Spatial Multi-Criteria Analysis (SMCA) For Basin-Wide Flood Risk Assessment As A Tool In Improving Spatial Planning And Urban Resilience Policy Making: A Case Study Of Marikina River Basin, Metro Manila - Philippines

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Abstract

The Philippines is one of the most natural hazard prone countries in the world, especially for water-related disasters (floods and landslides) triggered by typhoon. This study is motivated by the extreme flooding incidence in Metro Manila and surrounding areas in September 2009 during the most devastating typhoon to hit the country named as Tropical Storm Ondoy. Highly urbanized cities of Metro Manila in the downstream of Marikina River Basin suffered the most and the degradation of the upper part of the basin in Rizal Province has been identified as one of the main causes of such massive flooding. The research employed spatially explicit methods of assessment by using spatial multi-criteria analysis (SMCA). At the first stage, analytical frameworks were developed for Basin-wide Flood and Landslide Risk Assessment that integrate Hazard, Exposure and Vulnerability components. Necessary steps were taken including geodatabase preparation, variables definition, standardization of parameters, weight assignment of indicators, and sensitivity analysis. At later stage, analysis was applied in ArcGIS 9.3 software environment to conduct risk mapping. Identified Very High Flood Risk Areas were also validated by Satellite Images.

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1. Introduction

According to World Water Development Report in 2006, during the decade of 1992-2001, about 90% of all natural disasters worldwide were water-related or hydrological in origin (UNESCO, 2006). The Philippines is one of the most natural hazard prone countries in the world, especially for water-related disasters (floods and landslides) triggered by typhoon (World Bank, 2005). The most devastating typhoon to hit the country was Tropical Storm Ketsana (local name: Ondoy) in 25 to 26 September 2009, which affected 4,342,997 people nationwide and almost half of the casualties was in the nation’s capital (NDCC, 2009). According to the same situation report by NDCC, in Metro Manila (National Capital Region/NCR) alone, the damage and casualty data include; 871,882 persons affected, 207 dead, 395 injured persons, and 52,958 partially damaged houses. Cities in Metro Manila, which are located in the downstream of Marikina River such as Cities of Marikina, Quezon and Pasig, suffered the most. Those cities accounted for 48% of total affected persons, 82% of the dead (mostly drowned during the flood), and 41% of the injured and 99.6% of partially damaged houses in Metro Manila.

During the typhoon, the rains generated record-magnitude flooding in the Pasig-Marikina River Basin (Liongson, 2010) in Metro Manila where the water level of Marikina River reached 22.16 meters at Sto.Nino station (World Bank study team, 2012) from a normal level of 12 meters and precaution stage when it is more than 13 meters. The degradation of the Marikina watershed or upper Marikina River Basin – located in Antipolo city, San Mateo, Rodriguez, Rizal Province - is being blamed as the main cause of such massive flooding (BusnessMirror, 2010; manilatimes, 2011; MWCI, AECOM, & PAMB, 2012). Therefore, management of river basin as a whole becomes crucial in reducing disaster risk of urban areas in Metro Manila.

Land use and utilization have implications to water flows and quality through run-off and pollution. These processes affect the ground water supply and contribute to erosion, surface water pollution and causes flooding. For that reason, water problems such as flooding, need to be managed in integrative way with land use planning and management. In the case of Ondoy Flood, the characteristic of the flood can also be categorized as riverine flooding rather than local flood, consequently reducing the underlying risk factors cannot be treated locally or confined within a city itself. The most efficient way to deal with water-related natural disasters is to manage them on a whole-of-catchment basis, where the causes and effects of disaster occurrence can be managed (UNESCAP, 1997). Therefore, river basin is a suitable spatial framework for disaster risk reduction (DRR) efforts, and those efforts need to be integrated into land use planning / spatial planning.

Due to different spatial planning system, not all countries have river basin/watershed land use planning that support more coordinated multiple-local land use plans within a river basin, especially under a highly decentralized planning system. In the context of the Philippines, land use planning is divided into national, regional, provincial, and municipality/city level. A formal land use plan at river basin/watershed level does not exist, and only at the municipality/city level, the land use plan has legal or administrative legitimacy that is when the Comprehensive Land Use Plan (CLUP) is enacted through Zoning Ordinance (ZO). So on one hand, integrating flood management plan or DRR down to the local level land use/spatial planning is definitely very important, because its legitimacy provides higher potential in achieving objectives compare to other plans. On the other hand, basin-based land use plan as a bridging component between riverine flood risk reduction and land local land use plans, is not part of the planning system.

Resilience can be considered as the other side of coin of “vulnerability”, and it related directly to coping and adaptive capacity to disaster hazard. Spatial Planning as part of planning system and policymaking is actually part of vulnerability from governance aspect. Therefore, by improving planning practices and management in Spatial Planning, by mainstreaming DRR concept and by using river basin as spatial framework, it is expected in the long run that it will contribute to reduce vulnerability of the system and eventually increase the resilience of Marikina River Basin as a whole and urbanized downstream areas in particular.

The usage of GIS method and maps in integrating components of risk is a common practice in many studies and projects related to risk assessment. Perhaps because it provides several advantages, such as; it is a powerful tool to identify and to visualize all the components of risk (hazard, exposure, and vulnerability), less data-hungry, less time consumption especially in a well-established geodatabase condition, easier to be communicated with the stakeholder and decision maker, and relatively user-friendly. These are in comparison with other methods such as statistical analysis and modeling. The spatial techniques with GIS that mainly used in this study is overlay analysis which
integrates different data layers to provide composite maps (Malczewski, 2004). The complete analytical framework of analysis is actually a GIS-assisted Multi-criteria Analysis (MCA) or also known as Spatial Multi Criteria Analysis (SMCA). SMCA is combination of MCA and GIS (Meyer, Scheuer, & Haase, 2009). It can be viewed as a process that combines and transforms spatial and aspatial data (input) into resultant decision (output) through procedures (or decision rules) that define the relationship between the input maps and the output map (Malczewski, 2004).

The objective of this research is to develop and to utilize SMCA tools for basin-wide flood risk assessment, as input for determining flood risk reduction measures especially through spatial planning interventions. It is expected that the result of the research can be useful as input for improving Comprehensive Land Use Plans (CLUPs) of cities and municipalities within the Marikina River Basin/Watershed. One among others is by promoting coordinated trans-boundary land use plans which look at each local territory as part of a bigger watershed region/basin, and at the same time mainstreaming risk-sensitive land use planning.

2. Findings

During the profiling and data gathering to prepare geodatabase for risk components (hazard, exposure, vulnerability), there many information regarding the trend and current state of geo-physical and human environment in the basin, that explain clearly the factors contributing to the high risk and vulnerability to disaster risk (especially flood) in the study area.

2.1. Relatively high susceptibility to flood and landslide hazard due to geophysical and meteorological characteristics

Almost half (48.22 %) of basin are moderately to very steeply mountainous areas which are mostly covered by low permeability soil (clay), thus high run-off potential. The downstream sub-watershed only covers 11 % out of total watershed/basin, meaning that the small portion of downstream has to drain water from the rest 89 % areas of upstream. There is a short duration of dry season, and historically extreme rainfalls brought by typhoons often occur. Overall, about half (44 to 55 %) of the basin is highly susceptible to landslide especially in the upstream, while more than half of the lowland or the downstream area of the basin is highly susceptible to flooding.

2.2. Rapid Urbanization, urban densification and sprawling in the lowland and diminishing forest cover in the upland

By using data at barangay/village level (NSO Population census), the estimated total population of Marikina River Basin in 2007 is 2,150,512 people, which is a 25 % increase compare to the year of 2000. Analysis of time-series population data also reveals the extremely high population growth rate in this urbanizing river basin. Within three decades (1980-2010) population size of each LGUs in the fringe of Metro Manila and also the upstream areas of the basin (City of Antipolo, Rodriguez, San Mateo) have increased almost four times to almost ten times, while the LGUs in Metro Manila and the downstream areas (Cities of Quezon, Marikina, and Pasig) doubled or almost tripled.

The remote sensing analysis by using time-series satellite images from year 1972 to 2009 also shows the trend of urban areas sprawling toward upstream, north direction of Marikina valley (Quezon City, San Mateo, and Rodriguez) and east direction (Antipolo City) especially in Nangka Sub-watershed. This trends lead to more land conversion from agriculture or vegetated areas into built up areas. By year of 2009, the remaining forest cover is only 14 percent out of total basin area. In the lowland, urban densification continuously diminishes the vegetation or pervious land cover and at the same time increases population exposure to flood hazard.

2.3. Presence of Informal settlers in lowland and migrants in upland

The informal settlers in the downstream especially in the Cities of Quezon, Marikina, and Pasig, construct their shanties along rivers and creeks, thus, impeding the flow of water. They are also significant contributors of waste
into the waterways. From a DRR perspective, they increase the number of vulnerable population to flood disaster. Upland migrants in the forestland especially in Antipolo City has also increased and brought the problem of unsustainable farming practices that contribute to forest denudation, erosion, and sedimentation in the downstream.

2.4. Unsustainable land use practices in the upstream that lead to soil degradation, erosion and sedimentation

These issues mainly take place in forestland in the upper part of Marikina River Basin, which is covered by the administrative boundaries of Antipolo City, San Mateo and Rodriguez. Land cover changes analysis reveals that massive loss of dense vegetation cover or deforestation probably took place within the period of 1972 to 1993 but then the rate slowed down afterward. Besides forest denudation, unsustainable land use practices such as kaingin or slash and burn farming, charcoal making and timber poaching, mining and quarrying, logging, piggy also continued to happen. These problems contribute to increased soil erosion, sedimentation in Marikina River system, surface water siltation and pollution. Increasing lowest bed elevation in lower Marikina River and decreasing channel flow capacity are concrete evidences of sedimentation caused by soil erosion in the upstream.

2.5. Administrative Boundary Disputes and Overlapping land tenure instruments

After mosaicking administrative boundaries from each LGU within the basin, there are 9 percent areas (5,000 ha) of overlapping boundaries in the upstream of the river basin and 2 percent (1,006 ha) uncovered by city/municipal boundaries. Watershed Forest Reservation (WFR) now called Upper Marikina River Basin Protected Landscape (UMRBPL) is also having problems with overlapped land tenure instruments in the forestland. Overlapping authority and lack of clarity of property rights will impede any efforts for management plan implementation.

2.6. Flood and Landslide Hazard

The Proposed Alternative Flood Hazard Map in this study was derived by combining the WB & DPWH flood map with MGB Flood Map, and assigning the hazard level. While the Landslide Hazard Map is modified from Geo-hazard Map of MGB. Combining them as multi-hazard map (flood and landslide), It shows that almost half (44%) of the basin is highly susceptible to landslide, mostly located in the upper part such as in Antipolo City and Municipal of San Mateo and Rodriguez. While more than half of the downstream area, mostly in Cities of Marikina, Quezon, and Pasig, is highly susceptible to flooding.

2.7. Population and Asset Exposure (Physical Vulnerability) and Socio-Economic Vulnerability

The map that depicted the spatial distribution and defined ranges/classes for each of the exposure and vulnerability sub-indicators reveals several interesting spatial patterns. Population and building density are significantly concentrated along Marikina River, especially in the lower part, thus higher exposure to flood disaster. As we scrutinized from downstream (near or within Metro Manila) to the upstream (Province) of the basin, the dependent population (children and elderly) and population with low education level is increasing, thus the vulnerability is increasing across space and across time. People who lived in the city and municipalities (San Mateo, Rodriguez and Antipolo city) neighboring Metro Manila mostly do not really work there. Except in certain barangays that are located in the mountainous areas such as Marikina Watershed Reservation or having dumpsites and quarrying sites. These spatial patterns mostly coincide with the spatial pattern of population with occupation as farmers and forestry workers.

2.8. Resulted Flood Risk Mapping

The resulted flood risk assessment is composed of five risk levels, namely very low, low, moderate, high, and very high. From the Figure 4, several hot spots or the very high-risk areas can be identified, namely (from lower to upper); Barangay Kapasigan and Santolan (Pasig City) and Barangay Industrial Valley Complex (Quezon City). Most of the barangays along Marikina River in Marikina City especially Barangay Malanday, Tumana, and Nangka; Sta. Ana, Guitnang Bayan I & III (San Mateo); and Barangay Manggahan (Rodriguez). Most of these barangays are
located in Marikina and Nangka Sub-watersheds.

After validation of these identified Very High Flood Risk areas using high-resolution satellite images from Google Earth, it shows clearly that most of those areas are settlement located right next to Marikina and Nangka Rivers. The images depicted very dense building areas with irregular road pattern similar to the characteristics of slums or informal settlements. Cross checking with the data from Marikina City Settlement Office, Barangay Tumana and Malanday are indeed among the targeted informal settlers to be relocated. For example, the data from that office shows that there are 7,015 households of informal settlers in Barangay Tumana. Until this point, the resulted flood risk map derived from the SMCA analytical framework is proven logical.

Table 1. Properties of Resulted Flood Risk Map based on Hazard, Exposure and Vulnerability

| Risk Level    | Hazard                          | Exposure        | Population Density | Building Density | % of Dependent Age | % of Low Income Level | % of Low Education Level | % of Dependency to locality | Access to Water Supply |
|---------------|---------------------------------|-----------------|--------------------|------------------|--------------------|----------------------|------------------------|--------------------------|------------------------|
| Very High (5) | level 5 (> 3 m flood depth)     | high to very    | high               | high to very high| mostly medium to very high | low to medium        | mostly medium to very high | mostly medium to very high | mostly uncovered         |
| High (4)      | mostly level 4 and 5 (2-3 m and > 3 m) | medium to very high | mostly low to very high | low to very high | low to high       | low to very high     | low to very high       | low to very high         | covered and uncovered   |
| Moderate (3)  | mostly level 2 and 3 (highly susceptible & below 2 m) | mostly medium to very high | mostly low to high | low to high | low to medium | mostly low to very high | low to very high | low to very high | covered and uncovered   |
| Low (2)       | level 1 and 2 (low to high susceptible) | very low to high | very low to high | medium to high | very low to low | low to high | mostly low to medium | mostly covered |
| Very low (1)  | Level 2 (high susceptible)      | No Data         | No Data            | No Data          | No Data            | No Data             | No Data             | Covered                 |

For the purpose of formulating the relevant policies and communicating flood risk map to the stakeholder and decision makers, the properties of every risk level need to be elaborated in order to avoid misinterpretation (see Table 2). For example, the very high-risk areas do not necessarily mean having the worst condition for each of the risk components (Hazard, Exposure and Vulnerability). The presence of interaction of weights and ratings among these components during the aggregation or analysis process is actually one of the strengths of multi-criteria analysis. One simple example would be, an area with very high level of flood hazard (>3 meters of flood depth), very low exposure and high vulnerability, probably will have moderate risk level. However, the weakness also lies with the data that varies in resolution, which can result in deviation. For example the population density is an estimation using statistical data and under assumption that population is distributed equally across geographical space. Probably because of that condition, one the areas identified as very high risk areas in San Mateo also cover the agricultural land along the river.

3. Discussions

Spatial planning roles in flood risk management can be viewed in a narrow or broader way. A narrow one sees spatial planning as regulatory instrument to control land use change in flood prone areas (Hutter, 2007). While a broader view sees spatial planning as facilitation of participation and conflict resolution among different spatial claims (Neuvel&Knaap, 2010). In line with the broader view, Howe and White (2004) mentioned that inclusion of flood management measures in the land use plans would be beneficial because these measures become part of statutory plans and will attract public consultation. Spatial plans can also contribute in integrating urban design features that enable an increase in storage capacity of an area and to increase infiltration level, thus reducing run-off and peak flow (Howe & White, 2004).

“Making space for water or river” is an emerging policy and strategy of flood management in European countries, as exemplified in Netherland, UK and Belgium (Kelly & Garvin, 2007; Woltjer& Al, 2007). It symbolizes...
the shifting paradigm of flood management from flood defense perspective, which focuses on flood control by means of structural measures to drain water as fast as possible from certain areas, to a more sustainable approach by employing non-structural measures. Thus, flood plain management becomes important and the incorporation of flood management into land use / spatial planning even more crucial.

In most cases, the “space for water” as mentioned above is equal to flood plains or flood risk zones. The most common linkages between land use planning and flood protection is flood plain management. Floodplain zoning constitute an important tool to operationalize a risk-sensitive approach and it can be undertaken on the basis of floods of different average annual exceedance probabilities (the most commonly used for land-use planning purposes is the 1 percent or 100 year return period) (WMO, GWP, & APFM, 2007).

Risk map is dynamic or it may change over time, especially due to the changes in the socio-economic vulnerability components, while hazard can be considered relatively less dynamic. Therefore, the other alternative of defining flood plain is based on hazard level. For examples flooded area > 2 meters as flood way and below 2 meters as flood fringe. The definition of flood plain (flood way and flood fringe) and enforced by law like in US does not exist in the Philippines until now. However, as exercise to identify which areas that need spatial planning interventions, analysis of land use plans compatibility with flood plain can be conducted as input. Based on GIS map calculation result, an area of 1,082.26 hectares in the lowland Marikina River Basin is considered as flood way and about 818.93 hectares as flood fringe. The extent of local spatial plans in accommodating that floodplain (floodway and flood fringe) can be analyzed from the compatibility of allocated land use plan/zoning by each LGUs with the type of land uses considered appropriate in floodplain. For example, Agricultural Zone and Parks/Open spaces/Recreation can be considered compatible in flood way, while High Density Commercial Zone and High Density Residential Zone are definitely incompatible in flood way. In the flood fringe, the appropriate land uses should be low intensity/ low density development with adequate flood proofing measures. The result of the GIS maps overlay analysis show that there are 20 percent compatible land uses, 8 percent moderately compatible, and 72 percent incompatible land uses in the floodway. While for the flood fringe, there are 17 percent compatible land uses, 5 percent moderately compatible, and the rest 78 percent is incompatible. This result shows that the allocated land use plan and spatial measures to mitigate the problems are inadequate especially in the local spatial plans. Coupling this land use compatibility map and flood risk, it will provide aid tool for stakeholder consensus on DRR policies.

4. Conclusions

Conclusions can be drawn from this research as follows:

- The trend and current state of geo-physical and human environment in Marikina River Basin explain clearly the factors contributing to the high risk and vulnerability to disaster risk (especially flood).
- River Basin Land Use Plan is urgent, to improve coordination and integration. River basin master plan or a formal spatial plan for Marikina river basin does not exist. Therefore, there is no planning instrument acting as direct interface of integration between basin-wide flood management plan and local land use plans. The existence of River Basin Land use/ master plan will be beneficial to make more detail spatial allocation such as delineation of floodplain (floodway and flood fringe), and to mediate upstream and downstream water conflicts.
- The spatial multi-criteria analysis tools for disaster (flood & landslide) risk assessment developed in this research can serve as input for decision making to determine appropriate land use options that can tackle flood concerns. In other words, it can help to spatially mainstream disaster (flood & landslide) risk reduction into Spatial Planning and to help in prioritizing of areas to be tackled.
- Risk-sensitive and water-sensitive land use planning at the river basin/watershed level is the most suitable spatial framework and platform to integrate water-related disaster risk reduction (DRR) into local spatial planning, in order to achieve more a coordinated local land use plans (CLUPs) that lead eventually to increased urban resilience in Metro Manila and surrounding areas
- The main characteristic of Multi Criteria Decision Analysis as used in the study is the uncertainty due to the aggregation processes involved and the critical parts of the technical sum-weighted overlay method which include defining the ranges of values (class definition), rating (score/index), and assigning weight. At least there are three level of aggregation conducted, at the class definition level, sub-indicator level and lastly at
indicator level. Necessary steps were conducted to minimize the uncertainty and the validation of results identifying very high-risk areas using Google earth images shows the reliability of the analytical framework used in the study.

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