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A RAPID SCREENING METHOD FOR ECOLOGICAL RISKS POSED BY DIFFERENT LAND USE INTENSITIES
Case Study of Marikina City's River System

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ABSTRACT

Land use plays an important role in environmental and sustainability research because of its potential contribution to ecosystem protection or degradation. However, most risk maps used in comprehensive land use planning only identify areas *at risk*, for example, to various geophysical or climate- and weather-related hazards. It would also be useful to identify land areas that *pose a risk* to ecological systems. In this study, a simplified method adapted from the source-habitat approach and the relative risk model was used to explore the potential ecological risk of exposure to water pollutants posed by land uses on the river system in Marikina City. Geographic Information Systems (GIS) was used to relate the type and intensity of land use (the stressor/source) to the quality of the Marikina River system (the receptor/habitat) via proximity and drainage connections to the river system. The spatial processing of the risk components showed that overall, the Mixed-use Zones followed by the Socialized Settlement Zones posed the highest ecological risk to Marikina's river system. The method developed can provide stakeholders with a rapid screening approach to identify zones needing more comprehensive analysis in the process of land use planning and developing management policies that can help protect the river ecosystem.

KEYWORDS

ecological risk assessment, geographic information systems, GIS

INTRODUCTION

The quality of the water bodies in Metro Manila has continuously deteriorated because of the rapid increase of human population and industrialization coupled with the surge of urbanization (Jalilov, 2018; Yu & Sajor, 2008). The Marikina River, one of the five river systems that passes through Metro Manila, is not exempted from this deteriorating water quality (Kumar, Masago, Mishra, & Fukushi, 2018; ADB, 2008) because of the unrestrained disposal of domestic, industrial, and solid wastes. An inventory of Philippine water pollution sources indicates that the majority of the sources of water pollution are domestic wastewater discharges (i.e., those coming from the informal settlers) and industrial sources (EMB, 2014; Cabading, 2007). Land use and human activities are major contributors to poor water quality and they determine the kinds and amounts of contaminants that flow into nearby inland waters. Research on land use and human activities is crucial since they do not only affect these river ecosystems, which are complex mosaics of habitat types and environmental gradients, but also affect the nearby communities at multiple scales and through different exposure pathways (Allan, 2004).

The land uses within the surrounding areas of the Marikina river system, as well as its associated human activities, influence the quality of its water. Therefore, land management practices must incorporate the spatial complexity and connectivity of its different biotic and abiotic components. At the same time, there is a need for an effective and transparent means of relaying information on the effects of anthropogenic activities on various ecological assets. The Comprehensive Land Use Planning (CLUP) process of local government units (LGUs), including that of Marikina City, typically considers areas *at risk* to various hazards, but it would also be useful to identify land areas that *pose a risk* to ecological systems such as rivers.

Ecological risk assessments (ERAs) provide a systematic evaluation of the interactions between ecosystem disturbances and the ecosystem at risk, thereby offering a sound basis founded on scientific facts, laws, and relationships to develop protective and regulative measures and management policies for the ecosystem of interest (US EPA, 1998). ERAs have been utilized to estimate the effects of single pollutants to onsite-specific environments (Breton, Teed, & Moore, 2003; Qu, Chen, Bi, Huang, & Li, 2011). The stressor-receptor approach is often used in this case—the risk of a certain adverse impact or response is seen as arising from the exposure of a specific receptor (e.g., an endangered species) to a stressor (e.g., a chemical contaminant). ERAs have been used to evaluate the effects of multiple risk sources (i.e., multiple pollutants, anthropogenic activities, natural disasters) on a broader scale given the fact that landscape characteristics are heterogeneous (Yang, Mao, Li, & Gao, 2011) and that many environmental problems have impacts that are geographically larger in scale (Graham, Hunsaker, O'Neill, & Jackson, 1991) affecting numerous ecological assets (O'Brien & Wepener, 2012).

The urban ecosystem is an example of a broad area containing multiple stressors related to anthropogenic activities affecting a variety of receptors through complex exposure pathways (Hua, Shao, & Zhao, 2017). Urban ecosystem risk assessment has been growing as a field in recent years given its importance in providing inputs to the urban planning processes, (Hua et al., 2017) and approaches of regional risk assessments can prove useful here. "Regional" in this context refers to broad areas having definable characteristics, e.g., ecological characteristics, and should not to be confused with the administrative boundaries of a city or country. Regional risk assessments, as opposed to localized, traditional risk assessments, evaluate risk at a level that incorporates spatial characteristics and contains multiple stressors affecting multiple receptors (Hayes & Landis, 2004). These broad-scale risk components are similar to the traditional risk components in that stressors, receptors, and responses are represented as groups, i.e., a group of stressors is known as a source, which affect an exposed group of receptors in a habitat resulting in a multitude of possible impacts and interactions (Landis & Wiegers, 1997).

Where a quantitative calculation of risk probabilities becomes a time-consuming process due to the multiplicity of stressors and receptors, a relative risk method (RRM) can be used as part of a broad-scale ERA. The RRM is an approach, in the context of a broad-scale assessment, that involves identifying and ranking sources of stressors, and the exposures of and impacts on habitats, then integrating this information to produce relative levels of risk (Landis, 2004). In many cases, this integration is achieved by calculating an overall risk score through the use of Geographic Information Systems (GIS) (e.g., as seen in Hayes & Landis 2004; Bartolo, van Dam, & Bayliss, 2008). The value of the RRM is in the ability to quickly assess the importance of sources and habitats based on stakeholder-defined criteria to be able to set relative risk management priorities (Teng, Zuo, Xiong, Wu, Zhai, & Su, 2019; Liu, Zhang, Zhang, & Borthwick, 2018; Hua et al., 2017; Bartolo et al., 2008; Hayes & Landis, 2004; Wiegers, Feder, Mortensen, Shaw, Wilson, & Landis, 1998).

GIS methods have been incorporated to combine the multitude of stressors or threats, habitats of concern, and assessment endpoints (manifestations of impacts) by providing a spatially-explicit and comprehensive means of ranking these risk components and filtering each possible combination or interaction. GIS, as a spatial analysis technique, allows for the manipulation of large and complex datasets and the evaluation of complex interactions of the different components in the ecosystem being investigated (Chow, Gaines, Hodgson, & Wilson, 2005; English, 2007). For example, studies done in the Poyang Lake Eco-economic Zone of China used ArcGIS to explore ecological risk due to changes on its land use (Wang, 2021; Xie, Wang, & Huang, 2013). Findings reflect that regions with high ecological risk were predominantly in urbanized and industrialized areas due to the level of human disturbance (Wang, 2021; Xie et al., 2013). Land fragmentation due to agricultural exploitation also tended to increase ecological risk (Xie et al., 2013). Cui, Zhao, Liu, et al. (2018 used remote sensing, ArcGIS, and geostatistics to characterize the spatio-temporal characteristics and landscape patterns of ecological risk in Qinling Mountain wherein the research found that urban construction was also driving increases in ecological risk. Cooper (2011) utilized GIS to perform relative risk ranking to watersheds in Thompson Region, British Columbia based on their level of risk posed by anthropogenic impacts on water quality and stakeholders. Characteristics of the watersheds that were investigated included the different water and land uses within the watershed. Areas with the greatest risk comprised attributes relating to agriculture, mining, roads, and urban development in general, contributing to pollutant and/or sediment runoff.

The purpose of this study is to develop a rapid screening method to assess the risk of exposure of the Marikina River system to effluents from the different urban land uses. This method adapts the source-habitat approach and RRM for ERA and operationalizes it using GIS, specifically the ArcGIS platform. Given the time and resources needed for a comprehensive broad-scale ERA, this method is intended for use within the CLUP process of the LGUs as a quick and inexpensive way to identify zones requiring more in-depth study and, potentially, more regulation. The CLUP process includes the determination of zones and zoning ordinances. Thus, this study used maps based on zoning ordinances (rather than actual land use) to demonstrate the method. It is meant to be a rapid screening method for proposed land use to identify areas that may require further study before the proposed zoning ordinances are enforced. Prioritization of localities for more comprehensive study may be necessary when resources are limited, given the cost of establishing monitoring systems. Thus, the results of the rapid ERA can also provide input to management approaches. In this study, this method is employed to evaluate and map the ecological risks on Marikina City's river system that are associated with anthropogenic activities such as the manufacture of shoes, bags, and other small leather items; food processing; and other service-oriented activities such as parlors, internet cafes, and boutiques to name a few that occur in the different land uses within the city. Specifically, the assessment focuses on the risk posed by effluents from the intensity of the city's land uses (the sources) on the aquatic ecosystem (the habitat).

METHODOLOGY

Study Area

Marikina is one of the 16 cities comprising Metro Manila. The city, which is composed of 16 barangays and has a total land area of approximately 2,150 hectares (Marikina City Government, 2013a). It lies in a valley within 14.65°N, latitude and 121.10°E longitude (Marikina City Government, 2013b) . The Marikina River flows through the center of Marikina Valley, alongside the Valley Fault Line, between Capitol Hills and the Sierra Madre mountain range. The river has a length of 11 kilometers with a drainage area of 534.80 square kilometers (Marikina City Government, 2013a; Tachikawa, James, Abdullah, & Desa, 2004). Upper Marikina River is categorized as Class A (EMB, 2014), which is suitable as a source of completely treated public water supply (EMB, 1990). Its lower portion is categorized as a Class C (EMB, 2014) river suited for aquatic organism breeding, recreational activities (i.e., boating), and post-treatment industrial/manufacturing water supply (EMB, 1990). In addition to the main river, Marikina City also has a number of creeks or tributaries (Marikina City Government, 2013a).

Paradoxically, while the business school curriculum asks future leaders, i.e., students, to learn about leadership and management from multiple functional perspectives, business school programs themselves are not integrated across functions. Add to this lack of cross-functional perspective the belief that leaders should not value social and environmental systems in decision-making and the stage has been set for business-as-usual.

The zoning/land use classifications of the city, pursuant to the Marikina City Zoning Ordinance No. 303, Series of 2000, are divided into the following: (1) residential, (2) socialized housing zone and areas for priority development (APD), (3) commercial, (4) industrial, (5) institutional, (6) parks/open space/recreational, (7) cemeteries, and (8) cultural heritage zone (see Figure 1). The four major land uses in terms of existing land area in the city are the residential, commercial, mixed-use, and institutional zones (Marikina City Government, 2013a). The residential, commercial, and industrial zones are further subdivided into the low density (R-1, C-1, I-1), medium density (R-2, C-2, I-2), and high density (R-3, C-3, I-3) categories, which are defined by their principal uses (dominant uses or activities) and accessory uses (support uses), building height restrictions, number of units (where applicable), and by their contribution as a potential hazard/pollution source (for Industrial uses). The zoning map in Figure 1 is based on the zoning plan as has been enforced through the said ordinances from year 2000 and is consistent with the CLUPs published since then (Delos Reyes & Espina, 2016), the latest being the CLUP for 2013–2020 (Santos, 2017). This map was provided as a shapefile from the Marikina LGU.

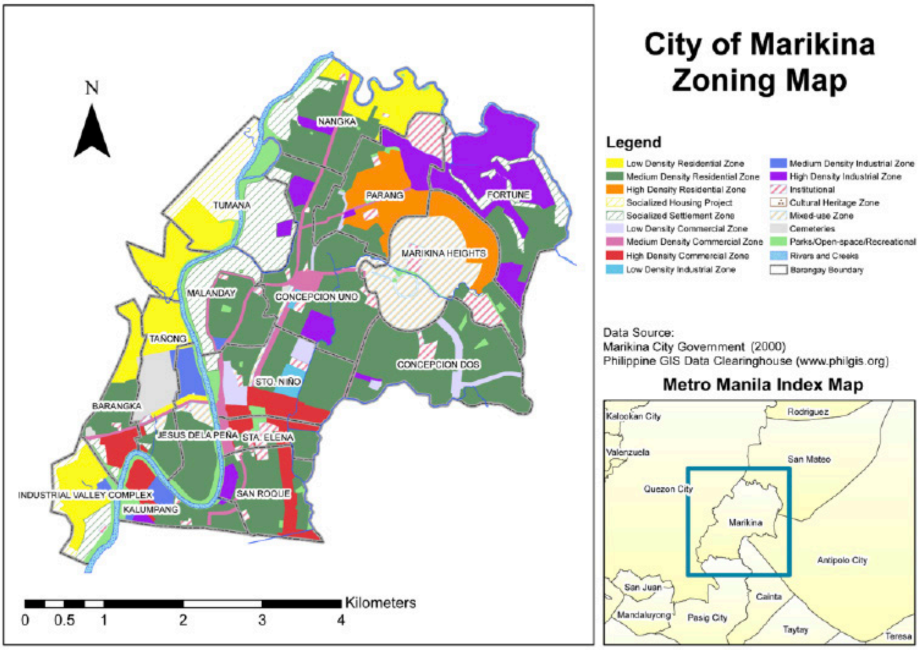

Figure 1: Zoning Map of the City of Marikina

Low density zones are only permitted to accommodate single family/detached dwelling units with a density of 20 dwelling units and below per hectare for residential areas; establishments that operate for a neighborhood size population of approximately 100 families for commercial areas; and manufacturing/processing establishments that are non-pollutive/non-hazardous and non-pollutive/hazardous for industrial areas (HLURB, 2014). Medium density zones accommodate housing, commercial, service, institutional, and other uses on a barangay scale (i.e., 21 to 65 dwelling units per hectare) for residential and commercial areas, and manufacturing/processing establishments that are pollutive/non-hazardous and pollutive/hazardous for industrial areas (HLURB, 2014). High density zones contain a mix of neighborhood-scale and metropolitan-scale commercial developments and high density/high rise dwellings (i.e., 66 or more dwelling units per hectare) for the commercial areas and residential areas, as well as manufacturing/processing establishments that are either: (a) highly pollutive/non-hazardous; (b) highly pollutive/extremely hazardous; (c) non-pollutive/extremely hazardous; and (d) pollutive/extremely hazardous (HLURB, 2014; Marikina City Government, 2000).

Socialized housing zones are allotted for the underprivileged and homeless where commercial uses are allowed only for those that are family-oriented (HLURB, 2014; Marikina City Government, 2000). Parks, open-space, and recreational zones are used primarily for parks, playgrounds, gardens, open spaces, outdoor recreational activities, sports, and other recreational land uses (HLURB, 2014; Marikina City Government, 2000). Cultural heritage zones are used primarily for mixed institutions and structures that contribute to the nation’s cultural heritage, and all other uses that have historical significance to the community such as museums, amphitheaters, and old houses (HLURB, 2014; Marikina City Government, 2000). Institutional zones are used mainly for government and private institutions providing services for the entire community, for the region, or for the country as a whole, and which are governed by specialized regulations including mental hospitals, rehabilitation and training centers, military and security services, and other services of the same nature and character (HLURB, 2014; Marikina City Government, 2000).

Marikina has emerged as a city known for its shoe manufacturing industry. However, the proliferation of industrial plants such as tobacco/cigarette manufacturing (e.g., Fortune, Philip Morris), food processing (e.g., Delfi Foods), tire manufacturing (e.g., Goodyear, closed in 2004), firearms manufacturing (e.g., Armscor), chemical plants (e.g., Paramount, Mc Cor, GM Chemical), textile (e.g., Manila Bay Spinning Mills), and ceramic plants (e.g., Noritake) also brought about the increase of urban settlements in the city (Marikina City Government, 2013c). The growth of Marikina unfortunately resulted in the deterioration of the Marikina River due to waste disposal from factories and domestic sources (Marikina City Government, 2002).

Adapting the Relative Risk Model and the Source-Habitat Approach

Sources are the groups of stressors or entities that can bring about harmful responses on the structure and function of an ecosystem, while habitats are the areas or ecosystems where ecological impacts due to the stressors are manifested (Landis & Wiegers, 1997). The RRM is one of the approaches in performing a broad-scale ecological risk assessment. It integrates the spatial aspect of multiple ecological entities and endpoints into the risk assessment process. This model ranks the sources of stressors and habitats in sub-regions, measures quantitatively (i.e., by scoring) the interactions between them and the possible effects they trigger, and, consequently, calculates the risk based on these factors in the regions of the study area (Liu et al., 2018; Bartolo et al. , 2008; Hayes & Landis, 2004; Wiegers et al., 1998). The RRM method assigns scores, typically on a scale of low, medium, and high, to the exposure of habitats to different sources and the associated impacts given context-specific criteria (Hua et al., 2017).

The extent of interactions between the sources and habitat indicates the level of ecological risk (Landis & Wiegers, 1997; Wiegers et al., 1998). With this in mind, we adapt a simplified version of the RRM to assess the risk of exposure of the Marikina River system. Given the intended use as a rapid screening method to be incorporated into the CLUP process, the “sources” to be considered refer to the intensity of the different land use types as reflected in the zoning map of the city. The specific habitat is the Marikina River system. To characterize the risk of exposure of the Marikina River system to the effluents coming from the different zones, two factors are considered: the distance of the zone to the river or its tributary, and the extent of the drainage system that would carry the effluent (literally, the exposure “pathway”) to the river system. While a sewage treatment plant began operation north of the city about four years ago, not all of the barangays of Marikina are connected to this facility and informal settlements would not be covered. We, therefore, assumed the worst case scenario of effluents draining into the river system directly.

Shapefiles on the zoning map, drainage systems, and Marikina River system were provided by the Marikina local government, while shapefiles of political boundaries were obtained through the open platform PhilGIS. The ArcGIS software was used to process and overlay the shapefiles towards calculating an ecological risk score as described in the succeeding sections. A flowchart for the GIS-based processing can be found in Figure 2.

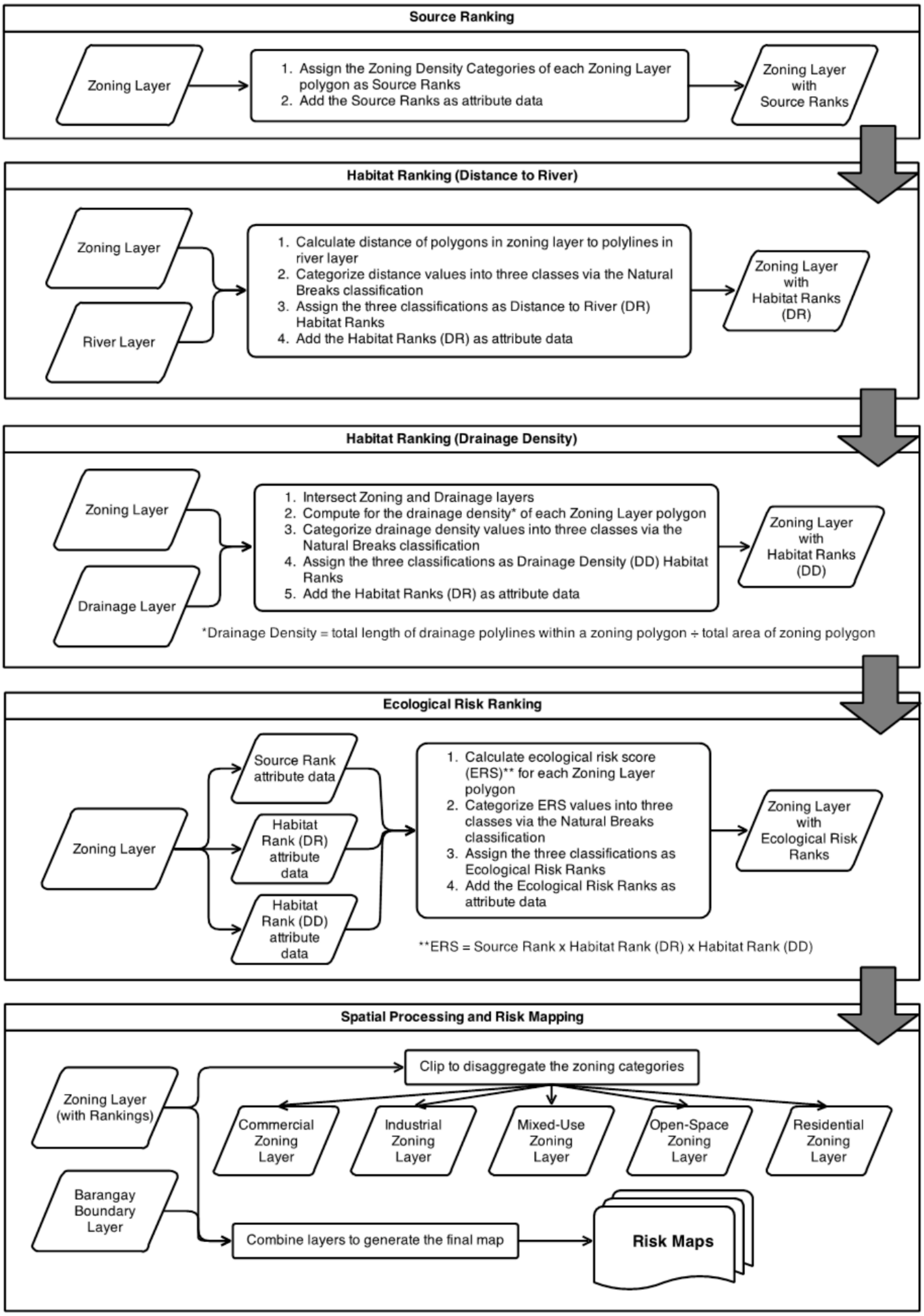

Figure 2: Diagram of the Flow of Data and GIS-based Data Processing

Defining Source Characteristics and Ranking

For this study, the sources were based on the different zoning/land use types of the city of Marikina (see Figure 1). Anthropogenic activities associated with these land uses were considered to exert pressures on its surrounding ecosystem (e.g., through the discharge of domestic effluents or industrial emissions). As the intensity of the land use within the city increases, so does the potential for contamination from both non-point and point source pollution. The zoning/land use types were grouped into five categories to collectively describe the combined attributes of individual land uses that influence water quality: (1) Commercial; (2) Industrial; (3) Residential (including socialized housing projects and settlement zones); (4) Mixed Use (cultural heritage areas, areas used for institutional/government infrastructures, and other mixed uses); and (5) Open Spaces (cemeteries, park space, and recreational space).

Sources are scored depending on the level of intensity (i.e., density of structures) of the land use within each of the different zoning subcategories. The zoning areas assigned a numerical score of 1 have a ranking category of *low*; those given a score of 2 are assigned a ranking category of *moderate*; while those that have a score of 3 are assigned a ranking category of *high* (see Table 1). In the case of Marikina Heights, there was a discrepancy between the shapefile provided and published accounts. The former identified the area as predominantly mixed use while the latter designated the area as predominantly medium-density commercial. Upon verification with Google Earth, we have maintained the classification of the shapefile, which is erring on the side of caution given that mixed use is ranked higher than the medium-density commercial use. Note that since the scores for the source ranking are based on the intensity of use (as indicated by the density) rather than the actual type of use, comparisons cannot be made across zone classifications representing different land use types. The Source Ranking Map can be seen in Figure 3.

Determining Habitat Characteristics and Ranking

For this study, the habitats at risk are based on the Marikina River system, which includes the main river and the creeks, as well as the city's entire drainage system. Effluents produced by the sources are assumed to discharge into the river system either directly or through the sewage lines. Therefore, the rankings for the habitat include two score categories: (1) distance to river (DR), which refers to the physical

Categories of Sources	Subcategories of Sources	Source Rank	Numerical Score
Commercial	Low Density Commercial	Low	1
	Medium Density Commercial	Moderate	2
	High Density Commercial	High	3
Industrial	Low Density Industrial	Low	1
	Medium Density Industrial	Moderate	2
	High Density Industrial	High	3
Residential	Low Density Residential	Low	1
	Medium Density Residential	Moderate	2
	High Density Residential	High	3
	Socialized Housing Project	High	3
	Socialized Settlement Zone	High	3
Miscellaneous/ Mixed-use	Cultural Heritage	Low	1
	Institutional	Moderate	2
	Mixed-use	High	3
Open-space	Cemeteries	Low	1
	Park/Open-space/Recreational	Moderate	2

Table 1: Summary of Sources and Their Respective Density Ranks and Numerical Scores

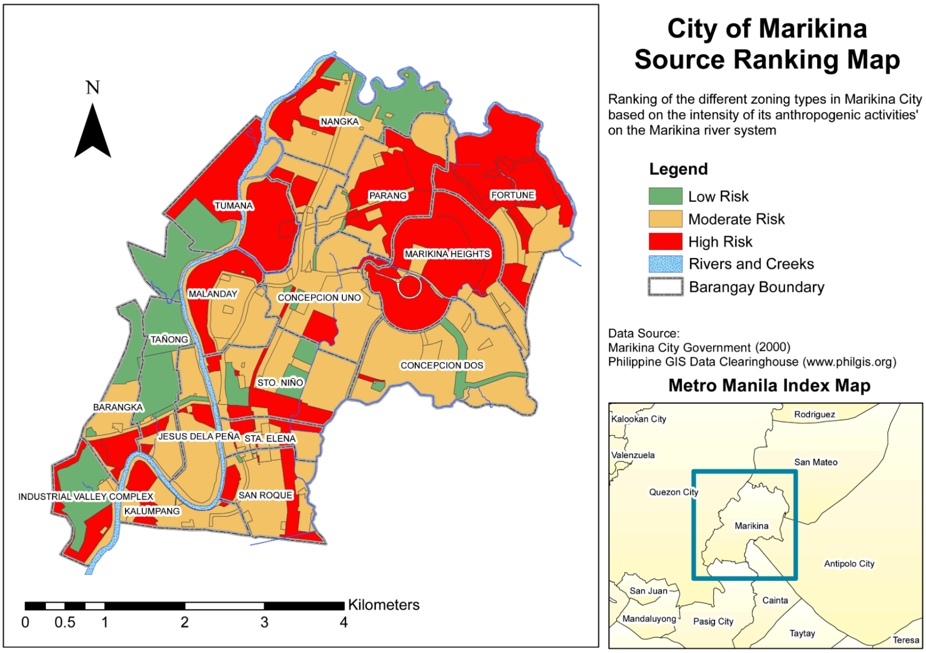

Figure 3: Map of Source Rankings for Marikina City

Distance to River Rank	Numerical Score	Distance Range (in meters)
Low	1	354.6 – 755.7
Moderate	2	115.7 – 354.5
High	3	0 – 115.6

Table 2: Summary of Distance to River Ranking Categories and Their Respective Numerical Scores and Value Ranges

proximity of the source to the river or a creek or tributary, and (2) drainage density (DD), which refers to the extent of the drainage system within the source that might carry the effluents to the river system. For both the DR and DD schemes in ranking the habitat, zoning areas given a numerical score of 1 have a ranking category of *low*; while those areas assigned a score of 2 are given a ranking category of *moderate*; and those that have a score of 3 are assigned a ranking category of *high*.

The DR scheme rankings indicated the proximity between the zoning areas to a nearby river or creek, which was calculated using GIS distance tools. The values were subjected to Natural Breaks Classification function of ArcGIS (also known as the Jenks Optimization Method) to produce the three-point DR ranking (see Table 2). The Natural Breaks Classification function is used to minimize the squared deviations of a group's means and is standard method for dividing datasets into homogenous classes. It is used to provide meaningful visualization of data identified by the iterative process (Esri, 2016; North, 2009). This type of classification function is commonly used in RRM (Hua et al., 2017). The Habitat Ranking map based on the distance to the river can be seen in Figure 4.

The drainage density criteria rankings represent the extent of the drainage lines within the zoning areas (Figure 5). This was calculated as the ratio of the total length of drainage polylines within a zoning polygon over the total area of a zoning polygon. Higher ratios were assigned higher ranking. Natural breaks classification was again applied to the calculated values for the drainage densities to create the three-scale DD rank (see Table 3). The Habitat Ranking map based on drainage density is shown in Figure 6.

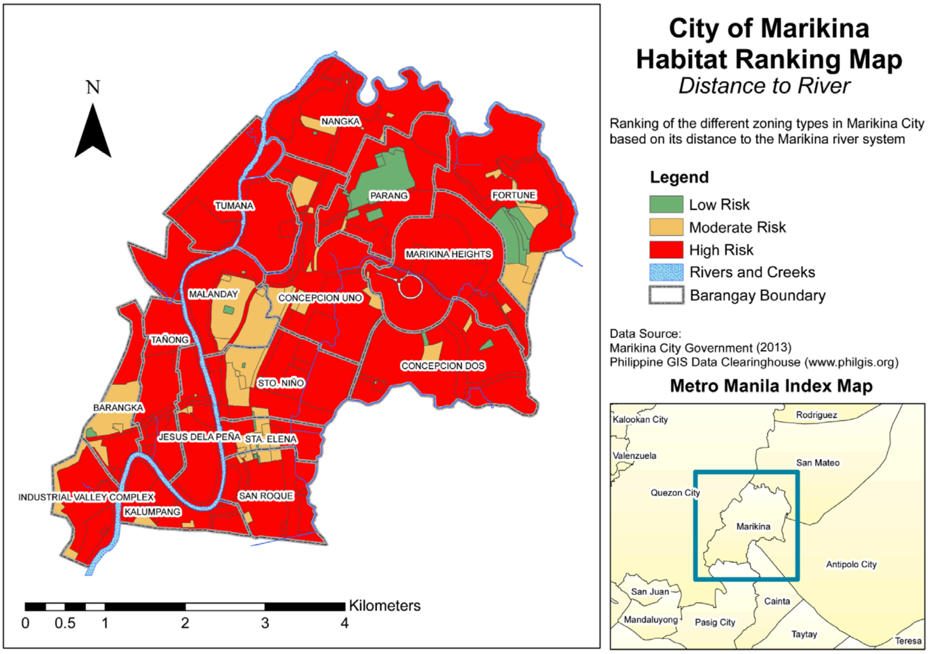

Figure 4: Habitat Ranking Map Based on Distance to the River System of Marikina City

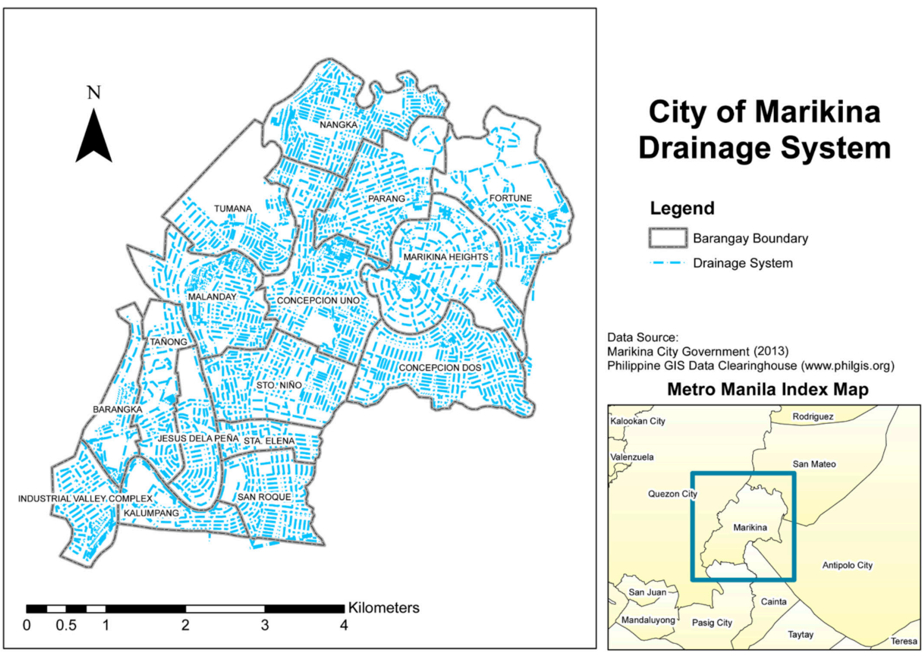

Figure 5: Drainage System of Marikina City

Drainage Density Rank	Numerical Score	Drainage Density Range
Low	1	0 – 0.015
Moderate	2	0.016 – 0.043
High	3	≥ 0.044

Table 3: Summary of Drainage Density Ranking Categories and Their Respective Numerical Scores and Value Ranges

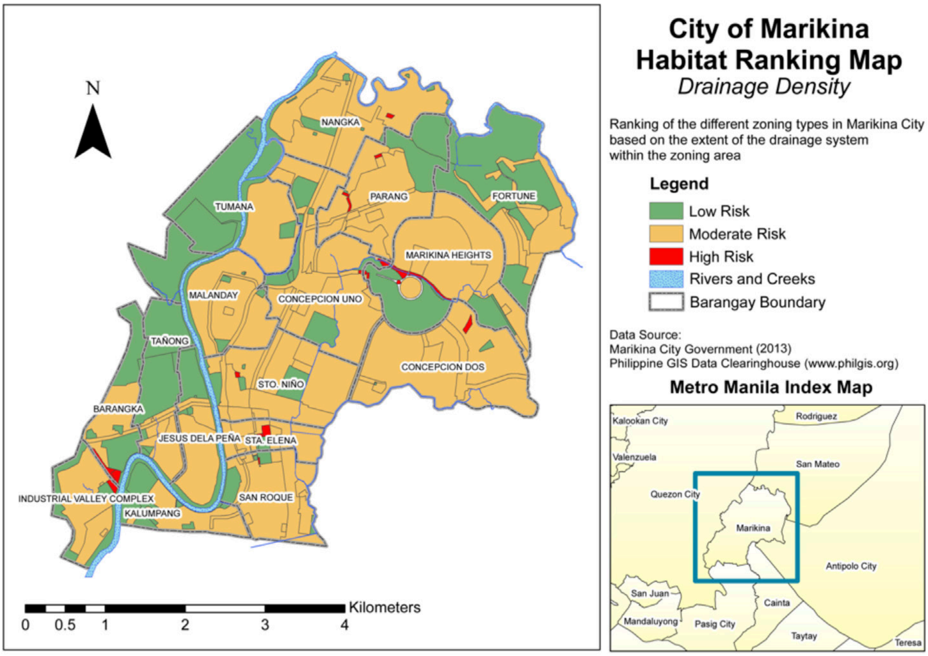

Figure 6: Habitat Ranking Map Based on Drainage Density of Marikina City

Developing the Ecological Risk Ranking Scheme

The relative ecological risks for each zoning area were calculated by integrating the source and habitat ranks created in the previous step to generate ecological risk scores per polygon representing the zones. Ecological Risk Scores (ERS) were determined by multiplying the source and habitat rank scores associated with the zoning area as indicated in Equation 1. These scores are indicative of the risk of exposure of the Marikina River system to the effluent generated by the different intensities of land uses. The three factors representing the source, the proximity, and the pathways to the habitat were given the same weight. The equal weighting between the two habitat factors (proximity as represented by distance of zone to the river system, and 'pathway' as represented by the drainage density) recognizes that a zone may be farther away from the system, but if it is directly connected to the river system through the drainage, then it could have equal chance of its effluent reaching Marikina River. The equal weighting between the source and habitat factors recognizes that a risk would not exist without the stressors or without the means for the stressors to reach the habitat.

$$ERS = S \times H_{DR} \times H_{DD} \qquad \text{(Equation 1)}$$

where: S = source score (zoning intensity)
HDR = habitat score (distance to river)
HDD = habitat score (drainage density)

The ERS values that were computed were subjected to Natural Breaks Classification to create a three-scale numerical ranking system to indicate the degree of the potential ecological impact that a certain location of a particular zoning subcategory has on the river system of Marikina City vis-à-vis other zoning areas. For the ecological risk rank, the zoning areas assigned numerical ERS ranging from 1 to 6 have a ranking category of *low*; those assigned a score ranging from 7 to 12 are given a ranking category of *moderate*; those that have a score ranging from 13 to 27 (maximum score) are assigned a ranking category of *high* (Table 4).

Source		Habitat (DR)		Habitat (DD)		Ecological Risk	
Numerical Score	Rank	Numerical Score	Rank	Numerical Score	Rank	Numerical Score Range	Rank
1	Low	1	Low	1	Low	1 – 6	Low
2	Moderate	2	Moderate	2	Moderate	7 – 12	Moderate
3	High	3	High	3	High	13 – 27	High

Table 4: Summary of Relative Ecological Risk Rankings

The integration of component scores as shown in Equation 1 is achieved first by creating a layer in ArcGIS for each of the three risk components consisting of the zoning map with attribute tables containing the scores as described in Tables 1, 2, and 3. These layers are then overlaid using the ArcGIS Union functions to calculate the overall risk score as seen in Table 4.

RESULTS AND DISCUSSION

A relative ranking system (i.e., low, moderate, high) was used in this study, which adapts the source-habitat approach as a rapid screening tool. With the Marikina River system as the ecosystem of interest, this tool identifies areas that pose the highest risk of exposure to water quality pollutants, based on the intended zoning, as determined through the CLUP process. The final ecological risk ranking map is shown in Figure 7.

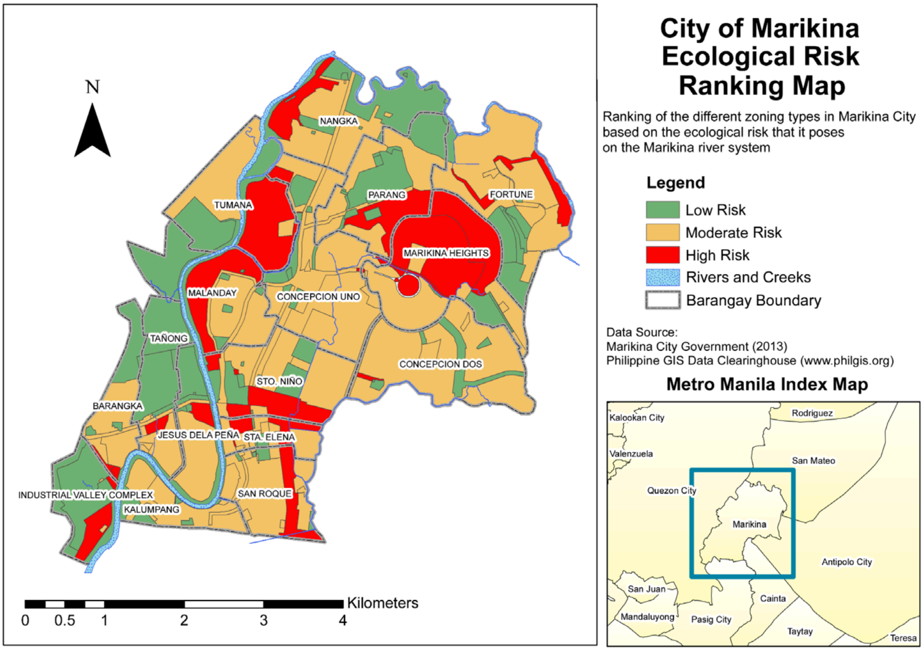

Figure 7: Map of Relative Ecological Risk Rankings for Marikina City

The areas that pose the highest risk to the Marikina River system are: the Socialized Settlement Zones of the Residential Category (found in the Industrial Valley Complex, Malanday, Tumana, Nangka, and Fortune barangays); some High Density Residential zones (found in Marikina Heights and Parang barangays); the Mixed Use Zone (found in Marikina Heights); and some High-Density Commercial Areas (found in the Sto. Niño, Sta. Elena, and San Roque barangays). This approach, however, only provides relative risk estimates rather than probabilistic risk, which means that the risk rankings for the area of interest in this study cannot be compared against other areas. For example, the *high*, *moderate*, and *low* risk areas of another city in Metro Manila may have different characterizations and severities of risk compared to the *high*, *moderate*, and *low* risk areas of Marikina City.

On the one hand, it may be argued that the rapid screening system tends to favor areas with fewer large structures over areas with many smaller units, given that the source scoring method ranks the former lower than the latter. However, on the other hand, areas with many different and/or independently-operating sources might be harder to regulate and would entail higher negotiating costs. Thus, the simple source ranking method used here accounts for this potential difficulty in monitoring and enforcement. Another implication of this system is that risk can be reduced by decongesting zones and creating buffer areas around the river and its tributaries. Managing the rapid urban densification and population growth would indeed have multiple benefits beyond arresting the degradation of the river system (Qu & Long, 2018; Peng, Tian, Liu, Zhao, Hu, & Wu, 2017; Arfanuzzaman & Atiq Rahman, 2017). However, this may not always be feasible or immediately implementable—for example, relocation/re-zoning can be contentious. The proposed rapid screening method can identify the zones for which more comprehensive assessment is needed to identify other management interventions and for which long-term monitoring and evaluation programs must be established if relocation/decongestion is not practical.

In addition, as previously mentioned, the source ranking approach employed means that comparisons cannot be made across zones or land use types (e.g., impacts of residential vs. commercial vs. industrial zones). The scores rank each of the risk components within the land use category rather than make a judgment as to which types of pollutants from the zoning categories pose less or worse risk. Thus, programs for long-term monitoring and evaluation of water quality would be crucial components of a comprehensive ecological risk assessment of the priority areas identified by the rapid screening method in this study. Different land use types are associated with different pollutants (e.g., domestic waste vs. commercial and industrial waste). For example, domestic sewage from residential areas is a source of water pollutants such as phosphates, nitrates, and ammonia (Wu et al., 2020; Guzman, 2001; Ennos & Bailey, 1995; Umaly & Cuvin, 1988; Chapman 1992).

Domestic sewage can also increase turbidity and total coliform (Zeilhofer, Lima, & Lima, 2010; Umaly & Cuvin, 1988; Chapman 1992). Untreated effluent from commercial areas are sources of phosphorus, nitrates, and ammonia, and increase turbidity and total coliform in water bodies (Chen, Elhadj, Xu, Xu, & Qiao, 2020; Umaly & Cuvin, 1988; Guzman, 2001; Ennos & Bailey, 1995; Umaly et al., 1988<; Chapman, 1992). Industrial effluents may also introduce phosphorus and ammonia into water bodies (Chen et al., 2020; Chapman, 1992; Guzman, 2001), and increase turbidity and chemical oxygen demand (COD) (Mullins, Jones, Glavin, Coburn, Hannon, & Clifford, 2018; Umaly & Cuvin, 1988; Huang, Zhan, Yan, Wu, & Deng, 2013). Effluent from thermal plants may even increase the temperature of water bodies (Al-Aboodi, Abbas, & Ibrahim, 2018; Umaly & Cuvin, 1988). How land use affects water quality could also be influenced by the season and landscape metrics. In a study by Marañon and Naputo (2019), various landscape metrics of built-up areas composed of residential, commercial, and industrial zones were found to be correlated with measurements of various water quality parameters in Meycauayan River in Bulacan, Philippines for the years 2013, 2015, and 2018. For example, the percentage of built-up area over the watershed boundary of the Marilao-Meycauayan-Obando River System was negatively correlated with biochemical oxygen demand (BOD) in Meycauayan River during the dry season but positively correlated with BOD during the wet season. This finding could be attributed to increased runoff carrying organic wastes from built-up areas when it rains during the wet season.

Unfortunately, historical water quality sampling of the Marikina River—including Evardo (2014), Adamos (2012), De Leon (2011), Benjamin (2008), Tolentino (2007), and Co (2003)—has not consistently included the range of pollutants associated with the different land use types in the zoning plan being implemented since year 2000. These have mostly been limited to temperature, pH, conductivity, turbidity, dissolved oxygen (DO) and salinity. De la Peña and Pael (2009) tested for the metals like Al, Cd, Cr, Fe, and Pb, but according to the Philippine National Standards for Drinking Water (PNSDW). We have not found literature to show that the study was repeated on a regular basis. Chounlamany, Tanchuling, & Inoue (2019) tested for chemical parameters such as COD, BOD, anions (Cl−, NO3−N, SO42−, PO43−P) and heavy metals, but the analysis was focused in the Quezon City section of the Marikina River since the objective was to assess the impact of leachate from the Payatas landfill. Even with these limited data, many of these sampling sites (refer to Evardo (2014) for more details) had measurements for conductivity, dissolved oxygen, and occasionally turbidity, which did not meet current Department of Environment and Natural Resources (DENR) and U.S. Environmental Protection Agency (EPA) benchmarks. These include sites that are also ranked as high risk in this rapid screening, such as those adjacent to the Socialized Settlement zones in Nangka and Tumana, within the Mixed Use zone in Marikina Heights, and adjacent to the High Density Commercial zone in Sta. Elena.

Thus, the rapid screening outcomes can be used as a starting point for designing and implementing more comprehensive water quality risk assessment and management programs that are customized to the potential effluent composition of the land use types. Data gathering efforts should include both the effluent volume and composition associated with the different land use types to better evaluate potential impacts on aquatic and other connected ecosystems. More detailed risk ranking systems can be developed to account for the combined exposure to the volume of the effluent versus the composition of the effluent. The water quality assessment can be further complemented by sediment quality assessment given that pathogens, nutrients, metals, organic chemicals, and other contaminants bind and accumulate in the organic and inorganic particles that settle to the bottom of streams and rivers, and potentially harm aquatic ecosystems (Burton, 2002). Runoff modeling and hydrological transport modeling (i.e., modeling of the flow and the direction of materials in the river) are also recommended to complement water quality sampling.

Data gathering efforts in priority areas should also include initial ground-truthing for the purposes of establishing the existing land use prior to the enforcement of the proposed zoning plans and regular ground-truthing to assess if actual land use evolves according to the plan. The initial ground-truthing in combination with the water quality monitoring and complementary mapping and modeling studies (e.g., models of pollutant fate and transport) can provide a clearer assessment of potential risks to monitor as land use evolves.

Overall, the method developed was able to demonstrate the importance of the geographical context of the multitude of stressors and the surrounding habitat in assessing risk. The results show that the intensity of the land use does not by itself dictate the level of impact, but that other factors like its physical proximity to the ecological asset and the presence of other exposure pathways are also of equal ground in determining risk to the river system.

CONCLUSIONS AND RECOMMENDATIONS

This assessment adapted the source-habitat approach with relative risk ranking to analyze the potential risk posed by the different land uses in Marikina City on the river system of the city. The approach, which is based on the intensity of the anthropogenic activities in each zone, proximity to the river and creeks, and the extent of the drainage lines within the zone, estimates the risk of exposure of the aquatic habitat to effluents. It is intended as a rapid screening method to be incorporated into the CLUP process. The objective of the screening is to identify zones to be prioritized for more comprehensive assessment and management given limited time and city resources. In the case of the city of Marikina, the results show that Socialized Settlement Zones, Mixed-use Zones, and High Density Commercial Zones are the land use types that potentially pose the highest risk.

It is important to bear in mind, however, that land uses of different categories have different associated pollutants. This screening method is only valid, therefore, to compare relative risk within, rather than across, land use/zoning categories. Zones ranking the highest in terms of posing a risk of exposure should undergo more comprehensive assessment, taking into consideration the volume and composition of the effluent. For this purpose, the relative risk approach may no longer be appropriate given the diverse impacts on the aquatic habitat of different pollutants. For the priority areas identified through the rapid screening method, more extensive water quality sampling and characterization, and hydrological modeling will be required for more in-depth exposure pathway analysis and impact analysis on the habitats at risk. Based on the factors considered in the risk calculation, decongesting the zones and moving potential polluters away from the sensitive habitats are the apparent strategies for reducing the risk. However, in cases when changes in zoning and relocation becomes a contentious strategy, a more comprehensive ERA can further identify other management interventions.

The method developed here was able to demonstrate the importance of the geographical context of risk. It provided a simple approach, utilizing data already available in LGUs, to conduct a rapid screening that directly relates the sources of stressors to the habitats of receptors. The method incorporated a flexible system for calculating risk scores that can be easily updated as more data becomes available. Also, because it is a straightforward approach aided by GIS, the maps can be easily replicated and used to provide testable hypotheses about the spatial distribution of ecological risks, which can also serve as the base for planning and conducting water quality sampling.

While the Marikina City local government provided valuable data input to the ERA, more iterative dialogue can provide more information and insights on management goals and perceptions of the sources of stressors/threats and habitats that are at risk. As part of the comprehensive ecological risk assessment of priority zones, more time and resources should be allocated for stakeholder consultation and engagement. Stakeholders would include not only the local government but also other sectoral representatives living and acting within the zones of concern. Such multi-sectoral collaboration can help ensure that the results of the risk assessment adequately reflect community priorities.

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