Using urban morphology for flood risk in residential areas in Ho Chi Minh city

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ABSTRACT:

Urban morphology in urban studies is used to classify and manage the distribution of urban densities. In urban planning, it helps to identify the emerging problems and solve the disorder of urban functions as in the megacity of Ho Chi Minh City. Rapid urbanization has increased the development footprint with disordered densities of building footprint, incomplete infrastructure and urban - peripheral instability. And it, then, caused more flood problems to the city.

This study was based on applying fractal geometry, GIS on large-scale maps for identifying residential density based on urban morphology. The land-use map and the building footprints map of 2010 were integrated in fractal geometry to analyze the distribution of urban areas by the large scale of GIS data.

This study showed HCMC had problems on irrational development in residential densities areas; and uneven development of population and residential density between the urban areas. At block scale of land-use block, in urban center had highest densities of building footprints and population, then, the medium densities in developing districts and rural-sub-districts. With these densities, there was more flood in high density areas, as in urban center, and less flood in lower density areas, as in sub-urban areas. These problems may cause some limitations to development of social, commercial, industrial, and infrastructure in HCMC. City needs to have flood control and management for development of the city.

Keywords: *Urban morphology analysis, development footprint, building footprint, residential density, flood risk*

1. INTRODUCTION

1.1 Urbanization and urban problems in Ho Chi Minh City

Ho Chi Minh City (HCMC) is still the largest city of Vietnam in education, science, economies of industries and services, etc. and has international relations. To this foundation, HCMC has increasingly received many immigrants from provinces and even outside country for educating, researching, and working, etc. Thus, landuse changed along with the expansion of development footprint due to urbanization. These have caused many problems in urban area as environmental quality and close link to climate change and flooding (OECD, 2014).

1.2 Increasing of development footprint and flooding problems

HCMC with high population rate requires more land for housing and residential areas. The dynamic urbanization has resulted in uneven spatial development of urban areas, such as over density in urban center with more housing and buildings, disorder density in developing and sub-urban areas; and high density in risk areas as in low-land areas.

The densities of residential areas refer to the increasing of building-footprint densities and other non-building facilities of the areas. They have close relationship to urban flooding. The previous researches showed in high density residential areas had more flooding problem than the lower density areas, high flood in the center rather than in developing and suburban areas.

Urban morphology can help to solve the problems of development footprint density and disorganization. Along with fractal geometry analyses, that urban morphology can identify the trend of urbanization and expansion flow of development footprint (Longley and Messev, 2002). In relationship of residential density to flooding, it helps to understand the flows and trends of residential expansion and flooding patterns. It also shows the development patterns of development footprint of the city. It is necessary for urban planning and management to solve the urban problems.

2. MATERIALS AND METHODS

Development footprint refers to the enlargements of housing and residential areas, infrastructure and urban services, and other non-building facilities. And building footprint refers to the site that is used by the build-up areas. To analyze the relationship of residential expansion and density to flooding by urban morphology, it needs to have the concepts of density and the density measures for urban residential areas. The density measures for the residential area excluding the non-local residential areas such as parks, schools, and open space, etc. are widely accepted in residential planning (Forsyth, 2003; Hess et al., 2007). Other widely accepted measure is to distinguish between gross density and net density of residential area. The gross residential density includes all the above land uses plus regional uses such as education, open space, commercial uses and transport; while net residential density includes the residential component plus local roads (Landcom, 2011). In identifying the residential density in urban morphology map, density is usually calculated by dividing an overlapping of the built-up area on land-use. This calculation must be localized and referenced by the real surface of land-use (e.g. the total area of the land-use). This research used net density definition for residential area.

In urban area, special in HCMC, the residential areas are developed on land-use block. Then, there are the net residential density on land-use block, the housing/building types on land-use block, and the residential population including person and household size on land-use block, etc. (Forsyth, 2003). From then, the net density is analyzed at the block level either as a measure of total buildings per block or as other statistical evaluates of residential amount per block level. Urban morphology analysis in this study was to analyze the residential density on the three indicators: number of building footprints, the land-use area per hectare and population density per land-use block (or block level). Furthermore, fractal geometry was helped to identity the density of building footprints on land-use block. From then the density distribution in different urban residential areas were analyzed and compared the flood risk areas.

Table 1. The standard of residential density ranges for the study area

Category	Residential density category	Number of building footprints (per ha)
1	High residential density	Over 50 building footprints per ha
2	Medium residential density	From 20 to 50 building footprints per ha
3	Low residential density	Below 20 building footprints per ha

Source: Department of Planning - Western Australian Planning Commission (2012)

To classify the distribution of residential density on HCMC urban morphology map, this study applied the category of residential density of Western Australian Planning Commission (2012). This category was with residential density analysis in high-, medium-, and low-levels (UN-Habitat, 2004; Landcom, 2011). (see Table 1).

2.1 Data set for urban residential density analysis

- Using GeoEye and Worldview-2 images of 2010 combine with cadastral map 1/2,000 scale (Source: HCMC DoNRE, 2010) to interpret and classify the building footprints map.

- Using Land-use 2010 with 1/25,000 scale (Source: HCMC DoNRE)

- Population census commune 2010 (Source: HCMC Statistical Office).

The input land-use and primary map data were sourced by the Department of Resources and Environment (DoNRE) in 2010 with the scale of 1/25,000. They were for analyzing the residential area. Building footprint data was supported by the HCMC Construction Department for mapping the building footprints map (1/2,000) which was updated on the GeoEye and Worldview-2 images. And the number and type of land-use classes chosen in research correspond to the spatial scale of preparatory building footprints used in urban morphology map.. Population data, in the form of statistical available for each municipal commune in the city's annual statistic, was integrated to the building footprint of the residential land-use cover. The population density was linked to building footprint density to show the density problems of residential areas.

Flood data from HCMC Steering Center of the Urban Flood Control Program (SCFC) and from HCMC Department of Transportation were integrated into base map to produce flood map. Then, the multi-criteria analysis technique in GIS was applied to integrated residential densities on land-use blocks in flooded area to analyze the relationship of residential density to flooding problems in HCMC.

2.2 Urban morphology and fractal geometry methods

Fractal geometry in urban morphology analysis is used to count the identification of residential densities based on Arcview 3.2 with a grid cell size of 1×1m and by Avenue program for urban morphology tool. These criteria of urban densities were either derived directly from the morphology map information of 2010.

Based on fractal analyses, the scales of residential densities were founded. The residential density of land-use blocks provided information on the concentration of the number of building types per land-use units. Then the built-up coverage ratio was computed. These results were used to evaluate the density levels and relate to spatial distribution in the urban area of HCMC. In the science of fractal geometry, Batty and Kim (1992) had analyzed the fractal geometry to identify the residential density on land-use block. Therefore, this study applied the Batty and Kim's fractal formula to identify residential densities to HCMC. The formula is the following:

$$D = \ln N(R) / \ln(r) \quad (1)$$

Where: N*(R)* is the count of buildings of each building type overlapping the feature of block (per unit area of building types, in square meters)

- *r* is perimeter meters of land-use block

In this case lnN(*R*) refers the density of each building type of land-use block, and ln*(r)* is the size of land-use blocks (block of an observation). D is the fractal geometry. With the formula 1, the fractal geometry "D" can measure a rate of the identity distribution of mean building count of a block as block density, and the constant k is 1.0 related to the mean connection of urban morphology map.

The value D is as the parameter to measure the identity of building types, residential density, and the values of built-up density on land-use block. When the D value is larger, the density on land-use block is larger as well as the identity of each building type (the same construction the number of building type on block). And D can explain the level of block for the most complex, cumulation of the number of building types with plane-filling perimeters as well. The analysis results of fractal geometry of this study were categorized in three degrees of residential density based on the category on Table 1.

Population values of land-use block were calculated from census data at the commune level. The general equation can be written as follows:

$$P_{bl} = P_{co} * U_{bl} / U_{co} \quad (2)$$

Where P_{bl} = population of land-use block; P_{co} = population communes; U_{bl} = residential areas of land-use blocks; U_{co} = total residential areas of commune.

To estimate the residential population densities of land-use block based on the result of equation 3, it can be calculated as follows:

$$P_{RD} = P_{bl} / U_R \quad (3)$$

Where: P_{RD} = residential population densities; U_R = areas of building footprints. Based on the equations 2-3 of method, research used GIS data of people living and building types within communes to estimate the number of people in a smaller area within the land-use block, or an area. This is defined as "the transfer of data from one set (source units) to a second set (target units) of overlapping, non-hierarchical, areal units. Area interpolation is closely related to population densities on each block (Langford et al., 1994).

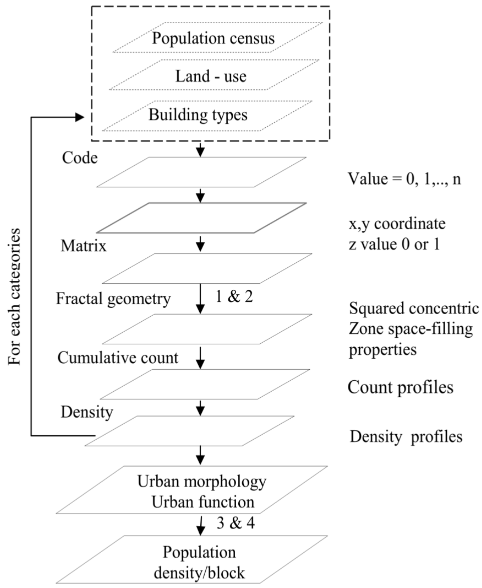

Figure 1. The method framework of urban morphology analysis of urban residential density in HCMC

An illustrated methodology was described in Figure 1. This methodology consisted of the population data, land-use, and building footprints layers. Those were input in the computer as the codes in the binary system (with 0 was unoccupied, and 1 was occupied). This binary system was presented in one matrix and was analyzed by fractal geometry for counting profiles.

3. RESIDENTIAL DENSITY IN HO CHI MINH CITY

3.1 Building footprints density in residential areas

The building footprint map and fractal geometry analysis result provided the spatial distribution of building footprints in HCMC. Applied with the category of residential density in Table 1, the spatial density analyzed by program tool in fractal geometry analysis had showed the results of residential densities in HCMC in the below Table 2 and Figure 2.

The numbers of buildings in these zones were nearly the same, but the area of land-use blocks is different. Therefore, there were big differences of buildings densities among three buildings zones – zone A (high density), zone B (medium density), and zone C (low density). Zone A had buildings density three times higher than of zone B, and eight times higher than of zone C. But the building areas were in converse, the area of zone A was about three times less than zone B and eight times less than zone C.

The D value of fractal geometry had estimated 1.31 to 1.67 synonymous with urban densities and buildings. D index in zone A was highest, then zone B and C, respectively. Corresponding density profiles for nearly the same were shown 1.7 for residential area to 1.8 for build-up area of Longley & Messev (2001).

The map showed the highest residential density of zone A concentrated in the urban center. And the lower densities of zone B and C were in developing districts

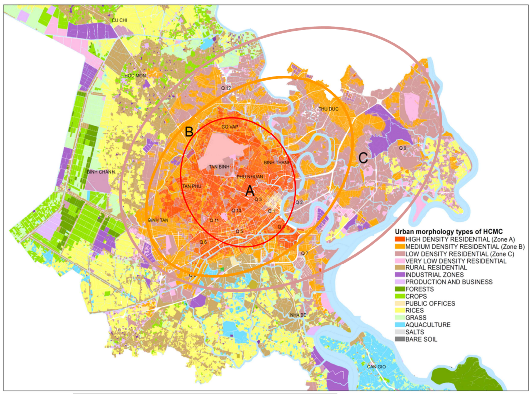

Figure 2. Urban Morphology Map of HCMC in 2010

3.2 Population density on residential areas

There was the relationship between building footprint densities to population densities in HCMC. The high density of buildings refers to high density of population. And conversely, the lower density of buildings refers to lower density of population living in residential areas. Figure 3 showed The very high population density of residential area has caused so many problems of drainage system and high sealed zone in the center, and led the serious problems of flooding in rainy season

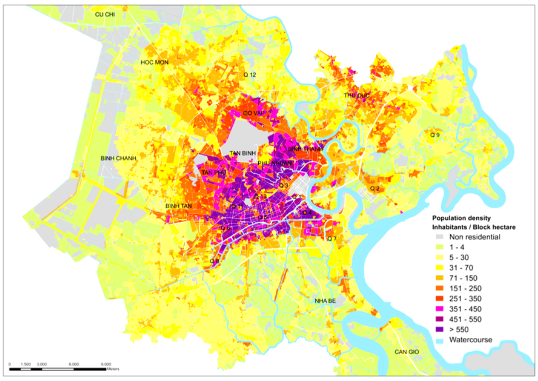

Figure 3. Population densities on land-use block of HCM in 2010

Table 2. Dimensions associated with partial building densities

Range	Zone	Area (ha)	Number of building footprints	Building footprints density (#/ha)	ln(area)	Dimensions D
High	A	1,721.22	260,245	151	7.45	1.67
Medium	B	5,413.64	268,701	49	8.60	1.45
Low	C	14,022.73	273,131	19	9.55	1.31
Total		21,157.59	802,077			

4. RESIDENTIAL DENSITIES AND FLOODING PROBLEMS IN HO CHI MINH CITY

Table 3. Flooding risk on urban residential areas

Residential areas	Rain (ha)	Rain & Tide (ha)	Tide (ha)
Urban high-density residential area	322.25 8.93%	212.68 5.89%	203.49 5.64%
Urban medium-density residential area	1136.18 17.27%	124.58 1.89%	321.30 4.88%
Urban low-density residential area	501.59 6.18%	109.07 1.34%	276.83 3.41%
New urban development residential area	71.92 1.71%	7.82 0.19%	274.68 6.54%
Rural medium-density residential area	29.74 0.98%	-	6.78 0.22%
Rural low-density residential area	-	-	5.70 0.10%
Total	2,061.69	454.14	1,088.77

Flooding problem in HCMC was illustrated in table 3. In the high-density residential areas of urban area, flood covered about 20.5 percent of total 3,606 hectares. In medium-density residential areas, flood covered about 24 percent of total 6,578 hectares. And in lower-density residential areas, flooded area covered about 10.9 percent of about 8,000 hectares. The least flooded area was in the rural areas with just from 1 to less than 2 percent of total. This result gave some significant information about flooding in HCMC, that flooding in this city was not strongly related to the terrain, but to development footprint and its density (as the density of residential areas-building footprints, and density of population).

5. CONCLUSIONS AND SUGGESTIONS

Urban morphology and geometry technique were used to identify the densities on urban residential areas in HCMC. The results of this research is to better understand the spatial distribution problems through the relationship between residential density areas, building footprint density, population density, and flooding. The big differentiation of urban residential densities between zone A, zone B, and zone C showed the uneven distribution of residential density in urban area of HCMC. It caused many problems in provisioning the urban infrastructure and urban services, and distribution of open space and green space. The flood reason was not strongly depended on terrain, but by urbanization and development process. The city government and urban planners may consider in encouraging the moving of people in zone A with very high residential density out to zone C or B, especially zone C with low residential density.

Results of urban morphology analyses: the urban and rural residential densities at the detail levels of the land-use block and building footprints; the area with high population density had high densities of building footprints. In contrast, the area with low population density had low densities of building footprints. Urban morphological analysis to flooding showed in center-districts: flood was concentrated in high- and medium-density built-up residential areas.

Sử dụng hình thái đô thị phân tích nguy cơ ngập lụt tại khu dân cư Tp. Hồ Chí Minh

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TÓM TẮT

Hình thái đô thị được sử dụng để sắp xếp và quản lí mật độ trong đô thị. Nó giúp xác định và giải quyết những bất ổn của các khu vực chức năng đô thị trong lãnh vực qui hoạch ở thành phố lớn như thành phố Hồ Chí Minh (TPHCM). Đô thị hóa làm gia tăng nhanh dấu hiệu phát triển không gian với mật độ xuất hiện dấu vết xây dựng lộn xộn trong khu dân cư. Cùng với cơ sở hạ tầng không đầy đủ và liên kết đô thị - nông thôn không bền vững sẽ gây nên những vấn đề ngập lụt nhiều hơn cho thành phố.

Nghiên cứu này sử dụng bài toán hình học fractal, ứng dụng kỹ thuật GIS dựa trên bản đồ tỉ lệ lớn trong phân tích hình thái đô thị để xác định mật độ các khu dân cư. Bản đồ sử dụng đất và bản đồ dấu vết xây dựng được đưa vào hình học fractal để phân tích sự phân bố dân cư năm 2010 .

Nghiên cứu cho thấy TPHCM có vấn đề về phát triển không hợp lí về mật độ các khu dân cư và sự phát triển không đồng đều giữa các khu vực chức năng trong đô thị trên một đơn vị sử dụng đất, được thể hiện qua mật độ xây dựng, mật độ dân số cao trong khu dân cư trung tâm, kế đến mật độ trung bình ở khu dân cư đang phát triển, và ở các quận, huyện ven đô. Với tình trạng này, vấn đề ngập lụt diễn ra nhiều hơn ở khu vực mật độ dân cư cao, và ít hơn ở khu vực có mật độ dân cư thấp. Các vấn đề này có thể làm hạn chế sự phát triển kinh tế-xã hội, thương mại, công nghiệp, và cơ sở hạ tầng của đô thị.

Từ khóa: *Phân tích hình thái đô thị, dấu hiệu phát triển, dấu vết xây dựng, mật độ dân cư, ngập lụt.*

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