Spatial analysis of urban growth based on city center and central business district (a case study of Antananarivo, the capital city of Madagascar)

A Fetraiaina, A Deliar and A B Harto

Department of Geodesy and Geomatics Engineering, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung, 10 Ganesha Street, Bandung, Indonesia

Abstract. The use of historical and present spatial data in urban growth analysis has been considered as a fundamental prerequisite in urban geographical studies, future planning and implementation of city development policies. In the current study, a comparative analysis of urban growth based on city center and central business district (CBD) of Antananarivo, the capital city of Madagascar was carried out. Four temporal satellite images of 5 years interval were used to determine the pattern, the process and general conditions of expansion of the urban extents in different directions. Pearson’s chi-square test and Shannon’s entropy measure were used to evaluate the degree-of-freedom and degree of sprawl towards the analysis of urban growth. To combine the previously mentioned statistics, the degree of goodness was used. The comparative analysis shows that there are contradictive results in the derived statistical measures from both considered urban growth centers indicating different conditions of urban growth. Deeper analysis accompanied by the theory of Von Thünen on urban land use support that the CBD is the most appropriate center of growth for the application of the previously mentioned statistical measures for the case of Antananarivo city.

1. Introduction

Urban growth can be seen as the process of developing urban centers. As a global process, urban growth involves a wide range of concepts and has various implications. Attempts to deal with its varying implications have been made from the view of recent social and economic history. Over the last two centuries, the expansion of large cities has been observed along with the growth of space on their adjacency [1]. The review of the relevant literature has shown that the growth in urban land cover generally has various ramifications such as betterment in both security and quality of residences, increase of employment opportunities as well as economic growth. In addition, increase of environmental degradation and disruption of the natural ecosystem, environmental pollution, loss of natural resources, and informal settlement were also documented. Finally, deforestation and food scarcity have also been reported as emerging issues [2,3]. Moreover, literature review highlighted that the state of being uncontrolled and dispersed of urban growth has generated large social focus hindering regional sustainable development. Since recently, those conditions of urban growth have become a big concern [4,5], especially in developing countries, such as Madagascar. Consequently, across previous literatures, it has been noted that researches focusing on urban growth has been carried out worldwide dealing with many aspects of the phenomena. Briefly, they cover the
pattern, the process, the cause and consequence of urban growth [6]. In the analysis of the growth of cities, two aspects of urban development are taken into account which are the pattern and process so that an understanding of the fast-changing urban landscape. Pattern of urban land-use refers to the spatial configuration of a metropolitan area in a temporal instant and process refers to the change in the spatial structure of cities over time.

The studies focusing on the process, the pattern, and the overall conditions of urban growth have been done by referring on one hand on city center (CC) [7] and on the other hand, on central business district (CBD) as central places of growth [6]. Particularly, the current study is focusing on a comparative analysis of the process, the pattern, and the overall conditions of urban growth by taking into account both the CC and CBD as center places of growth. However, in this study, simulation of urban growth in the future as well as the causes and consequences of various types of growth of urban boundaries, will not be dealt with. In addition, the analysis of the effects of changing land use during the past periods and the environmental impacts, which might be caused by the process of transition of these changes are will not be addressed either.

2. Study area location

Antananarivo, the capital and largest city of Madagascar is situated approximately at 1,280 m above sea level in the central highland region of Madagascar. The study area is located between the latitudes of 18°44’29” S to 19°06’20” S and the longitudes of 47°20’07” E to 47°43’45” E, covering an area of approximately 1683.05 km² including 2 Regions and 6 districts (See Figure 2.1). Demographically, it continues to form the majority of the city's estimated 1,300,000 inhabitants [8], as well as the surrounding urban areas which in all have a total metropolitan population approaching 3 million. The pillar of Madagascar economy is mainly relying on agriculture. Antananarivo contains a high proportion of Madagascar’s GDP which account for about 13% of it. Overtaxed infrastructure has been struggling to cope with the capital’s ever-expanding population, and urban planning has not kept pace with the city’s growth. Like any city constructed in the hills, Antananarivo’s space for expansion is significantly restricted. Aside from geographical considerations, the city is repeatedly prone to flooding in rainy seasons. Unregulated construction, haphazard parcelling of land, inefficiency of drainage system are mostly the major culprits in the city’s flooding problems. A well-concerted policy on means and coordination of efforts, effective urban planning has been needed to address such issues [9,10].

Figure 1. Location of study area

Figure 2. Displacements of the Built-up area gravity centers relatively to city center and CBD
3. Data and methodology

In the analysis of urban growth of the city, the following 4 years interval temporal satellite imageries covering the latest urban boundary were considered: Landsat 7 ETM image of April, 16th 2002, Landsat 5 TM image of August, 30th 2008, Landsat 8 OLI image of August, 12th 2013, Landsat 8 OLI image of June, 23rd 2018 (All have path 159 and row 073). Additionally, vector data of administrative boundaries (Region and district boundaries) were also used.

In the analysis of process of changes, the CC and the CBD were considered as the central places of growth of the city. CC is the center nucleus formation of the city in the ancient times while CBD is defined as the commercial and business center of a city also known as financial district. Geographically, they may coincide with each other but for the case of the city of Antananarivo, they are not. Each considered center of growth is identified by a circle, which is inscribed in the city in a way that the contiguous urban pixels are fully inscribed. The inscribed circle is partitioned into N equal sectors, forming N different directions, and covering the scope of the study from the considered center of growth of the city. This division is needed so that the process of changes in construction in different parts and directions could be statistically compared. The city expansion rates in different parts and directions are different along time. Therefore, the boundary under study is circular as opposed to using the conventional administrative boundaries.

![Research flow diagram](image)

**Figure 3.** Research flow diagram.

To attain the purpose of this study, multi-temporal Landsat satellite images were classified in order to differentiate urban from non-urban land use classes by means of maximum likelihood classifier. Classification accuracy assessment was performed for all classes. Particularly for the built-up class, a total of 890 pixels were used for each image. Overall accuracies of 93.50%, 91.18 %, 92.03%, and
94.08% were obtained for the 2002, 2008, 2013, and 2018 images respectively which can be stated as almost perfect and able to be used for further studies. The built-up areas (urban land use class) needed to be extracted zone-wise in order to form built-up area matrixes. The resulting built-up area matrixes were further used to achieve the research purpose as mentioned previously.

4. Results and analysis

4.1. Data processing based on city center and CBD

The study area was subdivided into 8 different directions in accordance to the research methodology. On one hand, the study area was subdivided based on city center as center of growth and on the other hand based on the CBD (Figure 4.1). The city center is located at the geographical location (18°55′25″S, 47°31′56″E) which coincides with the Kingdom palace Manjakamiadana, from where the city was built around the 17th and 18th century. The CBD is located at (18°54′21″S, 47°31′33″E). A circle having a radius of 20.45 km was drawn around the city center while for the CBD, it was 18.52 km. The circles were drawn so that the contiguous urban pixels remain included within the scope of study area.

4.2. Urban extent

The satellite image classification and feature extraction into built-up area (along with impervious area) and non built-up area for the 4 temporal instants gave the creation of abstracted and highly simplified visual images of the study area (Figure 4.1) illustrating the urban extent of specified time. The classified images indicate the presence of sprawl varying in size and directions. Such patterns can be understood intuitively, but they do not provide solid evidence for debating and deciding the future. To intelligently describe these different patterns, to understand their evolution over time, to compare each zone with others or to explain the statistical variations between these patterns, it is recommended to gain advanced understanding by means of various quantitative criteria for measurement.

4.3. Urban area and urban growth

The percentage of areas covered by impervious surfaces such as asphalt and concrete is an effective and straightforward measure of urban growth [11]. It is safe to assume that developed areas have a higher proportion of impervious surfaces than less developed areas [12]. Table 4.1 illustrates the zone wise built-up areas per time span, which directly specifies the conditions of the built-up areas across the city. For a better understanding, urban growth variation trend matrixes are shown in Figure 4.2 (Radar Chart). Table 4.1 and Figure 4.2 altogether contain the general information about the variation trend of the built-up areas. Urban growth rate can be calculated from Table 4.1. For the case of CC model, the urban

![Figure 4](image-url)
growth rate is falling gradually with the highest value of 171.45% and the lowest value of 9.81%. Even though the finding suggests an overall decrease of urban growth rate, it should be noted that a reduction of urban growth rate over time does not necessarily show any regular compression and suitable urban sprawl and development of the city. Therefore, the need for further analysis is evident.

Table 1. Zone wise built-up area (in hectares).

| Year | N    | NE   | E     | SE    | S     | SW   | W    | NW   | The city |
|------|------|------|-------|-------|-------|------|------|------|----------|
| 2002 | 628.50 | 235.32 | 68.47 | 31.18 | 124.90 | 83.67 | 278.26 | 559.52 | 2009.82 |
| 2008 | 938.50 | 442.04 | 175.12 | 84.64 | 273.31 | 168.78 | 559.88 | 890.48 | 3532.75 |
| 2013 | 1234.81 | 640.92 | 296.35 | 156.62 | 444.62 | 281.41 | 850.30 | 1163.90 | 5068.93 |
| 2018 | 1356.06 | 734.02 | 333.28 | 190.18 | 527.03 | 331.25 | 955.30 | 1306.31 | 5733.49 |

For the understanding of the different properties of urban growth, its discrepancy, there is the need to evaluate the observed and the expected growths. The observed growth urban land cover is the amount of urban growth in between two observation times. The theoretical expected urban growth can be estimated statistically by the products of the special time span of the analysis by the defined zone and dividing it by its total sum in the observed growth matrix [13]. It should be noted that expectations have been derived statistically because the analysed city has not had pre-defined planning policy and therefore there are no such expectations. Nevertheless, it can be observed that the available lands for development for each zone are uneven. So, if the city implemented the right planning policy and had the expected growth that had been pre-determined, such statistical approach should be adopted in this study.

4.4. Pearson’s chi-square statistics and urban growth

The Pearson’s chi-square distribution employs the freedom amongst variable pairs to explain the change in LULC within the same class [13]. It illustrates the freedom or degree of deviation of the observed urban growth over the expected urban growth. For each time span, the Chi-square statistical measure ($\chi^2$) was computed, and results are displayed in Figure 5.1.a (In blue colour for the CC model, and in red colour for the CBD model). By analogy, the results for each zone are shown in Figure 5.1.b. The chi-square has a lower limit of 0 when the observed value exactly equals the expected value. For the CC model, Figure 5.1.a shows that the degree-of-freedom are high (i.e. dissimilarity in observed and expected values) for the three temporal spans. Figure 5.1.b shows that freedom is low (i.e. observed and expected values are similar) for NE whereas it is very high for SW and NW.

The degree-of-freedom is indicative of the freedom of the variables. In the case of high deviation, the desired variable is independent of other similar groups of variables. Although there are only four
temporal instants in the analysis, 3 temporal gaps and so only one degree of independence can be identified. Considering additional temporal instants in the analysis can give more insights on the independence of variables [14]. Specifically, for this study, there is the lack of such additional data. High degree-of-freedom in a zone indicates unsustainable development in the desired zone over time and high degree-of-freedom for a defined time span indicates diversity and variability of urban growth in high scale. However, it is necessary to note that high degree of freedom cannot be regarded as urban sprawl, instead it should be considered as disparity in growth as a process and/or pattern.

4.5. Shannon’s entropy and urban growth

The Shannon’s entropy is considered as a well-accepted method of pattern determination and process of the sprawl formation of cities along time [5, 12, 15]. In this study, the Shannon’s entropy for each time span ($H_i$) has been computed from the information contained in urban growth rate table derived from Table 4.1. The degree of sprawl in this case is derived from the entropy value, which falls within the limit $0 \leq x \leq \log_e(m)$. At 0, the built-up distribution is said to be compact, while sparse distribution rises with increasing divergence from zero. However, where the entropy value is below half of $\log_e(m)$, it can be argued that the city has no chance of sprawl. Figure 5.2.a illustrates that the attained entropy for each timespan is greater than half of the index $\log_e(m)$ for both models. As such, one can conclude the city has undergone a sprawl during the study period. By analogy, in Figure 5.2.b, the same observation is noted for each zone but $m$ (number of zone) is substituted by $n$ (number of timespan).

4.6. Degree of goodness

The Chi-square model (degree-of-freedom) and the Shannon entropy model (degree of sprawl) are different measures and which may contradict with each other in some cases. Due to that, it is vital to determine the ‘degree of goodness’ of urban growth. The degree of goodness ($G_i$) actually refers to the degree at which the observed growth relates the expected growth and the magnitude of compactness (unlike sprawl). It is a straightforward measure. Positive values indicate ‘goodness’ whereas negative values indicate ‘badness’. For each timespan and each zone, the degree of goodness are shown in Figure 5.3.a and Figure 5.3.b respectively. Analysis shows that during the time span 2002-2018, the city has not experienced ‘goodness’ in urban growth for both models. Although, for the city center model, N and Ne zone have shown positive values, however, for the CBD model, high positive values can be seen in S, SW, and W direction. The overall goodness is even worse.

5. Analysis

In this part is going to be performed a comparative analysis of urban growth by considering on one hand the city center and on the other, the CBD as centers of growth of the city of Antananarivo. In addition to that, there will be discussions related to data processing as well as the results.

5.1. Comparative analysis of degree-of-freedom, degree of sprawl, and degree goodness

A comparative figure of the degree-of-freedom for each temporal span is visible in Figure 5.1.a. The trends of the degree-of-freedom for both considered urban growth centers as they are represented by the two lines (with equations) show a divergence of conditions of growth. Viewed from the center, the disparity of urban growth is continuously remaining high, which is not favorable for the sprawl of urban growth and thus for sustainable development of the study area in general. However, the decreasing trend of degree-of-freedom for the case of CBD illustrates a favorable condition for the sprawl of urban growth and thus for the sustainability of growth of the city over the time of study.
Concerning each zone, Figure 5.1.b shows that the shift of the chosen center of growth is remarkably affecting the patterns of degree-of-freedom. There is a quasi-incoherence since high contrast of magnitudes is observed for each zone. The highest degree-of-freedom is spotted in the NW zone for the CC model while it is spotted in the NE zone for CBD model.

A comparative figure of the degree of sprawl for each temporal span is visible in Figure 5.2.a. For both CC model and CBD model, the comparative figure shows high degree of sprawl over time (beyond the standard \(\log_e(m)/2\)), and which have stationary trends along time. So, it illustrates coherence in the intensities of sprawl as well their tendency. Such stationary behavior gives evidence that the city continues to be highly sprawling independently of the location the growth is observed from. Similarly, for each zone, the degree of sprawl is beyond the standard \(\log_e(n)/2\) (See Figure 5.2.b). Their magnitudes are included in between 0.75 and 0.95 for all zones, signifying that each zone is highly sprawling. The overall degrees of sprawl are all also higher than the standard for both city center and CBD models (2.89 for the CC model and 2.98 for the CBD model).

A comparative figure of the degree of goodness for each temporal span is visible in Figure 5.3.a. It shows that for both models, the degrees of goodness are all negative, showing badness of urban growth. Such fact illustrates that the city has not experienced compression of urban areas along study time. That can be interpreted as independently of the chosen center of growth, the growth of the city does not manifest goodness thus less favorable to sustainable development. The overall degrees of goodness are all negative for both CC and CBD models (-2.93 for the CC model and -2.58 for the CBD model), which support the fact of unsustainability of development of the city.
The trends of the degrees of goodness for both considered urban growth centers show a divergence of behaviors (Figure 5.3.a). The trend of degree of goodness is increasing for the CBD model, meaning the city area is described as getting compressed over time, which is a good condition for sustainability of development of the city. However, for the CC model, it is remaining worse, and stationary over time, meaning no sustainable development can be observed.

Taking into account the comparative analysis of above, it can be concluded that the conditions of growth are at some point incoherent and contradictory. Thus, in order to define the most appropriate conditions of growth of the city, there is the need to estimate the most suitable center of growth of the city. Such approach will be addressed in the discussion part of this work.

5.2. Direction of development of urban areas

The displacement of the center of gravity of urban area (centroid of built-up area) for each observation time was analyzed. In doing so, the locations of the centroids of urban areas were determined. The centroids’ locations are displayed in red point, green point, yellow point, and blue point within the ellipse for the year 2002, 2008, 2013, and 2018 respectively. Figure 5.4 illustrates that they are moving in the NE direction referring to the city center, meaning that the city has been developed in that direction along the study time. Generally, the average speed of the centroids was found to be approximately 26.66 meters/year. The motion of the centroids of urban areas in the NE direction of the study area may be explained by some reasons. The geographical condition of the study area allows to observe undevelopable lands mainly composed of paddy fields in the valleys in the North zone, North-West zone, and East zone which slow down the expansion of urban areas in those directions. Besides, the CBD is located closer to the NE zone. In the Von Thunén’s theory of urban land use, urban land users (commercial users, resident users, etc) tend to secure land parcels around markets and commercial centers (as an example of CBD) in order to benefit of the easy accessibility to such places [16]. So, for such reasons, urban areas in the NE zone have thrived remarkably.

6. Discussions

In the current study, better results could have been achieved in the condition that smaller temporal gap images were considered. More or less divisions than in this study could have been taken into account in order to get a better insight of the city urban growth. There is the assumption that the potential of growth is the same in all directions within the circular area since it does not consider other variables that may cause uneven growth (property of land, commercial centers, road networks, past policy, etc) Apart from a circular area, other limits could also have been considered such as natural limits, city extent, administrative boundaries. The ongoing research model does not directly depend on how the study area has been considered or subdivided neither on the number of divisions. Clearly, higher number of divisions allows the possibility of more detailed analysis and results in greater reliability.

The simplified approach for the analysis of urban growth pattern may lead to a number of critics. They may be the non-consideration of other variables as previously mentioned as well as socio-economic variables such as education, income per household, type of residential areas which are not accessible temporarily for the study area. Nevertheless, it is reminded that in developing countries, city growth is
accompanied with unplanned development initiatives in opposition to industrialized countries. Thus, the proposed approach is most suitable for developing countries. For industrialized countries, most of the cities have well-defined policies for urban growth and policy variables need to be considered in the estimation of expected growth. In many cases, cities do not have historical data on urban development. So, the application of spatio-statistical models appears to be not feasible. In most cases, there is the need of simple analytical approach that requires a minimum set of data input. The demand for simplicity comes from this point of view and it goes without saying that the proposed approach will be very useful in terms of simple methods for extracting historical data from satellite images and in terms of statistical analysis.

For each direction, the different properties of growth in terms of growth rate, disparity of growth, urban sprawl, and compression of urban areas could be extracted and used for deeper analysis. Analysts might need such information for assessing how a given policy works for each direction, for finding any hindrance to urban area expansion and so on. The different properties of growth were considerably affected by the shift of the considered center of growth leading to uncertainty in the observed phenomena. The trend of degree of goodness increases for the CBD model, meaning the city is described as getting compressed over time, which is a good condition for the sustainability of development of the city. But, for the CC model, a totally different fact can be observed since the trend of the degree of goodness remained worse, and stationary over time, meaning the city is found to be expanding in an unsustainable way. Such incoherence is significant since the most suitable description is needed which may help local administrators and planners to understand the past, the present in order to plan and prepare for the future. Due to the previously mentioned incoherence, the most suitable center of growth used to observe the growth of the city of Antananarivo need to be estimated.

It was found that the centroids of urban areas during the successive observation times were located nearer to the CBD (1.60 km) rather than the city center (3.58 km). It is also shown in Figure 4.2 that the spatial distribution of urban areas is in a higher degree more evenly balanced for the case of CBD model while it is obviously unbalanced for the case of CC model. The CC has been built upon hills which has limited its expansion down to the lower parts surrounding the hills mostly due to geographical constraint (steep slopes). However, the CBD is located away from the foothills in the North West direction and seems to be a more favorable location for promoting the expansion of the city. Moreover, Von Thünen location theory applied to urban land use shows how market processes can determine the urban land use pattern in different locations. In this theory, the market center is considered as the city core and all urban users (commercial users, residential users, etc) have the preference to occupy sites closer to the market center to benefit of the easy accessibility. Due to the competition to secure sites nearer to the market center, land values decline with increasing distance from the market center [19]. Particularly for the case of the city of Antananarivo, the market center is nothing but the CBD of the city. The CC, which has been established in the ancient times at the location of the kingdom castle Manjakamiadana has become an emblematic location where commercial and business activities could not continue to thrive any further due to restrictions mostly the geographical conditions. Considering the above-mentioned analysis, it can be estimated that the CBD is the most suitable location as center of growth in the application of the statistical measurements which were used in this study.

Lastly, the degree of goodness as an indication of sustainable development can be debated and assessed in terms of methods of measuring sustainability based on empirical evidence. In the sustainability measures, there is no hesitation that the general expectation is a lower degree of freedom and lower degree of sprawl. Since the degree of goodness is based on two variables: observed and expected growth variables, this method is introduced as a direct measure of urban growth. In depth analytical research would explain the correlation between degree of goodness and sustainable urban growth. Detailed discussion about sustainable development is not within the scope of this study. In reality, sustainable development is seen as a multilateral process which takes into account the
development of all the effective aspects of human and creatures’ lives [17]. In that sense, it resolves the conflicts between various competitive objectives involving the simultaneous pursuit of economic welfare, environmental quality and social equity. Hence, it is a continuous and evolving process. The process of achieving sustainability is very important and serves as a means of reaching the destination (desired future state). However, the trend of sustainable development is not a sure process. Instead, this is a multidimensional set based on interactions between system features and specifications in the future. Thus, it is obvious that the model of goodness does not have the ability to directly determine sustainable development. Rather, there is a possibility that the degree of goodness model can be converted into one definite index of sustainable development. Yet, before drawing such conclusion, it is recommended to make a correlation between the two to determine its reliability.

7. Conclusion and recommendations
The current study was intended to perform a comparative analysis of urban growth by considering on one hand the city center and on the other hand the CBD as centers of growth of Antananarivo, the capital city of Madagascar. Several statistical models were applied for studying the urban growth as a process, pattern, and the overall condition as well. The comparative analysis shows that there are contradictive results in the derived degree-of-freedom and degree of goodness from both considered urban growth centers indicating different conditions of urban growth. Further analysis accompanied by the Von Thünen’s general theory of urban land use supported that the CBD is the most appropriate center of growth for the city of Antananarivo in the application of the statistical measures used in the current study. Therefore, the city has had a high degree-of-freedom, and has sprawled as well. The sprawling tendency remained quasi-static while the degree-of-freedom tendency was decreasing. The degree of goodness was found to be inappropriate but it was increasing along time which implied a compression of urban area over time thus favorable condition for the sustainability of development of the city. The city of Antananarivo was found to be expanding in the North East direction. The proposed models can be useful tools for identifying urban growth patterns and their general tendencies. The models shown in the study have been devised experimentally and not presented by the strong theories which are limited to a special zone. Therefore, they can be easily applied in other cities which have spatial and attribute data from the past and present, particularly the developing countries. Such study would be helpful for the local authorities and proponents in terms of guiding future planning, policy-making, and for debating. Lastly, a new hypothesis, which can be put forward based on the analysis in the study, is that the degree of goodness model can be regarded as a sustainable development index and constitutes a vital tool to future researchers which still need deeper studies. Also, higher resolution data (temporal resolution, spectral resolution, spatial resolution, and radiometric resolution) are recommended in order to get more detailed information of urban growth in a given study area.

8. References
[1] Clark D 1982 Urban geography: An introductory guide Taylor & Francis p 231
[2] Muniz I, Calatayud D, Garcia M A 2007 Sprawl causes and effects of urban dispersion Indovina F (Ed.) The Low-Density City Diputacio de Barcelona (cord) Barcelona pp 307–47
[3] Iqbal M F, Khan I A 2014 Spatio-temporal land use land cover change analysis and erosion risk mapping of Azad Jammu and Kashmir, Pakistan, Egypt. J. RS. Space Sci. 17 pp 209–29
[4] Al-Awadhi T 2007 Monitoring and modeling urban expansion using GIS and RS: Case study from Muscat, Oman Proceedings of Urban Remote Sensing Joint Event pp 11–13 April 2007 Paris France
[5] J A V, Pathan S K, Bhanderi R J 2007 Spatio-temporal analysis for monitoring urban growth - a case study of Indore city Journal of Indian Society of RS 35(1) pp 11–20
[6] Bhatta B, Saraswati S, Bandypadhyay D 2010 Quantifying the degree-of-freedom, degree of sprawl, and degree of goodness of urban growth from remote sensing data Applied Geography 30(1) pp 96–111 https://doi.org/10.1016/j.apgeog.2009.08.001
[7] Dadras M, Shafri H Z M, Ahmad N, Pradhan B, Safarpour S 2015 Spatio-temporal analysis of urban growth from remote sensing data in Bandar Abbas city, Iran Egyptian J. of RS. and Space Sci. 18(1) pp 35–52 https://doi.org/10.1016/j.ejrs.2015.03.005
[8] Donque G 1968 Les Problèmes fondamentaux de l’urbanisme tananarivien Revue de géographie 13 (Juillet-décembre 1968) pp. 7–56 Available at: http://madarevues.recherches.gov.mg/?Les Problemes-fondamentaux-de-l-urbanisme-tananarivien (Accessed: 25 February 2019)

[9] Madagascar en chiffre - INSTAT Madagascar 2013 Available at: https://www.instat.mg/madagascar-en-chiffre/ (Accessed: 25 February 2019)

[10] Nanjala Nyabola 2015 Antananarivo: A city of contradictions New African Magazine Available at: https://newafricanmagazine.com/news-analysis/long-reads/antananarivo-city-contradictions/ (Accessed: 25 February 2019)

[11] Barnes K B, Morgan J M III, Roberge M C, Lowe S 2001 Sprawl development: Its patterns, consequences, and measurement A white paper Available from Towson University

[12] Sudhira H S, Ramachandra T V, Jagdish K S 2004 Urban sprawl: metrics, dynamics and modelling using GIS Int. Journal of Applied Earth Observation and Geoinformation 5 pp 29–39

[13] Almeida C M, Monteiro A M V, Mara, G, Soares-Filho B S, Cerqueira G C, Pennachin C S L, et al. 2005 GIS and remote sensing as tools for the simulation of urban land-use change Int. Journal of Remote Sensing 26(4) pp 759–74

[14] Bhatta B 2009 Spatio-temporal analysis to detect urban sprawl using geoinformatics: a case study of Kolkata Proc. of 7th All India Peoples’ Technology Congress pp 434–42 Kolkata 06 - 07 February Forum of Scientists, Engineers & Technologists

[15] Li X, Yeh A G O 2004 Analysing spatial restructuring of land use patterns in a fast-growing region remote sensing and GIS Landscape and Urban Planning 69 pp 335–54

[16] Harvey R O, Clark W A V 1965 The nature and economics of urban sprawl Land Economics 41(1) pp 1-9

[17] Hasna A M 2007 Dimensions of sustainability Journal of Engineering for Sustainable Development: Energy, Environment, and Health 2(1) pp 47-57