CONCEPTUAL IDEAS OF LAND USE ZONING FOR URBAN FLOODING MITIGATION IN DEVELOPING COUNTRY-PHNOM PENH CITY AS A CASE STUDY

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This study developes a conceptual ideas of land use zoning for urban flooding mitigation based on watershed unit and Hydrological Sensitive Areas (HSAs) for controlling the development of area having high potential of accelerating flood risk in the urbanized area of Phnom Penh City (PPC) under the lack of public databases. This study is carried out under three contexts. (1) Illustration of waterhed unit in the middle scale planning, (2) Computation of Wetness Index, Soil Water Storage based on the creation of soil databases and impervious cover ratios, Topographical Index, HSAs and threshold of HSAs for PPC, and (3) Case study to reflect on the development stages in PPC with respect to HSAs and master plan as part of watershed. The combination of HSAs and watershed unit is proved useful and can be used as zoning indicator for urban flooding mitigation planning in PPC.

Key Words : *watershed unit, Hydrological Sensitive Areas (HSAs), Wetness Index, Topographical Index, threshold of HSAs*

1. INTRODUCTION

Dominantly, urbanization process deleteriously impacts on land use change in term of increasing impervious cover and surface runoff, which has been causing urban flooding in the urbanized area[1), 2)]. These issues are even worse in particularly for developing countries.

Cambodia is one of the countries situated in Mekong River Basin. Phnom Penh City (PPC), a capital of Cambodia, is located at the intersection of Mekong, Tonle Sap, and Basak Rivers. From 2003, after a decade of cutting edge economic development, purchasing of public spaces and land reclamation for land use development have been gradually raising among investors. The manner of current land use development and design is more focusing on the aesthetic aspects with ideal infrastructure being shaped symmetrically and geometrically regardless of concerns respecting to topography, soil and imperviousness conditions. Consequently, it's been causing many negative effects to the social and environmental aspects. Particularly, it's been accelerating the urban flooding extents in every raining season. With great concerns of current land use development trends, this study develops a conceptual idea of controlling the development through the zoning indicator known as Hydrological Sensitive Areas (HSAs) and watershed unit.

The aim of this paper is: (1) Illustration of defining threshold for watershed unit in the middle scale planning, (2) Computation of Wetness Index, Soil Water Storage based on the creation of soil databases and impervious cover ratios, Topographical Index, HSAs and identifying threshold of HSAs for PPC under limitation of public databases, and (3) Case study to reflect on the development stages in PPC with respect to HSAs and master plan as part of watershed.

2. OVERVIEW OF PPC AND CURRENT SITUATION OF URBAN PLANNING

Original PPC is known as a city with urban development closely related to water[3)]. Since 2003, land use development have been remarkly raising among both local and foreign investment in term of building satellite cities to respond with the rapidly growing of populatin and economic.

With parralle to the development, quality of life has been increasing; however, it's brought about intensifying the urban flooding extent in rainy season

(May-October) due to the increasing of impervious cover but decreasing of water storage and absorbable soil. Unavoidable events of urban flooding happens in PPC every raining season with repeated negative impacts to the quality of life including issues of health, traffic, damage infrastructure, losing individual income and governmental buget for the reconstruction of infrustructue.

On the other hand, In PPC, law on land use planning, urbanization and construction was created in 1994. Law on the environmental protection and natural resource management was promulgated in 1996[4]. Whereas land use data or other urban relative development is mostly not considered as open source.

3. CONCEPTUAL IDEAS OF LAND USE ZONING FOR PPC

(1) Importance of watershed in urban flooding mitigation

With great concerns of current land use development trends in PPC where flooding is one of the main issue in urban planning, watershed-based method, a useful key concept applied for not only in hydrology, environmental management but also land use and landscape planning fields[5], is introduced for flooding mitigation planning in PPC.

(2) Terminology of catchment, sub-watershed and watershed

An area of land where all the surface water flows into the common outlet is known as catchment. While a sub-watershed is composed of two or more catchments; a watershed is composed of many catchments and sub-watershed[5], as shown in **Fig. 1**.

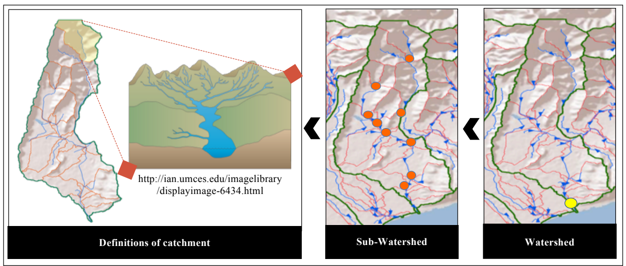

Fig.1 Terminology of catchment, sub-watershed and watershed

(3) Scale of watershed unit to discuss land use planning for PPC at middle scale

In this study, watershed delineation is performing using ArcHydro in ArcGIS 10.2 platform. Bascially, scale of watershed is based upon the stream definition, one of the procedures in watershed delination, in which threshold value is required to input, is critical issue to decide the scale of watershed.

To define the scale of watershed to discuss about land use planning in PPC at middle scale, comparing the most approache value between trialling threshold values of stream area to obtain average value of watershed and defining the average area of Sangkat (territorial division of PPC below district level) average area is implemented similar to the existing study[6), 7)].

(4) Research framework

Watershed-based methodology for land use planning in PPC is developed based on three scales: macro, middle and micro scales as shown in **Fig.2**. In this paper,concept on watershed-based land use planning at middle scale is disccussed.

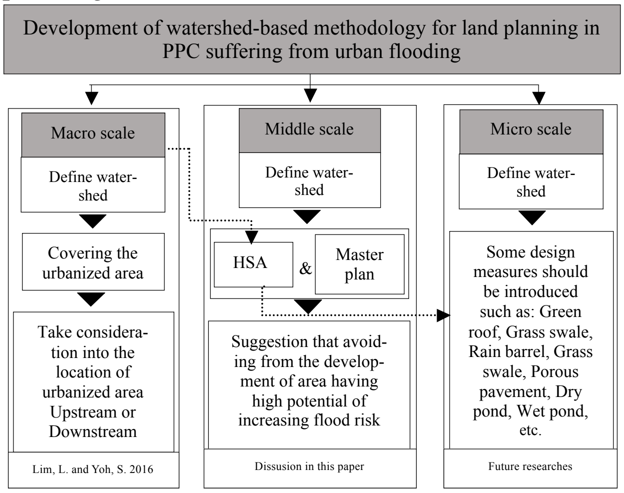

Fig.2 Research framework

4. HYDROLOGICAL SENSITIVE AREAS IN PPC

(1) Definition of Hydrological Sensitive Areas (HSAs) and its importance

Hydrological Sensitve Areas (HSAs) are area where Topographical Index (TI) is greater or equal to a given threshold value[8)].

TI is used to simulate the surface runoff contributing area's pattern based on the variable source area (VSA) hydrology, in which the capacity of soil saturation is exceeded and the generation of runoff is dominated by both expansion and contraction of the development in these saturated areas[9)]. It's the tendency given point in a watershed likely to become saturated area and served as a source area for surface runoff [8), 10)]. Topographically, this index was primarily known as wetness index, in which the distribution of soil moisture in the landscape is predicted, and mainly it depends on the flow accumulation slope derived from Digital Elevation Model (DEM). However, in this study, from the viewpoint of watershed planning applied into the land use planning in the urbanized area, the heterogeneous with various soil types, land cover as well as land use and slopes are essential to take into consideration. In this respect, the existing method accounts not only the topographical condition, but also soil water storage is applied[8), 10)]. The formula can be expressed as:

$$\lambda = \ln\left(\frac{\alpha}{\tan\beta}\right) - \ln(K_s D_{ISA}) \qquad (1)$$

$$\begin{cases} \ln\left(\frac{\alpha}{\tan\beta}\right) & \begin{cases} \alpha \text{ is runoff contributing areas per contour length in m} \\ \beta \text{ is slope in radian} \end{cases} & (2) \\ K_s = \frac{d}{\sum_1^n (d_i/k_i)} & \begin{cases} d \text{ is total thickness of the soil above the restrictive layer} \\ d_i \text{ is the thickness of layer i} \\ k_i \text{ is the saturated hydraulic conductivity of layer i} \end{cases} & (3) \\ D_{ISA} = D - (D \times ISA) & \text{ISA: proportion of pixel } (0-1) \text{covered by impervious surface} & (4) \end{cases}$$

When the development taken place on the area defined as Hydrological Sensitive Areas, planners should take into consideration the planning not ex-exacerbates the runoff process. Threfore, instead of proposing planning full of building lots causing the increase of impervious surface, planning with open space or garden or greenery can be pondered.

(2) Computation of HSAs in PPC

a) Preparation of GIS-based spatial databases

To perform the computation of HSAs in PPC, necessary data is collected as shown in **Table 1**.

Table 1. Data source and usages

Data source	Computation of	Scale/ other
Shuttle Radar Topographical Mission (SRTM)[11)]	Wetness Index	90m
Sub-soil data (374 points)	Saturated hydraulic conductivity (Ks) and Depth to restrictive layer (D)	Excel and AutoCAD files
Landsat 8 OLI (1/15/2015) with Max cloud=0%[12)]	Impervious cover ratios	30m
Base maps[13)] (population, administrative boundary)		Shapefiles

b) Wetness Index

Normally, the higher the value of Wetness Index, the more likely the saturation of the grid occurred in the storm events[8)]. Based on **Eq. (2)**, Wetness Index is defined as shown in **Fig.3.**

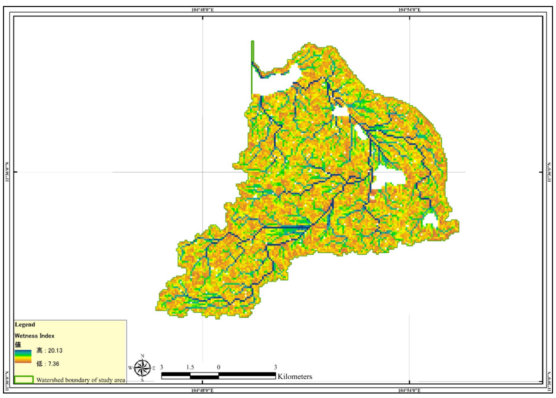

Fig.3 Wetness Index of PPC at macro scale

c) Soil water storage

Saturated hydraulic conductivity (Ks) and Depth above restrictive layer (D)

Two components including saturated hydraulic conductivity (Ks), soil's ability measurement to transmit water when submitting to the hydraulic gradient[14)], and depth above resticitve layer (D) where the restrictive layer is a layer that water cannot surpass as bedrock layer. Based on **Eq. (1)**, the deeper the depth to restrictive layer, the higher the saturated hydraulic conductivity, but the lower the value of topographical index.

Unlike most of the existing researches using open source of the NRCS Soil Survey Geographic (SSURGO) soil databases to extract both Ks and D, this study creates the soil databases based on closed source data of bore log used for foundation design in construction field.

In term of making these soil databases, ideal method cannot be realized since the total depth of the majority of sub-soil data is below 50 m; the bedrock cannot be figured out whereas some soil texture classes cannot be defined in the lists of the saturated hydraulic conductivities' indicative values[15)]. Therefore, it's necessary to make some assumptions based on reliable source, method and logical way.

The procedures and assumptions for creation of Ks and D in this paper are summarized as shown in **Fig.4**.

Following the procedures and assumptions based on **Figure 4** and **Eq. (3)**, the results of mean saturated hydraulic conductivity (Ks) and depth above restrictive layer (D) are compuated as shown in **Fig.5** and **Fig.6** respectively.

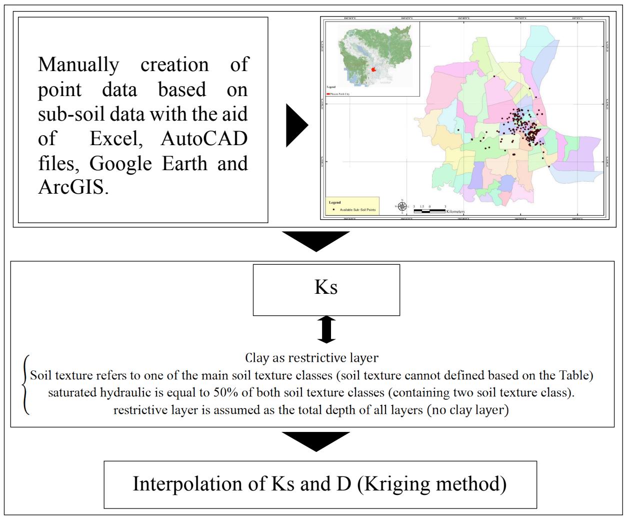

Fig.4 Procedures and assumptions for creation of Ks and D

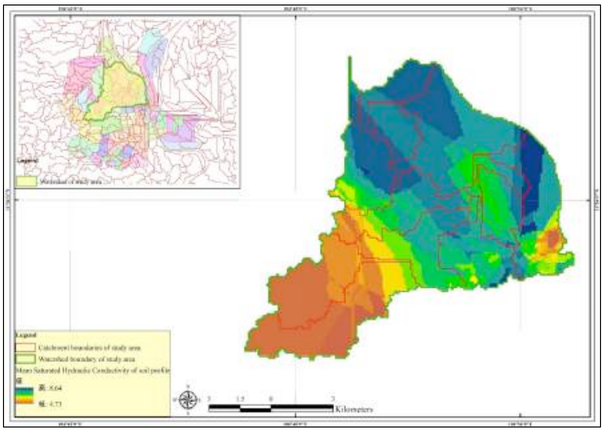

Fig.5 Mean saturated hydraulic conductivity (Ks) at macro scale

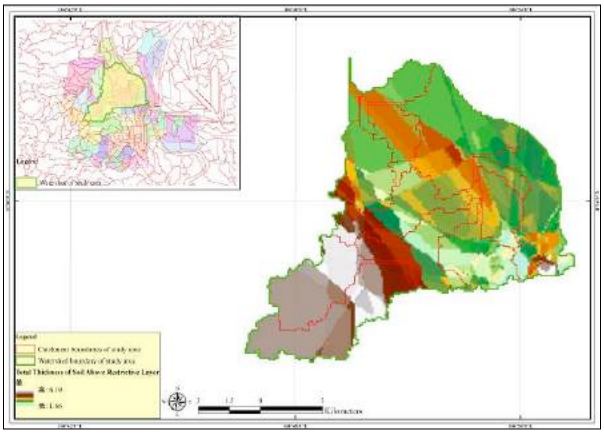

Fig.6 Depth above restrictive layer (D) at macro scale

Depth above restrictive layer to account for impervious surface area ratios

According to **Eq. (4)**, to computate depth above restrictive layer to account for impervious surface area ratios, spatial database of impervious surface area is needed; however, this data is not available for PPC. In this respect, impervious surface area ratios are created based on the Landsat data, population data, ratios of impervious cover and calculation of imperviousness[16], and typical residential density[17].

The procedures are summarized as shown i **Fig.7**, and the result of depth above restricitive layer to account for impervious surface ratios is shown as **Fig.8**.

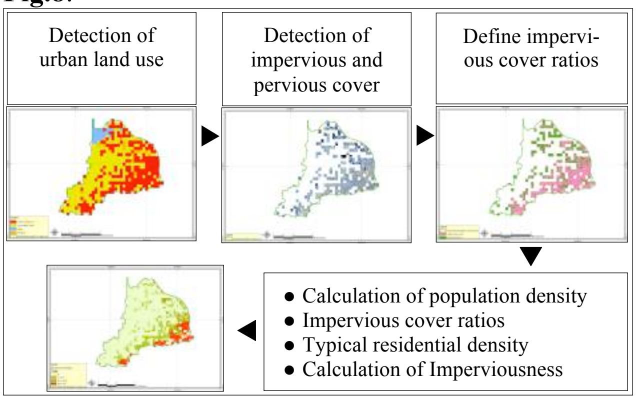

Fig.7 Procedures of creating impervious surface area ratios at macro scale

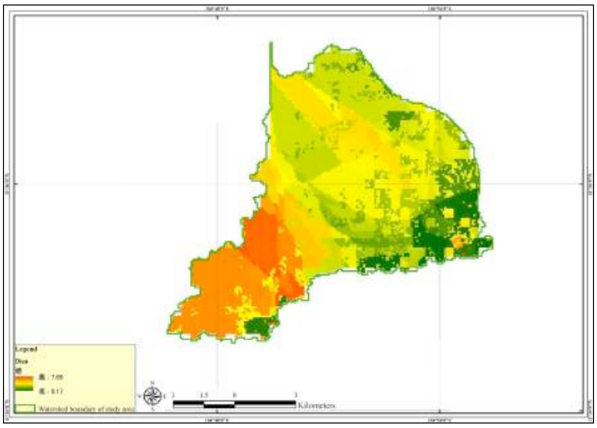

Fig.8 Depth above restrictive layer to account for impervious surface area ratios at macro scale

Topographical Index

From **Eq.(1)**, Topographical Index is compuated as shown in **Fig.9**. The higher the value of TI, it implies that certain places with higher topographical index are source of runoff or saturation excess.

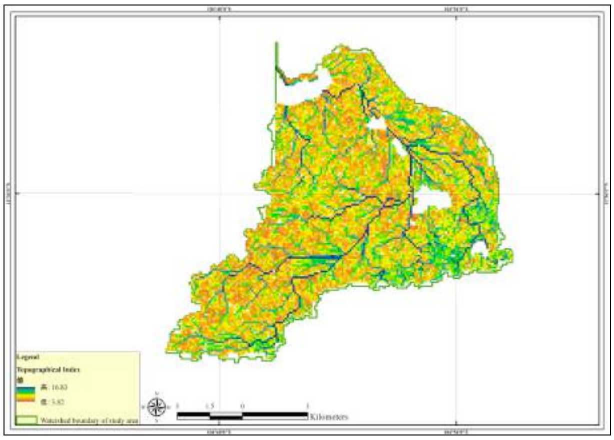

Fig.9 Topographical Index at macro scale

Threshold value for HSAs in PPC

Several sets of HSAs could be defined using different threshold values.Threshold value proposed by existing study[10] can not reflect on the actual condition of HSAs for PPC, therefore defining threshold value of PPC is essential. To identify threshold value for PPC, the existing result of food-ing simulation[18] is used for comparing the matching level of trialed threshold values of HSAs. The methods are summarized as shown in **Fig.10**.

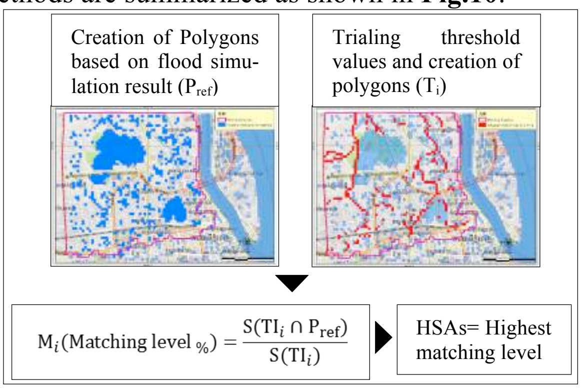

Fig.10 Methods to define threshold value of HSAs for PPC

Finally, 1.8 standard deviation above mean value of TI (11.21) is defined as threshold value of HSAs for PPC as shown in **Fig.11**.

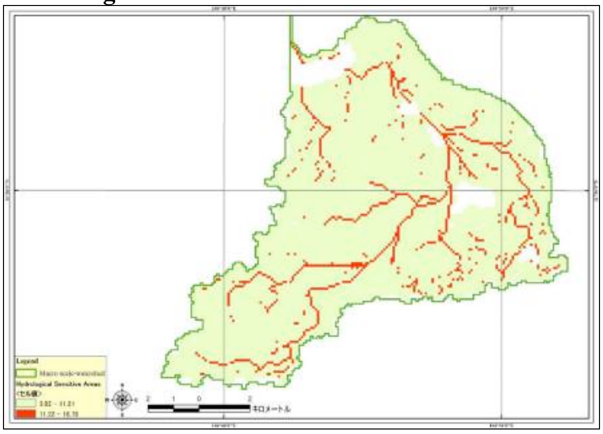

Fig.11 HSAs for PPC at macro scale

(3) Case study at middle scale

One middle scale watershed is used as case study to reflect on the HSAs, actual condition of HSAs based on the site survey and master plan in 2020 as shown in **Fig.12**.

From the overalying maps between HSAs and master plan in 2020, fourth development stages are defined including developed area, ongoing development area, redevelopment area and new development area with corresponding Hydrological Sensitive Areas (HSAs) are shown as in **Fig.12**.

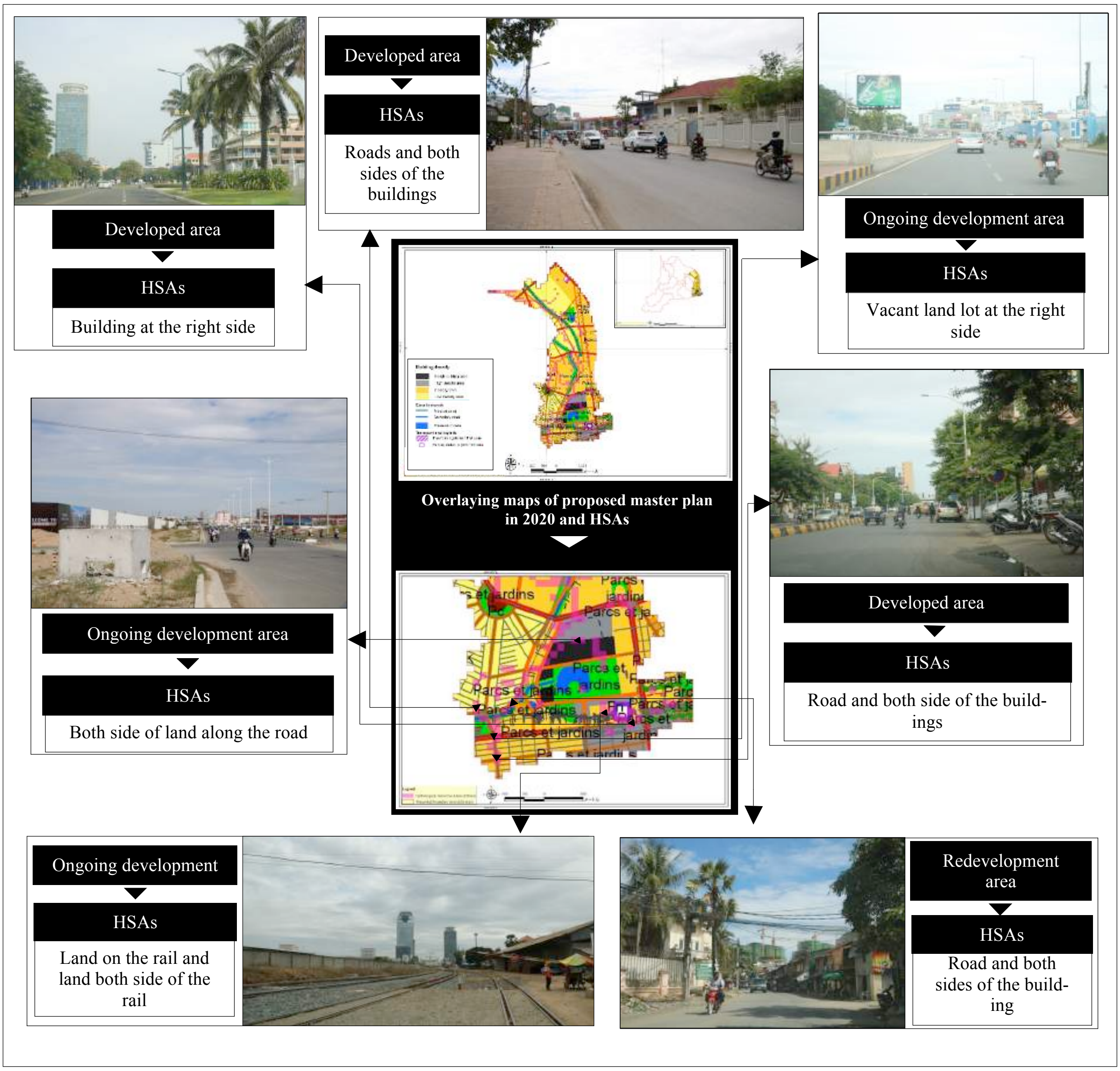

Fig.12 Development stages based on HSAs, Site survey and master plan in 2020

5. CONCLUSIONS

The combination of watershed unit and Hydrological Sensitive Areas (HSAs), source of runoff and extremely critical areas discussed on the urban development issue in developing countries, where is sensitive to urban flooding, is demonstrated at middle scale planning. Considering HSAs in the development plan enables planner to avoid for the development of the areas having high potential of incrasing flood risk. It can be used as indicator for controlling land use so that mitigation of urban flooding can be implemented right before it takes place.

Hints for both future and current development reflecting on the master plan and actual condition of HSAs at middle scale planning is illustrated. Understanding about these trends, on time measures based on the classified development status are grasped. For better future sustainable planning, in developed areas, ameliorating areas in term of retrofitting is taken into consideration. Alternatives can be proposed for the installation of green roofs, rain barrel, grass swales, bioretention, porous pavement, retention or detention introduced in the future researches. While ongoing development stage, modification of the early plan incorporated with above measures for reducing runoff is suggested. Whereas, in redevelopment stage, land use zoning method and design from watershed based planning perspective developed in this study can be considered. Prior to the redevelopment stage, application of developed method to the new development area can come out with more efficiency results since it begins with the method proposed at macro scale.

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