Risk Evaluation of Community-Based Water Systems from Nonpoint-Source Pollution in Eastern Visayas, Philippines

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Abstract. This study evaluated the risk posed by nonpoint-source (NPS) pollution to the 266 community-based water systems (CBWS) in Eastern Visayas, Philippines. Geographic Information System (GIS) techniques, together with Multi-Criteria Decision Analysis (MCDA) was used to develop a Nonpoint-Source Pollution Potential Index (NSPPI) to identify and classify the potential locations of water systems that are at risk from NPS. In developing the NSPPI, this study used three features that contribute to NPS pollution (taken from the original Agricultural Pollution Potential Index (APPI) model) as follows: Runoff Potential Index, Sediment Yield Potential Index, and Nutrient Yield Potential Index. Results showed that 22% (n=59) of the CBWS is at high risk of NPS pollution, 42% (n=111) is categorized as moderate, and 36% (n=96) as low. Using NSPPI as a primary risk evaluation of CBWS from NPS pollution is a cost-effective screening tool in identifying priority sites for environmental management intervention.

Keywords: Non-point-source pollution, community-based water system, water management, Philippines

1. Introduction

NPS pollutants are a primary threat to the quality of surface and subsurface waters. Protecting water sources from NPS pollutants is important to protect public health, and to ensure good water quality for human consumption.

At present, there are numerous approaches used to assess the spatial distribution of NPS pollutants and to mention a few: the statistics method (Byron & Goldman, 1989; Kronvang et al., 2003); the export coefficient model (Ding et al., 2010; Endreny & Wood, 2003); the physical watershed model (soil and water assessment tool – SWAT) (Arnold et al., 1993; Yang et al., 2013); and the Agricultural Nonpoint Pollution Potential Index (APPI) (Petersen et al.,1991).

This study employed the Agricultural Pollution Potential Index (APPI) method as used in similar studies (Yang, et al., 2013; Guo et al., 2004; and Phetprayoon & Sarapirome, 2012); and used the Multi-Criteria Decision Analysis (MCDA) in QGIS to develop a Nonpoint-Source Pollution Potential Index (NSPPI) to evaluate the spatial distribution of NPS pollutants and its potential NPS risks to the 266 community-based water systems in Eastern Visayas, Philippines.

2. Materials and Methods

2.1. Study Area

This study was conducted in Eastern Visayas, Philippines, a group of three islands: Leyte, Biliran, and Samar (Figure 1). Eastern Visayas has two types of climate based on the Corona system: Type II (no dry season but a distinct maximum rainfall from November to January) and Type IV (an even distribution of rainfall year-round and a short period of dry season from February up to May) (Kintanar, 1984).

2.2. Data Sources

For this study, various data were collected as follows: (1) Information on the 266 community-based water systems (CBWS) were obtained from the National Community-Driven Development Program (NCDDP) of the Department of Social Work and Development, (2) Rainfall data were obtained from Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), (3) The USGS Digital elevation model (DEM) were obtained from the NASA's Earth Observing System Data and Information System (EOSDIS), (4) Data on Global Hydrologic Soil Groups (HYSOGs250m) for Curve Number-Based Runoff Modeling was obtained from Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) (Ross et al., 2018), (5) Land Use/Land Cover data from USGS Earth Explorer website and the Department of Environment and Natural Resources, Region 8.

2.3. Runoff Potential Index

The runoff potential index of the study area was calculated using the Curve Number (CN) method; this method uses the accumulated rainfall excess depth calculated by Soil Conservation Service Curve Number (SCS-CN) as proposed by the Soil Conservation Service of America

(Williams & LaSeur, 1976). In this study, the CN values were determined from the land cover data and the hydrologic soil group data from ORNL DAAC. Runoff potential calculated using curve number has been largely used in other NPS pollution studies (Phetprayoon et al., 2009; Yang, et al., 2013; Guo et al., 2004). The runoff potential index of Leyte and Samar is shown in Figure 3.

2.4. Sediment Yield Potential Index

The sediment yield potential index was determined based on the concept of soil erosion computed using the Revised Universal Soil Loss Equation (RUSLE) model (Wischmeier & Smith, 1978; Renard, 1991). RUSLE model is extensively discussed in Foster et. al. (2003).

The R-factor (rainfall-runoff erosivity factor) was computed through the Inverse Distance Weighted (IDW) interpolation method using the mean annual rainfall data from 2016 – 2019. The sediment yield potential index is shown in Figure 4.

2.5. Nutrient Yield Potential Index

The nutrient yield potential index (Figure 5) is the result of the application of fertilizers to the land. Commonly, this is indicated by nitrogen which is the most important component in chemical fertilizer; and is usually quantified by the net nitrogen load per unit area. For this study, the probable usage of agricultural fertilizer for each type of land use was evaluated as high, moderate, low, very low, and not significant based on the likelihood of the land type to use fertilizer following the methods of Guo et. al. (2004) and Phetprayoon et. al. (2009). Table 1 presents the associated probable nutrient loading values according to the rates of fertilizer application to the various types of land uses in Eastern Visayas.

Table 1. Nutrient loading category based on an assumed fertilizer application rate of the different types of land uses in Eastern Visayas (calculated from Magcale-Macandog et. al., 2016).

Nutrient Loading	**Fertilizer Application Rate** (kg/ha/year)	**Land Uses**
High	>150	Rice fields, Vegetable Farms, Sugarcane, Maize, Cassava, Potato, & other Field Crops
Moderate	>100 to <150	Orchard, Perennial, Mixed Perennial, Vegetables
Low	>50 to <100	Palm Oil, Cocoa, Fruit Trees, Rubber, Coconuts & Similar Crops
Very Low	<50	Fishponds, Coffee, Soya
NS	≈ 0	Built Areas, Mangroves, Open Forests, Marshland, Wooded Land & Shrubs, Grasslands, Deciduous, Evergreen Forests & Swamps

2.6. MCDA and QGIS in developing the NSPPI

MCDA) and GIS techniques, together, were used to develop an NSPPI map. The process followed two essential steps: (1) the calculation of runoff potential index, sediment yield potential index, nutrient yield potential index, and the creation of the map indices using GIS techniques; (2) the integration of these indices using MCDA (Malczewski, 1999; Phetprayoon and Sarapirome, 2012). The values of the map indices were normalized using Z-score normalization before the integration into an NSPPI map. Relative weights were assigned to the indices as follows: 0.50 for runoff potential index, 0.35 for sediment yield potential index, and 0.15 for nutrient yield potential index for a total of 1 for NSPPI. A raster calculator in QGIS was used to combine the three raster datasets into an NSPPI map (Figure 6).

3. Results and Discussion

3.1 Profile of the Community-Based Water Systems

Figure 2 shows the location and distribution of the 266 community-based water systems in Eastern Visayas. The consumers of these community water systems are around 46,898 households comprising around 215, 000 individuals. The provincial distribution of these 266 community-based water systems are as follows: Biliran(n=1), Eastern Samar (n=63), Leyte (n=71), Northern Samar (n=19), Samar (n=58), and Southern Leyte (n=54).

There was ten (10) Level III water supply facility (characterized by a water source, a reservoir, a piped distribution network with an adequate treatment facility, and household taps; generally suited for densely populated urban areas. Furthermore, most (n=171) of the water systems are in Level II (composed of a source, a reservoir, a piped distribution network with an adequate treatment facility, and communal faucets, generally suitable for rural and urban fringe areas; and there were sixty-six (66) Level I facility that normally serves an average of 15 households (PSA, 2020).

3.2 Nonpoint-Source Pollution Potential Index (NSPPI)

The result of the NSPPI map is shown in Figure 6. The community-based water systems were categorized based on their locations on the NSPPI map. Three categories were identified: (1) high NPS pollution potential category, (2) moderate NPS pollution potential category, and (3) low NPS pollution potential category.

Table 2. NPS pollution potential risk classification of the 266 community-based water systems based on their location on the NSPPI map.

NSPPI	**Level I**	**Level II**	**Level III**	**RCS**	**RWS**	***n***
Low	10	70	5	4	7	96
Moderate	34	68	2	0	7	111
High	22	33	3	0	1	59

The first group is 59 CBWS that belong to the high NPS pollution potential category comprising 22 Level I, 33 Level II, 3 Level III, and 1 RWS (Table 2). These water systems are located mostly in high slopy areas, in hilly to mountainous terrain, and areas with poor forest cover.

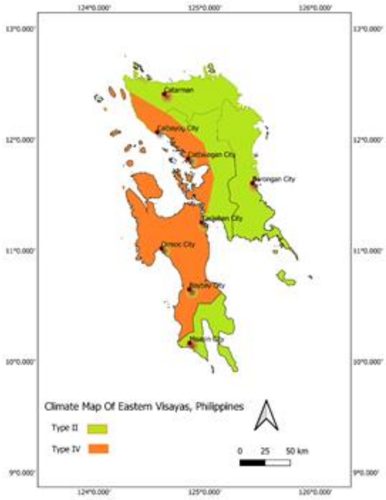

Figure 1. Eastern Visayas and its climate based on modified Coronas

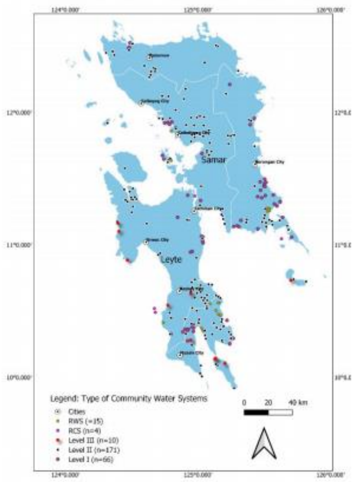

Figure 2. The distribution of the 266 community-based water systems.

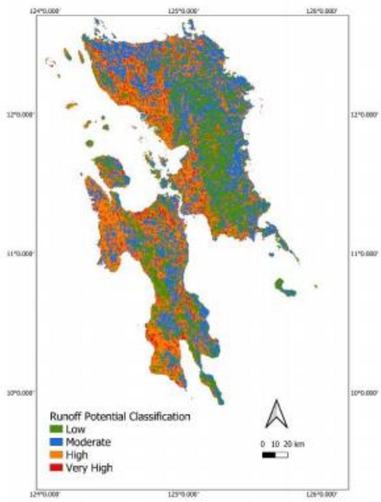

Figure 3. Runoff Potential Index

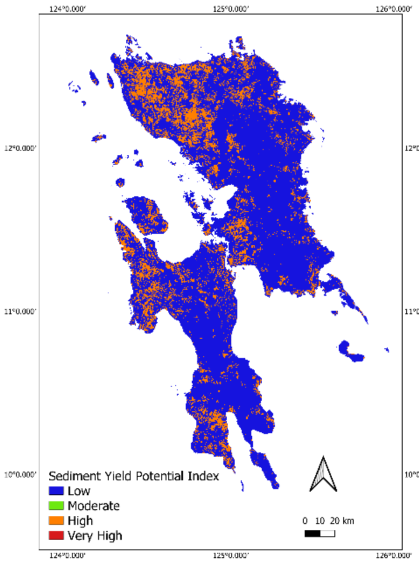

Figure 4. Sediment Yield Potential Index

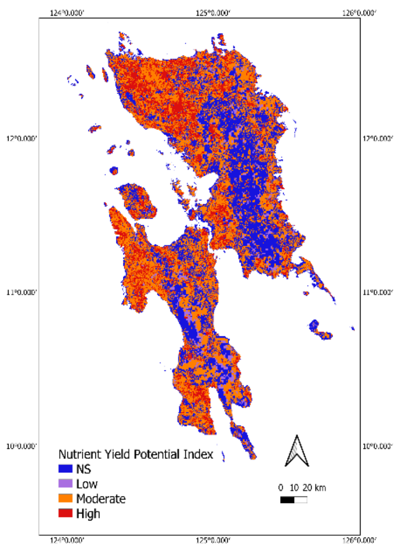

Figure 5. Nutrient Yield Potential Index

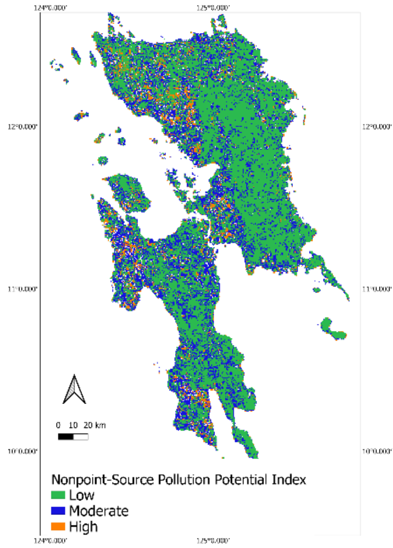

Figure 6. Nonpoint-Source Pollution Potential Index (NSPPI)

The second group included 111 CBWS that belongs to the moderate NPS pollution potential category comprising 34 Level I, 68 Level II, 2 Level III, and 7 RWS. These groups' CBWS are mostly located in the northern and western side of Samar, and the northern and southeastern side of Leyte; and most are located close to farm areas planted with annual and perennial crops. The third group is 96 CBWS that belongs to low NPS pollution potential comprising 10 Level I, 70 Level II, 5 Level III, 4 RCS, and 7 RWS. These groups are mostly located on the central section of Leyte and in the central-eastern side of Samar which is near or inside forested areas.

4. Conclusion and Recommendations

This study concludes that the resulting NSPPI map generated using MCDA-QGIS techniques can be a useful and beneficial tool in NPS pollution assessment. Indeed, the NSPPI map serves as a good preliminary tool in the risk evaluation of CBWS from NPS pollutants. This method is possibly a cost-effective screening tool in identifying priority sites for environmental management intervention of CBWS that are potentially exposed to high risk of NPS pollutants.

There are many advantages in spatial analysis using maps in NPS assessment such as data can cover large areas; convenience in identifying and investigating spatial patterns; maps are effective in presenting information and communicating findings; and most importantly the cost of obtaining data for this type of study is very minimal as most can be downloaded or accessed online for free, for example, free data can be obtained from NASA's Earth Observing System Data and Information System (EOSDIS) that provides NASA Earth science data from various source such as satellites, aircraft, field measurements, and other related data sources (https://earthdata.nasa.gov/eosdis); another is the Oak

Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) that offers Earth science data for global change research and Earth systems studies and is sponsored by NASA (https://daac.ornl.gov), another is the Remote Sensing and Landsat Data from USGS (https://www.usgs.gov/products/data-and-tools/real-time-data/remote-land-sensing-and-landsat) to mention a few. Additionally, tools to process and analyze these kinds of data can be downloaded online and used for free; for this study, we used QGIS, a free and open-source Geographic Information System (https://qgis.org/).

On the other hand, there are also many disadvantages of spatial analysis using maps in NPS assessment, to mention a few: the method cannot describe the variations, dynamics, and concentration of NPS pollutants; it cannot predict the patterns of distribution or relationships between parameters under study; and the fundamental nature and characteristics of the environment i.e., it is extremely dynamic, and conditions could change drastically within a very short period that could possibly result in a shorter life span of research results useability.

Lastly, results of this type of study should be provided to relevant government agencies to help in the management and protection of surface and subsurface waters in the country.

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