REMOTELY SENSED URBAN COMPACTNESS INDEX OF ULAANBAATAR (MONGOLIA) AND TONG LIAO (INNER MONGOLIA, CHINA)

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Abstract：

Urban area expansion and land use change are mostly direct and indirect result of the driving force of economic and social changes in country or region. There are no significant places like Mongolia and China, where unexpected rate of urban expansion has occurred over the 50 years. Urban expansion generally leads to an increase in motorized transport, air, water and noise pollution, energy consumption, a loss of agricultural land and a reduction of biodiversity. Information on existing urban sprawl metrics and the course of land use change is essential for urban planning as a "crucial clue". Through the example of remote sensing data measurements in Ulaanbaatar and Tong Liao city footprint, this paper will illustrate how urban compactness metrics and Landsat and BlackBridge satellite imagery could be used effectively on urban planning strategy. Remote sensing method changes urban analysis more convenient and their results more vivid than early manual conventional measurements. Urban footprint total area and compactness index (C index) were identified, based on urban map layers with had been extracted from satellite imagery over the period from 2000-2010. In addition, previously processed on-site survey data had been used for more precise delineation of built of area, with are series of cadastral map and time series land use planning data's in National Land Information Database. Compared analysis of cities represents forms and structural changes of the urban expansion between 2000-2010 in Ulaanbaatar (Mongolia) and Tong Liao (Inner Mongolia, PRC) whereas, unplanned city compared to strict planned one. Calculated C index analyzed by combining two terms of urban external shape, urban morphology to be implicit thematic urban shape and structure changes. The compactness index is broadly accepted application of urban study particularly in urban sprawl and we use it like as a significant method. The urban shape of Ulaanbaatar is relatively not compact and leap frog and strip development is main reason to it. The C index of Tong Liao has been increasing slowly and the parameter characteristics of territory boundary are relatively compact and regular, which suggests that strict planning and land administration avoids negative urban expansion. Study has demonstrated that the GIS analysis with the compactness metrics have a good assistance to comprehend urban land use evolution and obviously support future urban development plan.

Keywords: urban geography, urban sprawl metrics, area perimeter ratio index

NEW ASPECT AND IMPORTANCE ：

The "Urban Sprawl" phenomenon is associated to low density, spatial isolation, land fragmentation, and scattered location of urban uses within the territories. Many scholars have invented or modified many particular metrics to measure urban sprawl depending quantifying goal and own point of views on sprawl vs. compact city. Sthakis et al. (2013) get in conclusion that the "quantification" is "not an easy task"; however "it's able to calculate urban compactness". They noted importance of monitoring measurement of compactness and intensification change through time would give to planner possibility to have clear view on city development. Bertaud and Malpezzi in 1999 were defined compactness index/ dispersion index as to be used to analyze the city shape performance. They argued the city shape with minimum distance between residence and central business district etc. has best shape performance. Regarding compactness, based on urban morphology many scholars suggested indicators are: mixed-use, and intensity (Bai et al., 2012).Burton (2002) proposed a metric of compactness in composition of density, mix-of-use, and intensification. Tsai (2005) has classified metrics into three classes—density, diversity and spatial structure pattern and proposed to use Moran, Geary, and Gini coefficients to measure compactness through urban simulation analyses. Turskis (2006) proposed for urban compactness: population density, evenness of population distribution, population proximity to working places, population proximity to public amenities, and density of public transport network.Turskis (2006) proposed for urban compactness: population density, population distribution, population proximity to working places, population proximity to public amenities, and density of public transport network.

RESEARCH METHODOLOGY ：

2.1. Spatial analysis method of GIS

GIS spatial analysis is most important part of urban sprawl measurement which is given basic parameters and shape information. Spatial analysis contains conventional overlay, weighted overlay, buffering, network analysis, principal component analysis etc. GIS spatial analysis is particularly easy and innovative to use for urban shape study and more interactive and demonstrative for presentation of end results to decision makers and public (Fan et al., 2012). In this study mostly used conventional overlay, weighted overlay, principal component analysis for data interpretation.

Compactness metrics

In 1822, first time Ritter proposed to measure a shape's compactness using a simple ratio of the perimeter (P) to the area (A) of the shape: (P/A) (Frolov 1975, Li et al., 2013). Since than many alternative and modified forms of geometry were proposed and most commonly acceptance get by 'circularity ratio' $4A/P^2$ by Miller (1953) and the compactness ratio $2\sqrt{\pi}A/P$ by Richardson (1961) in compactness measurements (Li et al., 2013). In urban morphology context, Christaller (1968) in his 'central place theory' figure out hexagonal shape as most compact arrangement. Today, compactness ratio is broad accepted application of planning, urban study particularly in urban sprawl researches (Chandra et al. 2009).

Compactness ratio is calculated by equation:

$$C = 2\sqrt{\pi A}/P \quad /1/$$

Where C is compactness of urban area; P is the perimeter of built area; A is the area of built district. Higher compactness index or change trend presents high compactness of urban extent and urban concentration land development.

Controversial concept manifested Soviet/Russian land use scholars based on theory "quadrate geometry compactness" mainly cited in land use planning Russian literatures. Compact is the plot or use of land having a given area of the smallest perimeter. Geometric figure having the smallest perimeter is foursquare and it should be used as a standard for evaluating the compactness, they argued. According to this concept, coefficient of compactness is ratio of an actual perimeter of plot (land) to the perimeter of the square of the same area: closer to 1, would be the compact land use (Volkov, 2002).

$$C = P/4\sqrt{Pi} \quad /2/$$

Where P is the actual perimeter of area, Pi is perimeter of the square of the same area

In addition, similar method of perimeter-area fractal dimension used as comparative compactness metric. The fractal dimension explains the ratio of area to perimeter of land uses.

Fractal dimension is calculated by equation:

$$FD = \frac{2\lg(P/4}{\lg(A)} \quad /3/$$

Where FD is fractal dimension, P is the external perimeter of city area; A is the area of city.

DATA USED IN THE STUDY :

National Land Information Database, facts and Landsat TM image, Cadastral Map and Urban Planning Data in 2000-2010 were used in this study. The sprawl is defined based on the Geographical Information System Analysis Method. The relative measurements were taken from the statistical data on population and economic activities of Ulaanbaatar and Tongliao. The measurement derived from the combined analysis between urban external shape and urban morphology is implicit thematic urban shape and structure changes.

The result of the comparative analysis on Urban Compactness of Ulaanbaatar (Mongolia) and Tongliao (Inner Mongolia Autonomous Region of Republic of China) :

Population density is related to the urban sprawl and its growth and development since the urban sprawl is the mirror projection of the population. The urban expansion is getting bigger and impacts to population change in the certain time, cause of the following factors such as overgrazing, desertification, global warming, agriculture sector destruction in the rural areas and rapid urbanization (rural area's population movement to the urban areas, transformation of nomadic livestock husbandry, reduction of forest and surface water). The sudden rate occurred on by start of urban land privatization free in charge to Mongolian citizens. (Myagmartseren et all., 2013).

LEGEND

▭ Ulaanbaatar city area

Value
Population density (population/area sqr km)
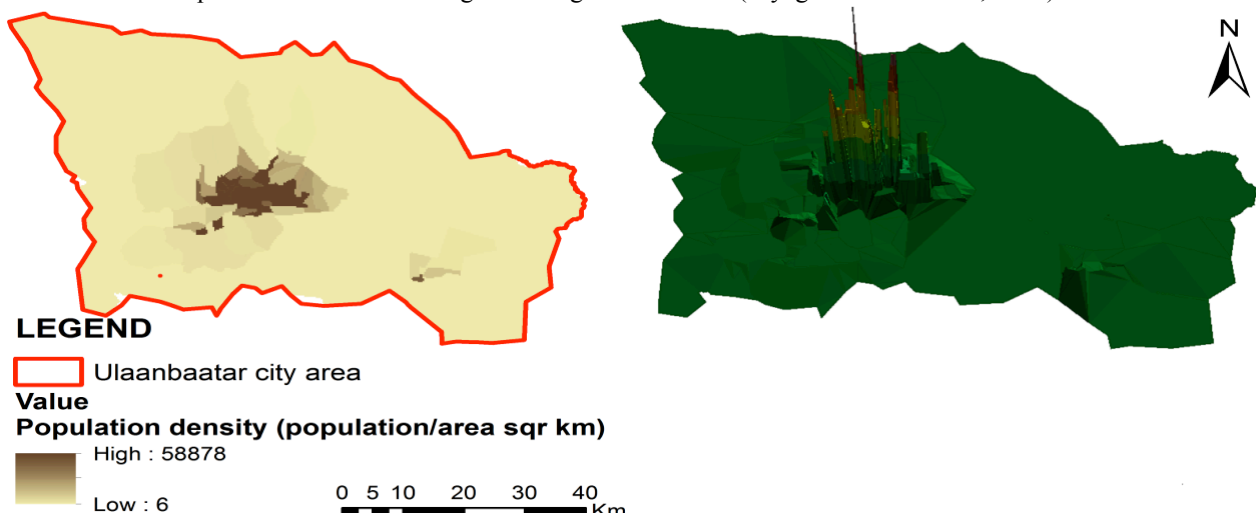
High : 58878

Low : 6

0 5 10 20 30 40 Km

Figure1. Population density at the district level in Ulaanbaatar

The population concentrated in built up areas, where infrastructure, health care, and education service is higher. In the other hands, rural migrants and natural disaster refugees/ poor people start to adverse possession in urban fringes, trespass for public land grabbing in the green zone, pre-urban agriculture zone's was main reason of urban sprawl-slum district. There isn't any significant readjustment plan and old district reconstruction existing and therefore urban expansion is only easy way to land exploitation.
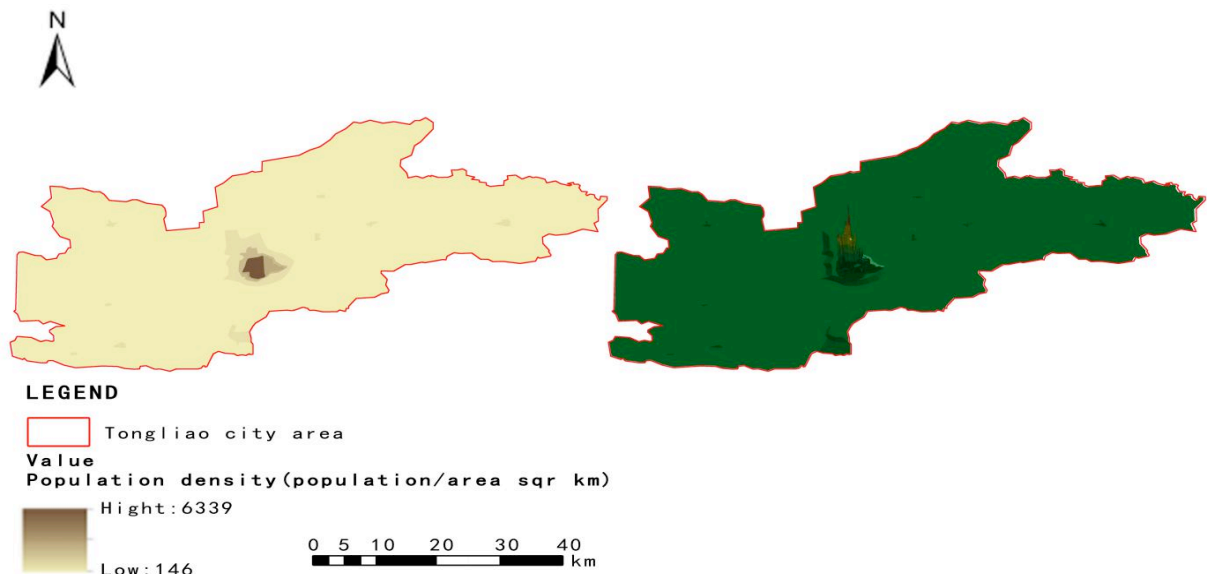

Figure 2. Population density at the district level in Tongliao city

Migration of the herders, farmers, and local citizens played a very big role in urban sprawl expansion. (the migration to and from Ulaanbaatar is presented in the Table 1)

Table 1. Migration and refugee's 1st factor; unemployment, poverty, and not well- being life

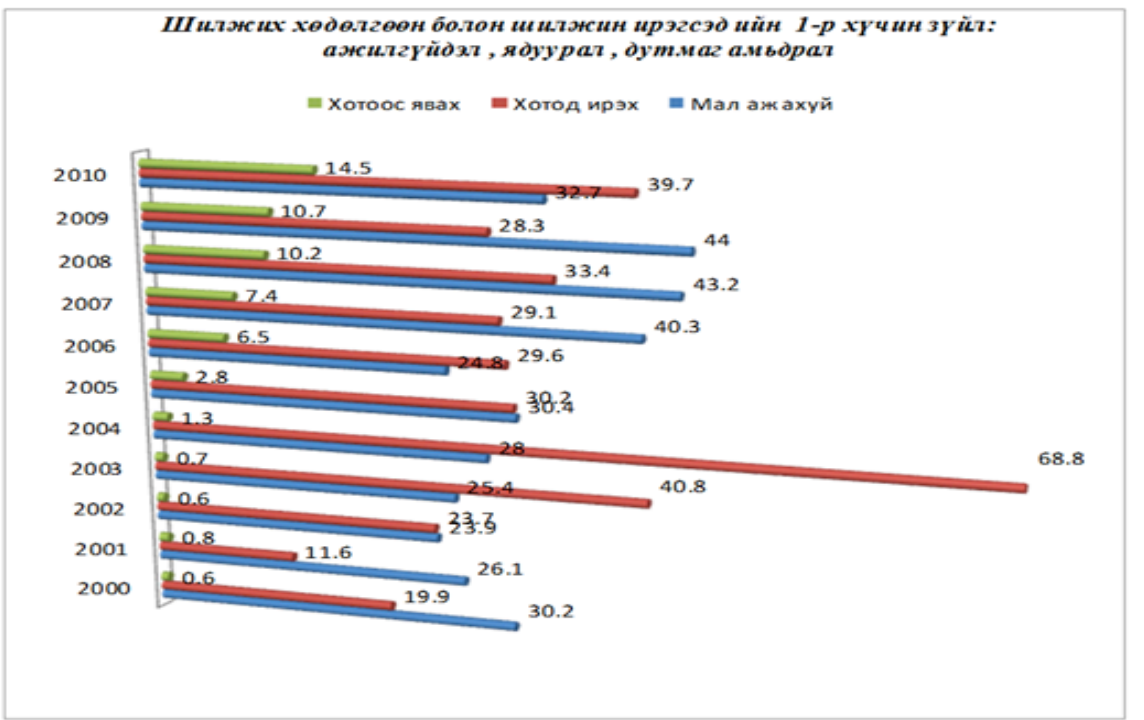|	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Livestock husbandry	30. 2	26. 1	23. 9	25. 4	28. 0	30. 4	34. 8	40. 3	43. 2	44. 0	32. 7
Migration to UB	19. 9	11. 6	23. 7	40. 8	68. 8	30. 2	29. 6	29. 1	33. 4	28. 3	39. 7
Migration from UB	0. 6	0. 8	0. 6	0. 7	1. 3	2. 8	6. 5	7. 4	10. 2	10. 7	14. 5

Figure 1. Migration and refugee's 1st factor: unemployment and poverty

The number of nomadic livestock in rural areas and to Ulaanbaatar has direct relation to the situation shown in Table 1 and Figure 1. One key factor for such rapid urbanization is probably natural disaster- Dzud (harsh winter impacts) to rural population have to lost most number of livestock which means collapse of substantial household revenue and mass poverty in the rural regions or appearance of natural disaster refugees.

Urban land use changes and expansion :

Urban expansion in Ulaanbaatar in 40 years was in high rate (Gantulga, 2010). Today 1.3 million out of 3.0 million population is living in Ulaanbaatar and near area. The area of Ulaanbaatar has 4740 sq.km of the total area of Mongolia which is 1.57 million sq.km.
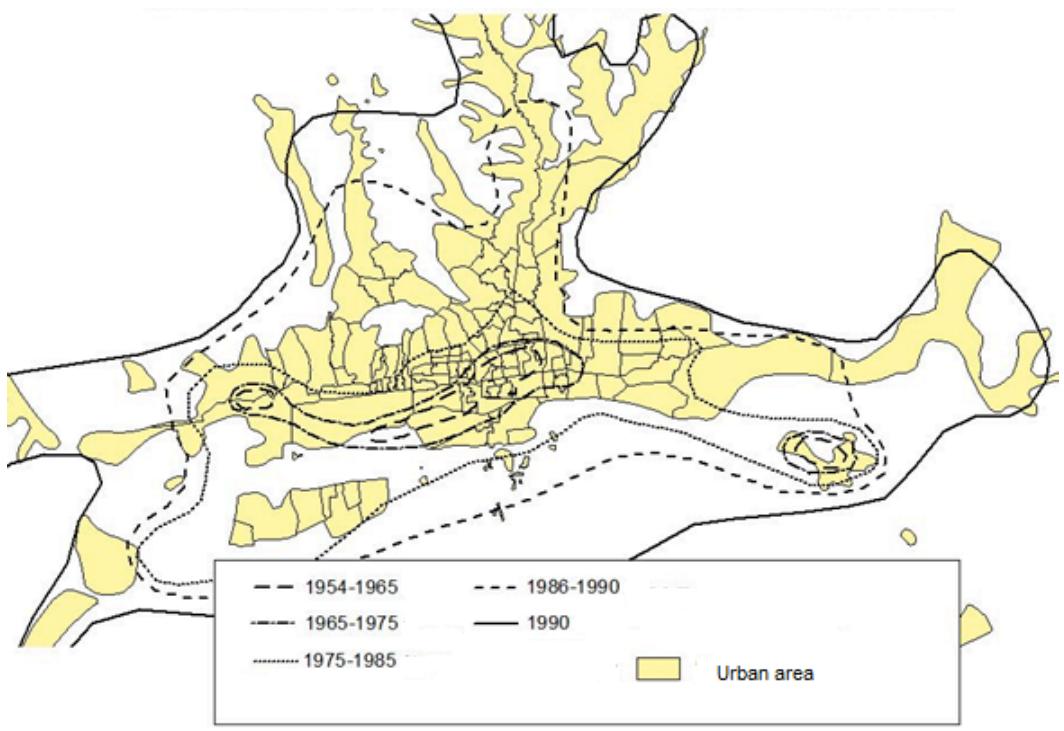

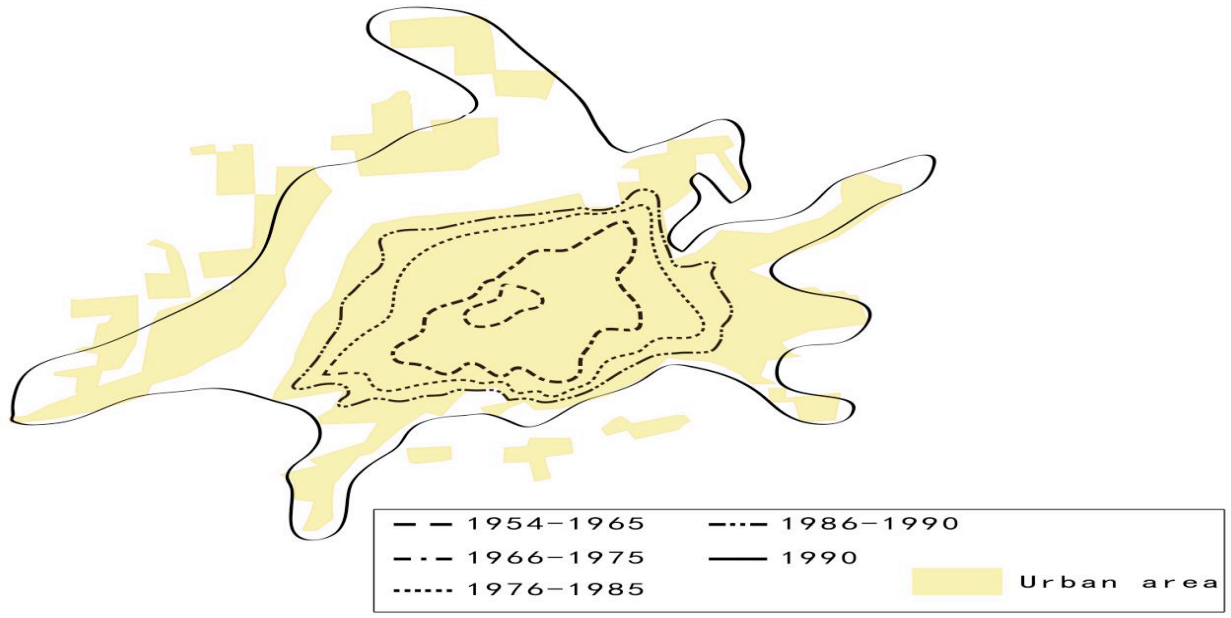Figure 2. Urban expansion during 1954-1990. Courtesy of Gantulga G.

Figure 3. Urban expansion in Tongliao in 1954-1990

Judging from the land usage during the last decade, the urbanization trend is in high rate. (The land usage in Ulaanbaatar and its expansion is shown in Figure 3) . In 1956, the number of population in UB was 118,000 and it increased up to 1.3 million that is one of third of total population of Mongolia.[19], [20] . The sudden growth of the urban population is related to the land privatization without of any charge in Mongolia in 1990-2000.
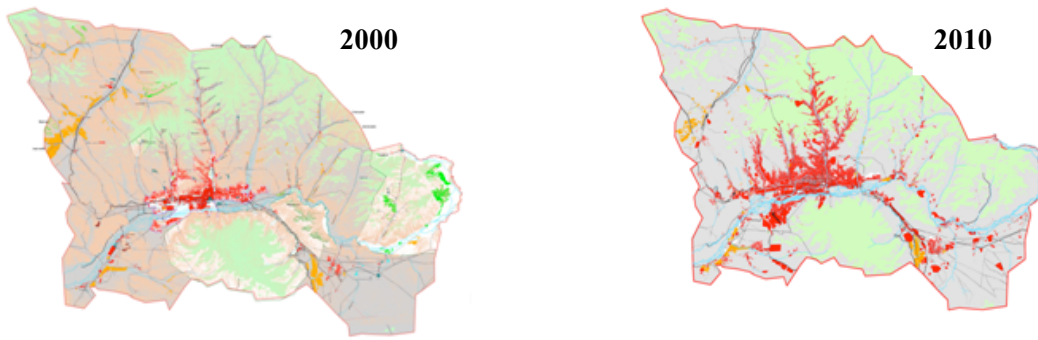
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Figure 4. The situation of urbanization in Ulaanbaatar in 2000 – 2010 is
highlighted with red in the above figure.
Source: Cadastral map, land usage planning map, and National Land Information Database
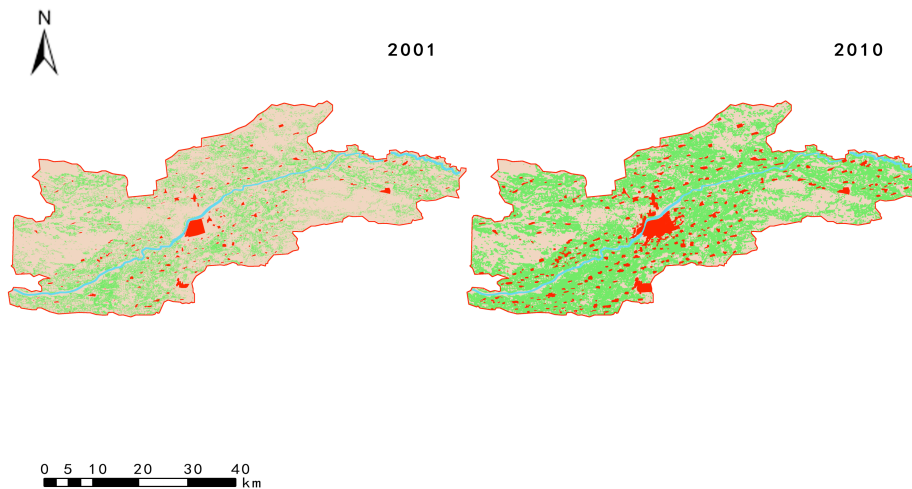

Figure 5. Urbanization situation in Tongliao in 2000 - 2010 was
highlighted with red in the above figure.
Source: Cadastral map, land usage planning map, and National Land Information Database

> Unregulated massive movement from rural areas to Ulaanbaatar has influenced in urban expansion. The rapid expansion of the Ger district which covers about 32% of the total area (See the Figure 4) gave negative influence on the Green Zone, wetlands, water buffer zones, open space, public land conservation and green developments.

Defining the Urban area density in the equal area of circle and square

In this research, to calculate the compactnessindex, there is a need to identify the meaning of "equal area circle" and "equal area square" (Table 2): The ratio of the total area compared to the some area shaped in the circle or square which has the same size of area to the Central Business District (CBD) or Urban Administrative Hall is considered compact or density.   In addition, the fractal dimension called Perimeter-area is used as comparative measurement of the density. The fractal dimension explains the ratio of the total area to the perimeter of the used land.

Table 2 Urban compactness metrics based on equal area circle and square. (Ulaanbaatar City)

Year	Population	Area (ha)	Perimeter (m)	Diameter of equal area circle (m)	Length of equal area square (m)	Compactness index (by Richardson method)	Compactness index (By Volkov method)	Fractal dimension index
2000	773613	29556	147539	9699.5	17192	0.41	2.1	1.078
2010	1161785	46010	678550	12101.9	21450	0.11	7.9	1.207
ΔT	388172	16454	531011	2402.4	4258	-0.3	5.8	0.129
Mean	38817.2 year/p	1645.4 year/ha	53101.1 year/m	240.24	452.8	-0.03	0.58	0.0129

5

For Ulaanbaatar, its area growth is because of Ger District expansion and it is less compared to the perimeter growth. Judging from it, the high ratio of area and perimeter leads to the incorrect urban sprawl and the city planning chaos.

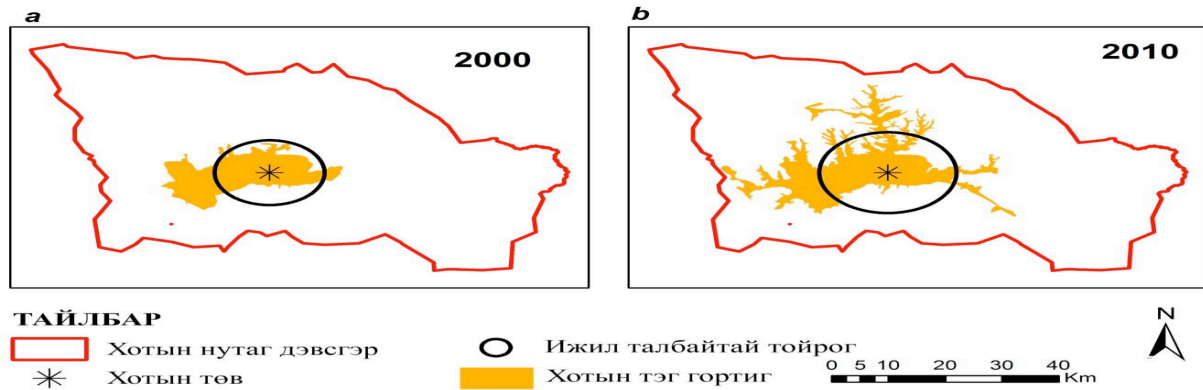Equal area of Square of Ulaanbaatar City in 2000-2010 is shown in Figure 6.

Figure 6**. Ulaanbaatar expansion in 2000-2010 is shown by the equal area circle**

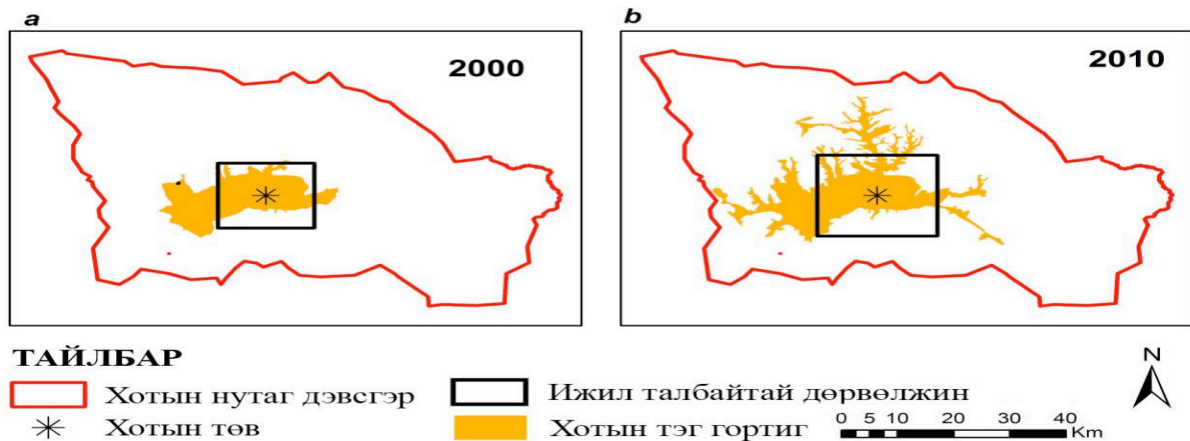The equal area of square for Ulaanbaatar area in 2000 - 2010 is shown in Figure 7.

Figure 7. Urban compactness dimension compared to the equal area of circle and square (Tongliao City)

The ubran sprawl in **Tongliao** City is relatively sustainable and going through right way compared to the urban sprawl in Ulaanbaatar. It is because of the right management of factory and residential apartment construction work. On the other hand, it is because of the right planning management to establish new city center for the purpose of decentralizing.

The equal area circle of Tung-Yao in 2000-2010 is shown in Figure 8.
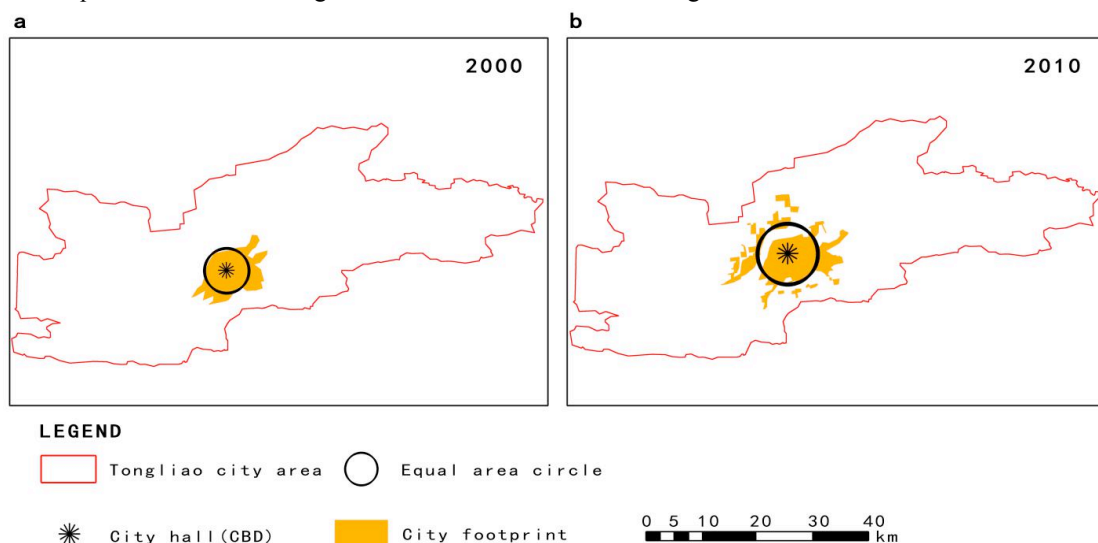

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Figure. 8 Equal-area Circle for Urban Sprawl in **Tongliao** city in 2000 - 2010

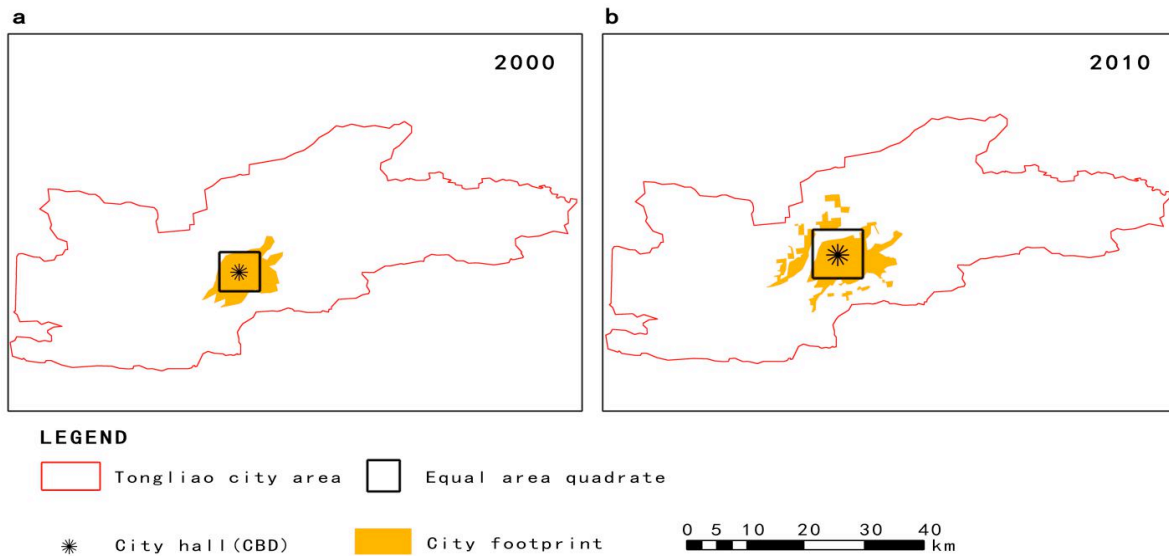Equal-area Square for Tung-Yao city in 2000 - 2010 is shown in Figure 9.

Figure 9 Comparison of Tongliao City Sprawl in 2000 - 2010 to the equal-area square

Compactness ratio

Compactness ratio is the key index in the urban geography for research of urban spatial expansion/ sprawl. Therefore, changes of urban compactness will illustrate trend of urban spatial expansion mode; the scientists defined that "when the city develops quickly, the compactness ratio will decrease; when the city is at the stage of internal-filling and reconstruction, the compactness ratio will increase." [22].

The compactness ratio of Ulaanbaatar in 2000-2010 / Table 2/. According to the two theories, UB is shown very young and at the first stage of the development and it needs to start construction, especially to develop the land. The situation to move to the urban areas because of the natural disasters, to settle down outskirts of the urban areas illegally, and to I increase the Ger Districts at the agricultural land designated areas.

Fractal dimension

The fractal dimension is used for the density comparison as the area- perimeter method. Fractal dimension explains the ratio of the area to perimeter of land uses and reflects the filling ability of territory to space and the complexity of city and built-up land boundaries. [23. 123]. In this paper, the territory boundary perimeter and built-up area parameter measurement for fractal dimension tells the city area segregation or fragmentation in high rate and leap frog and strip development is main reason of fractal dimension index increase. In brief, Ulaanbaatar City Land Use Development is unsustainable in sense of land management.

Table 3. Comparison of urban density in Ulaanbaatar and Tongliao in 2000-2010 compared

to the equal area Circle and Square

City	Year	population	Area (ha)	Perimeter (м)	Diameter of equal area circle (м)	Length of the equal area (м)	Compactness Index (by Richardson)	Compactness Index (By Volkov)	Index of fractal dimension
UB	2000	773613	29556	147539	9699.5	17192	0.41	2.1	1.078
Tung -Yao		3027274	453187	4768572	31790.5	20520	0.59	2.1	1.596
UB	2010	1161785	46010	678550	12101.9	21450	0.11	7.9	1.207
Tung -Yao		3139153	595350	6834925	45236.7	36737	0.46	6.6	1.795

Table 4. The difference between Ulaanbaatar and Tongliao City for the ten years compared to the equal-area circle and square and comparison of the annual average growth (AAG)

City	Year	population	Area (ha)	Perimeter (m)	Diameter of equal area circle (m)	Length of the equal area (m)	Compactness Index (by Richardson)	Compactness Index (By Volkov)	Index of fractal dimension
Ulaanbaatar	ΔT	388172	16454	531011	2402.4	4258	-0.3	5.8	0.129
	AAG	38817.2 year/p	1645.4 year/ha	53101.1 year/m	240.24	452.8	-0.03	0.58	0.0129
Tongliao	ΔT	111879	142163	2066353	13446.2	16217	-0.13	3.2	0.199
	AAG	11187.9 year/p	14216.3 year/ha	206635.3 year/m	1344.62	1621.7	-0.013	0.32	0.0199

Judging from the above table, the density of Tongliao City is relatively higher than the density of Ulaanbaatar City and it is relatively sustainable and centralized in the city center.

Radial Fractal

The scientists defined that the compactness ratio decreases when the urban area develops rapidly, and it increases when the urban area is at the stage of internal development and reconstruction.[22].   According to the theory, the compactness ratio of Ulaanbaatar in 2000-2010 shows that it is young and at the first stage of its development and it is necessary to develop reconstruction work, especially land use development. The fractal dimension is used for the comparative compactness dimension as the perimeter-area method. The fractal dimension means the ratio of the perimeter of the used area compared to the total area. It shows how the area is used for construction and the other purpose. [23:123]. In this paper, the territory boundary perimeter and built-up area parameter measurement for fractal dimension tells city area segregation or fragmentation in high rate and leap frog and strip development is main reason of fractal dimension index increase [Figure 12,13].
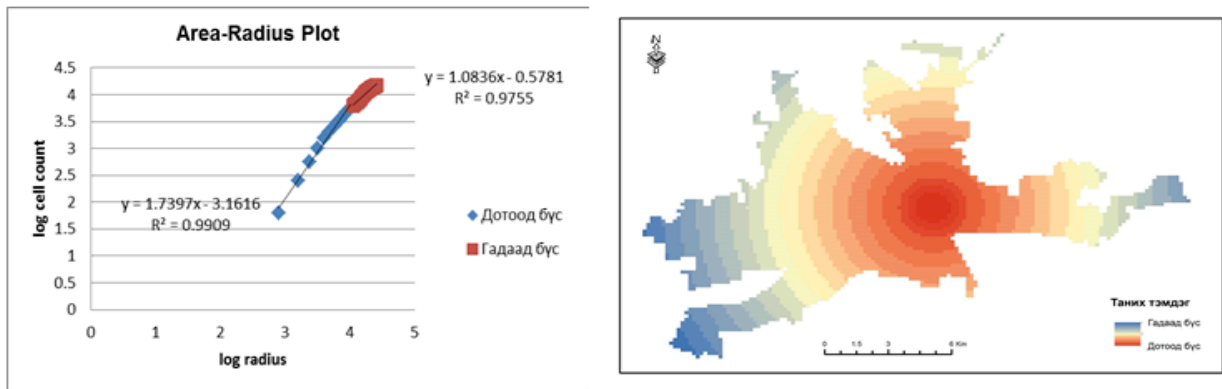

Figure 10. Ulaanbaatar City density in 2010 is divided into the zone based on the radial fractal method.
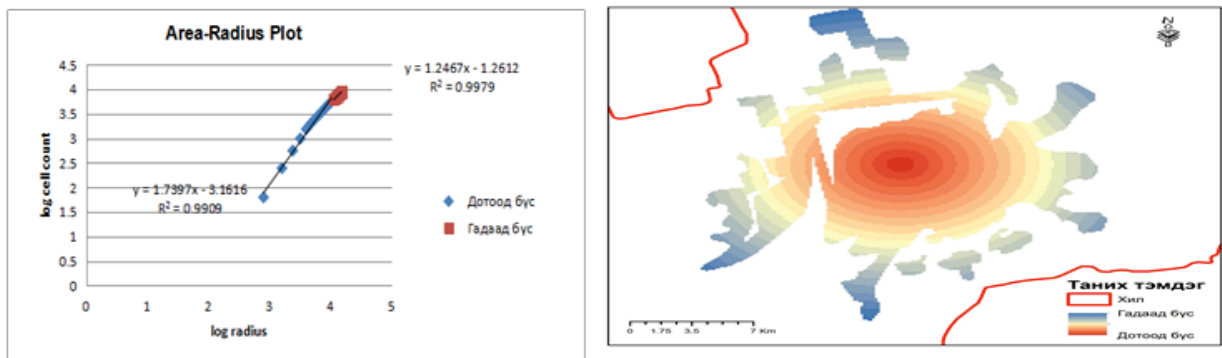

Figure 11. Tongliao City density in 2010 is divided into the zone based on the radial fractal method.

DISCUSSION AND CONCLUSION

The compactness ratio and fractal dimension index are the methods those are accepted into the international urbanization study and especially it is the most suitable method to be used to define the urban expansion and sprawl.

Compared to Tongliao City sprawl to the Ulaanbaatar, the growth of area and perimeter are relatively stable and it shows the right way of urban sprawl. It relates to the right usage of construction planning management when they built the factories and apartments. On the other hand, the management to establish new urban area for the purpose of decentralizing the urbanization impacted a lot.

For Ulaanbaatar city, the ratio of area expansion is less than the perimeter growth. It shows the wrong urban planning and makes the urban planning mess. The following factors may have contributed to such a mess urban planning.

- The migration of the population from the rural area to urban area unregulated.

- The Urban sprawl in Ulaanbaatar in 2000-2010 is considered Ger District Sprawl. In other words, majority of the migrants from rural area are living in the Ger District.

- Urban residential zone planning is weak or it is not related to the social-economic needs and demands. In other words, speed of the demographic growth is not reflected in the urban planning.

- Economic capacity of urban development is weak.

The rapid growth of the Ger Distict expansion in urban area is giving negative impacts on urban green zone, water resources area zone, open space, community land trust, and green zone's development.

The following study results should be highlighted as a conclusion :

1. For Ulaanbaatar, the area expansion for the last 10 years reached up to 16454 hectare, it means the average growth per year is 1645.4 hectare while the growth of perimeter is relatively high or 531011 m (53101.1 year/m). It depends on less compact and sprawl and ribbon development. Urban general shape (morphology) includes forms of "Octopus tentacles".
2. But for Tongliao City, the growth of area for the last ten years was 142163 hectare and the annual average growth is 14216.3 year/m. It shows the more relatively stable urban growth.
3. Since preplanning and changing the Ger District in Ulaanbaatar is very significant, the best way is to do it through land use planning. This is why it is needed to renovate the urban planning at the capital city level and ensure the sustainable development of the rural areas.
4. Comparing the expansion of area in Tongliao City (S=142163 ha, P= 2066353 m) to Ulaanbaatar (S=16454 ha, P= 531011 m), area and perimeter growth is relatively stable and it shows the right urban sprawl. It is related to the right management of the factory and apartment construction work according to the urban planning. On the other hand, it depends on the right management of the urban planning through the way to establish new urban area for the purpose of decentralizing.
5. This survey proves that studying the urban sprawl by using the data processed through Land Information System and remotely sensed data survey is more efficient.
6. Looking from the C index and the other indicators, the land use development in Ulaanbaatar is unstable and stability of the land use development in Tongliao City is medium.
7. Re-planning and changing the Ger District in Ulaanbaatar is very significant for increasing the density and it should be done through the Land Use Planning.
8. It is very important to re-plan urban development and to pay more attention to the sustainable development of the rural areas at the national level.
9. For Ulaanbaatar, expansion of the area is less compared to the perimeter growth because of unregulated migration to the urban, weakly developed urban residential zone planning in Ulaanbaatar, and weak connection with the socio-economic needs.

6. References

1. Administration on Land Affaires Geodesy and Cartography (ALAGaC). 1975-2006. State land resources registration reports. Archive materials. Ulaanbaatar, Mongolia

2. Angel, S., Parent, J. and Civco, D. (2007). Urban sprawl metrics: an analysis of global urban expansion using GIS. Proceedings of ASPRS 2007 Annual Conference, Tampa, Florida May 7–11.

3. Angel, Shlomo, Jason Parent, Daniel L. Civco, and Alejandro M. Blei, 2012, The Atlas of Urban Expansion. Lincoln Institute of Land Policy. Puritan Press, Inc., Hollis, New Hampshire ISBN 978-1-55844-243-6

4. Yongping Bai, Baoguo Shi, Baoxin Di, 2012. Comprehensive Level of Urban Compactness and its Influence Factors in the Cities along Longhai-Lanxin Railway. International Conference on Artificial Intelligence and Soft Computing. Lecture Notes in Information Technology, Vol.12

5. Basudeb Bhatta. 2010. Analysis of Urban Growth and Sprawl from Remote Sensing Data. Springer-Verlag, Berlin Heidelberg e-ISBN 978-3-642-05299-6 , DOI 10.1007/978-3-642-05299-6 D.

6. Batty M., 2001. "Exploring isovist fields: space and shape in architectural and urban morphology", Environment and Planning B: Planning and Design, (28), pp.123-150

7. Bayanchimeg Chilkhaasuren, Batbayar Baasankhuu. 2012. Population and economic activities of Ulaanbaatar. Statistical department Ulaanbaatar city.

8. Bertaud, Alain and Stephen Malpezzi. The Spatial Distribution of Population in 35 World Cities: The Role of Markets, Planning and Topography. Center for Urban Land Economics Research, 1999.

9. Burton, E. 2002. Measuring urban compactness in UK towns and cities. Environment and Planning B: Planning and Design (29), pp. 219-250.

10. Chandra, S., Chhetri, P., and Corcoran, J., 2009. Spatial patterns of urban compactness in Melbourne: an urban myth or a reality. In: B. Ostendorf, P. Baldock, D. Bruce, M. Burdett.

11. Corcoran, eds. Proceedings of the Surveying and Spatial Sciences Institute Biennial International Conference, Adelaide, Australia, 231–242.

12. Christaller, W., 1968. Wie ich zu der Theorie der zentralen Orte gekommen bin. Geographische Zeitschrift, 56 (2), 88–101.

13. Ewing, R.H. Characteristics, Causes, and Effects of Sprawl: A Literature Review. In Urban Ecology; Marzluff, J.M., Shulenberger, E., Endlicher, W., Alberti, M., Bradley, G., Ryan, C., Simon, U., ZumBrunnen, C., Eds.; Springer: New York, NY, USA, 2008; pp. 519–535.

14. Fan, Wenping, Shi, Yishao and Liu, Yan (2012) Application of GIS in quantifying the urban form: a case study of Shanghai. Journal of Digital Content Technology and its Applications, 6 23: 344-353. doi:10.4156/jdcta.vol6.issue23.39

15. Fang, C., Qi, W. Researches on comprehensive measurement of compactness of urban agglomerations in China. Acta Geographica Sinica. 2008, 63(10): 1011-1021.

16. Frolov, Y.S., 1975. Measuring shape of geographical phenomena - history of issues. Soviet Geography Review and Translation, 16 (10), 676–687.

17. Galster, G., Hanson, R.,Wolman, H., Coleman, S. and Freihage, J. (2001). Wrestling sprawl to the ground: defining and measuring an elusive concept. Housing Policy Debate, 12(4), 681–717.

18. Gantulga Gombodorj. 2010. Urban zoning and land use classification of Ulaanbaatar. Dissertation of PhD. NUM. Ulaanbaatar.

19. Grubler, A., 1994, Technology, In: Changes in Land Use and Land Cover: A Global Perspective, W.B. Meyer and B.L. Turner II (eds.), Cambridge University Press, New York, p. 287-328.

20. Huang, J., X.X. Lu and J.M. Sellers. 2007. A global comparative analysis of urban form: Applying spatial metrics and remote sensing. Landscape and Urban Planning, 82(4):184-197

21. Jabareen, Y.R. Sustainable Urban Forms: Their Typologies, Models and Concepts. J. Plan. Educ. Res. 2006, 26, 38–52.

22. Jinlong Chu, 2007. "Study on quantitative analysis of urban spatial form", Southeast University Press, Nanjing.

23. Rajashree Kotharkar , Pankaj Bahadure and Neha Sarda. Measuring Compact Urban Form: A Case of Nagpur City, India. Sustainability 2014, 6, 4246-4272; doi:10.3390/su6074246

24. Kumar, J.A.V., Pathan, S.K. and Bhanderi, R.J. (2007). Spatio-temporal analysis for monitoring urban growth – a case study of Indore city. Journal of Indian Society of Remote Sensing, 35(1), 11–20.

25. Wenwen Li, Michael F. Goodchild & Richard Church (2013): An efficient measure of compactness for two-dimensional shapes and its application in regionalization problems, International Journal of Geographical Information Science, DOI:10.1080/13658816.2012.752093