency Management, 7(1).

Launch of Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. (2012). Int J of Dis Res in the Bu Env, 3(1).

RIDD, M. (1995). Exploring a V-I-S (vegetation-impervious surface-soil) model for urban ecosystem analysis through remote sensing: comparative anatomy for cities†. International Journal of Remote Sensing, 16(12), pp.2165-2185.

University of Moratuwa, (2012). Cities and Climate Change Initiative Negombo, Sri Lanka: climate change vulnerability assessment. climate change and vulnerability assessment. Negambo,SriLanka: UN-Habbitat, pp.1-3.