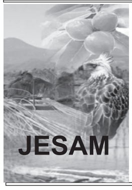

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A River Health Status Model Based on Water Quality, Macroinvertebrates and Land Use for Niyugan River, Cabuyao City, Laguna, Philippines

ABSTRACT

A health status model was developed for Niyugan River. It consists of two component parameters: response and pressure. The response parameters, water quality and Ephemeroptera-Plecoptera-Trichoptera (EPT) proportion measure the current state of the river. Pressure parameters, land use, infrastructure, and riparian vegetation proportion represent the factors that can worsen the current river condition. Water quality indicator values were determined using on-site measurements and analyzed water. Benthic macroinvertebrates were collected from all the sampling sites. Land use, infrastructure, and riparian vegetation proportions were derived from a map created using Arcmap10. For efficient parameter input and sensitivity analysis, a calculator-like interface was developed using Stella. The score resulted to 37.07, corresponding to a "poor" health. Sensitivity analyses showed that the health score is influenced at a greater extent, by the combination of water quality indicators rather than the number of water quality indicators in the model and by the magnitude of separate indicators within a parameter category. It is suggested that the model is evaluated using data sets from other rivers to further investigate its sensitivity. This model can serve as a basis for developing more dynamic river health models for the Philippines.

Key words: *river health, model, Niyugan River, EPT richness, water quality, land use, Stella*

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INTRODUCTION

Countries now are starting to address the environmental and health hazards that have arisen from the misuse and abuse of rivers, lakes, and other aquatic ecosystems. This is because they have realized that appropriate management of water use will be a major key in sustaining life, given the global climate change (*Palmer and others 2005*). In the Philippines, where there is an increasing number of polluted aquatic ecosystems (*USAID and DILG, 2007*), researches and studies directed to restoring, rehabilitating, and managing deteriorating water bodies are gradually getting greater priority. This study believes that appropriate management and restoration techniques can only come after establishing the overall health of aquatic ecosystems-- in this case, river tributaries.

Rivers are very valuable resources that provide people with an array of ecosystem services. Although the term 'river health' is a concept that is widely used, it is difficult to be described in precise scientific terms (*Schofield and Davies 1996*). According to *Wang et al.* (*2010*), both development and ecological protection aspects are within river health. It means that the concept does not only focus on the maintenance of the ecological integrity of the river, but also to its efficiency in providing services like water supply, flood control, environmental purification, biological protection, and recreation. As there can be a lot of parameters that can be used to represent river health, researches should specify, define, and justify factors used to describe a river condition.

Through the years, a huge number of river health indicators have been used: water quality parameters (dissolved Oxygen, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Turbidity, and Total Dissolved Solids (TSS), among others), habitat heterogeneity, ecosystem metabolism, invertebrate population, and primary productivity, to name a few. Among these, water quality parameters are the most commonly used. These are exactly what the Laguna Lake Development Authority (LLDA) uses to establish and report the health status of the river tributaries of Laguna Lake, the biggest lake in the Philippines. The thresholds used for the water quality parameters are based on the Department of Environment and Natural Resources Administrative Order number 34 (DAO-34) in 1990. Niyugan River is one of the tributaries of Laguna Lake that passes through a number of barangays in the Cabuyao subwatershed.

The absence of an assessment method that considers the responses of the physical and biological river components to indicate its health makes it difficult to get an overview of the overall health of a river. The Laguna Lake Development Authority also has not developed a model that integrates anthropogenic pressures like land use and riparian condition indicators to its present assessment and monitoring of river health. This study aimed to: develop an environmental profile of Niyugan River using water quality parameters, Ephemeroptera-Plecoptera-Trichoptera (EPT) proportion, land use and infrastructure, and riparian vegetation; develop a mathematical model to combine the weighted scores of the mentioned parameters; develop a calculator-like interface using Stella modelling software; and evaluate the sensitivity of the model.

MATERIALS AND METHODS

Location and Description of the Study Area

The study was conducted in Niyugan River Subwatershed, located within Cabuyao City, Laguna, and 45 km away from Manila. It is bounded on the east by Laguna de Bay, on the west by the Cavite, on the north by Sta. Rosa and on the south by Calamba. Cabuyao City has 18 barangays, 13 of which are part of the Niyugan River subwatershed (**Figure 1**). The total area of the subwatershed is 2,945.50 ha. Based on the 2007 census, the Niyugan River Subwatershed has a total population of 142,638 and an annual growth rate of 9.46%. Manufacturing industries in the area are engaged in food processing, textile, garments and electronics manufacturing. These industries are heavily concentrated in Barangays Diezmo, Pittland, Pulo and Banaybanay (*Cabuyao City CLUP 2010*).

The Niyugan River subwatershed shares the geophysical characteristics of Cabuyao City. Cabuyao City has a relatively flat terrain. It consists mostly of rolling narrow plains. The remaining areas, which are situated in the western side, have few elevated portions. The climate in Cabuyao can be characterized as Type I, according to Coronas climate classification. An annual mean rainfall of 2000 mm is recorded in this city. Cabuyao has general climatic conditions with annual mean temperature of 27.5ºC and annual mean relative humidity of 76% (*Cabuyao City CLUP 2010*). Niyugan River is one of the major river systems in Cabuyao City. It has a total length of 14.02 km and has a total area of 6.69 ha. It extends from Barangay Don Jose (upstream) to Barangay Marinig (downstream). It is surrounded by varying types of land uses: agricultural, residential, commercial, and industrial.

River Health Indicators

The river health indicators incorporated in the model were selected from widely used indicators of river health. The indicators were selected based on relatedness to the river health monitoring by LLDA, efficiency in representing river health, appropriateness, with respect

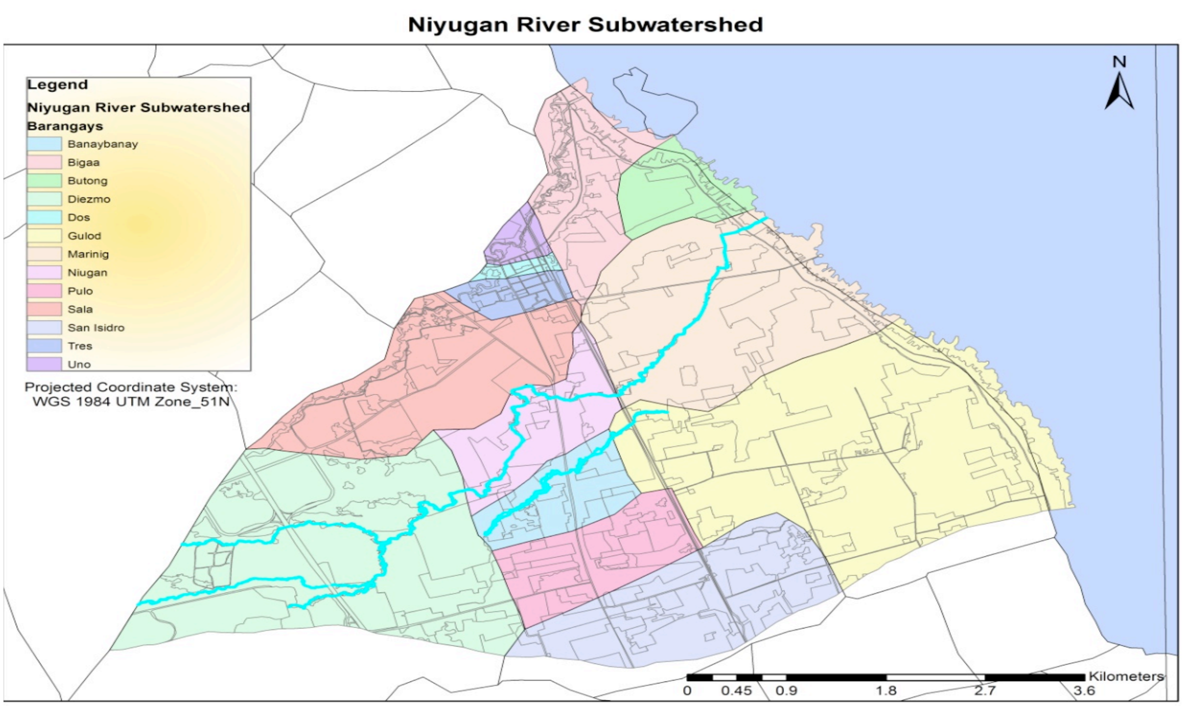

Figure 1. Niyugan River Subwatershed covers 13 barangays within Cabuyao City.

to the characteristics of the Laguna Lake Tributaries, availability of equipment or techniques to derive measures, and availability of experts for consultation. The indicators were categorized into response and pressure indicators.

Response indicators identified were water quality parameters and macroinvertebrate (Ephemoptera, Plecoptera, Trichoptera) proportion. Most of the water quality parameters used by LLDA in monitoring the tributaries of Laguna Lake were adopted since the model that was developed is for a tributary of Laguna Lake. The chosen water quality parameters were: pH, Cadmium (Cd), Lead (Pb), and Chlorophyll a (Chl a) concentrations, Total Dissolved Solids (TSS), Surfactants (in the form of Methylene blue-active substances), air and water temperature difference, Dissolved Oxygen (DO), Electrical Conductivity (EC), Biological Oxygen Demand (BOD), Phosphorus (P), Total Kjeldahl Nitrogen, (TKN), and oil and grease (OG).

Pressure indicators were riparian cover proportion and catchment disturbance factors such as land use, and infrastructure. Details on the computation of the parameters can be found in the Model Development section.

Sampling Stations

Eight sampling stations were established within the length of Niyugan River. These sampling stations were chosen based on the different prevailing land uses in the river's reaches:

Sampling Station 1 (SS1)- located in the mouth of the river, opening to Laguna Lake; Sampling Station (SS2) - located in the middle of a subdivision, representing the impact of residential land use; Sampling Station (SS3)- located in the middle of agricultural lands; Sampling Station (SS4)- area surrounded by agricultural and residential areas; Sampling Station (SS5)- located in a tributary of the Niyugan River; Sampling Station (SS6)- area surrounded by industrial and residential areas; Sampling Station (SS7) - inside a newly developed subdivision; and Sampling Station (SS8) - inside a golf course. Sampling stations 1, 2, and 3 are located downstream, 4, 5, and 6 in the midstream, and 7 and 8 in the upstream (**Table 1** and **Figure 2**).

Table 1. Codes, Names, Coordinates, and Barangays of the eight Sampling Stations in Niyugan River.

Station Code	Site Name	Latitude	Longtitude	Barangay
SS1	Marinig-Butong Boundary	14.28385	121.14348	Marinig
SS2	St. Joseph VI Marinig	14.28266	121.14065	Marinig
SS3	Slaughter House	14.27824	121.13998	Marinig
SS4	Salang Langka Bridge	14.26611	121.13227	Sala
SS5	Balakbakan	14.26308	121.13334	Sala
SS6	Sala Bridge	14.26568	121.12679	Sala
SS7	Southpoint Subdivision	14.24799	121.11317	Diezmo
SS8	Sta. Elena Golf Course	14.24380	121.10652	Don Jose

Figure 2. Eight sampling stations were established in Niyugan River.

GIS Mapping and Land Use/Infrastructure Classification

The subwatershed's land uses were classified as the following: barren, industrial/commercial, cropped/agricultural land, grassland, residential, forests, and agroforests. Vegetation up to 50 m from the riverbanks were considered to be riparian vegetation of Niyugan River. Infrastructures identified were railways and sealed and unsealed roads. These land uses and infrastructure types were digitized in Google Earth application and were then exported to ArcMap10, licensed under the Research Institute for Humanity and Nature for analysis. Barangay and subwatershed boundaries were derived from Laguna Lake Development Authority, GEOFABRIK, and Global Administrative Areas (GADM).

Water Quality Parameters

Water sampling was done on January 25, 2012, from 8:00 to 11:00 am. Three sampling sites, approximately, 10 m from each other, were selected in each sampling station. Air and water temperature, DO, and EC were measured onsite using a pre-calibrated Horiba (D-55) water quality meter. The probes were immersed in water and the parameter readings were noted after measurement stabilization.

Water samples were also collected from each sampling station for the parameters that were not measured onsite. Sterile bottles were used to contain water samples for the coliform test. Except for samples for oil and grease test, which required glass bottles, wide-mouth plastics bottles were used for all other samples. The samples were collected approximately at the midpoint of the water column by immersing the sampling bottle and preventing the bottom sediments from being incorporated in the sample. The samples were kept iced. A total of five 1-liter composite samples (combination of water in the three sampling sites) from each sampling station were collected and brought to MTEC Water Treatment Technologies, Inc. for the analysis of TSS, BOD, Cd and Pb concentrations, P, TKN, OG, Surfactants (as methylene blue-active substances), and Total and Fecal Coliform (**Table 2**).

Macroinvertebrate Sampling

This study adopted the EPA protocol-based macroinvertebrate sampling strategy developed by *Jackson and Flowers* (*2007*). The goal of the sampling strategy was to sample all possible microhabitats in each sampling station. These included areas along the margin of the stream that had slow currents, shallow riffles/runs with moderate to fast velocities, shallow and deep pools, root masses, and leaf and wooden debris. Benthic macroinvertebrates were collected from each station by sampling benthic habitats with a kick net, by scrubbing rocks and wood with a brush in a bucket of water and collecting the material in a 125-μm mesh sieve, by hand-picking specimens from natural substrates (rocks, leaves, wood, etc.), and by sieving smaller sediments. The collected specimens were immediately preserved in 90% ethanol. The collected specimens were then identified up to order level, since the model requires only the proportion of the pollution sensitive orders, Ephemeroptera, Plecoptera, and Trichoptera.

To compare macroinvertebrate diversity among the sampling stations, Simpson's diversity index, in the form of 1-D, was computed for each station. A Bray-Curtis Cluster Analysis was also run in BioDiversity Pro software to evaluate the similarity of macroinvertebrate abundance among the stations.

Correlation with Water Quality Parameters and EPT Richness

SPSS 19, licensed under the Research Institute for

Table 2. Methods of analysis for the water samples brought to MTEC.

Parameter	Unit	Method of Analysis	Volume, ml (minimum)
Total Suspended Solids	mg L^{-1}	Gravimetric	500
Biological Oxygen Demand[a]	mg L^{-1}	5-day BOD Test	1000
Cadmium	mg L^{-1}	Inductively Coupled Plasma	500
Lead	mg L^{-1}	Inductively CoupledPlasma	500
Phosphorus	mg L^{-1}	Vanadomolybdo-phosphoric Acid Calorimetric	500
Total Kjeldahl Nitrogen	mg L^{-1}	Kjeldahl	500
Oil and Grease	mg L^{-1}	Partition Gravimetric	1000
Surfactants	MBAS mg L^{-1}	Methylene Blue	1000
Total Coliform[b]	MPN 100 mL^{-1}	Multiple Tube Fermentation	200
Fecal Coliform[b]	MPN 100 mL^{-1}	Multiple Tube Fermentation	200
Chlorophyll *a*	ug L^{-1}	Spectrophotometric	50

[1] Inputs include kerosene, transport rental, packaging materials and depreciation of implements
[2] NEDA Agriculture Sector Prescribed minimum wage rate per day of PhP 220.00

Humanity and Nature was used to run a correlation analysis between the water quality parameters and EPT richness.

Model Development

Benchmarking and Reference Conditions

The reference values that were used for the water quality indicators are derived from DAO-34 water quality criteria set for Class C, since all the rivers draining to Laguna Lake are intended for fishery, recreation, and industrial water supply. Water quality benchmarks can be changed if the rivers that will be assessed belong to Classes A, B, or D. The reference condition for the benthic macroinvertebrate proportion was from the study of *Romero and Labuguen* (*2010*). No reference conditions were used for land use and infrastructure and riparian vegetation (**Table 3**).

Computing Model Parameters

Response Parameters

Water quality index. The index equation was based on the water quality index (WQI) endorsed by the Canadian Council of Ministers of the Environment. This index allows measurements of the frequency and extent to which parameters exceed their respective guidelines at a specific monitoring station (*CCME 2001*). This index equation was chosen because it summarizes into a convenient mean, the complex water quality data. The CCME WQI has three elements: Scope - the number of water quality parameters (variables) not meeting water quality objectives (F 1); Frequency - the number of times the objectives are not met (F 2); and Amplitude - the extent to which the objectives are not met (F 3). The index produces a number between 0 (worst) to 100 (best) to reflect the water quality (Lumb and others 2010). The index will be computed using the following formula:

$$WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{\sqrt{3}}\right)$$

$$F1 = \left(\frac{\text{\# of failed parameters}}{\text{Total \# of parameters}}\right) \text{ x } 100$$

$$F2 = \left(\frac{\text{\# of failed tests}}{\text{Total \# of tests}}\right) \text{ x } 100$$

The extent (excursion) to which the failed test exceeds the guideline: this is calculated in three stages. First, the excursion is calculated:

$$excursion = \left(\frac{failed\ test\ value}{guideline\ value}\right) - 1$$

In the case where a minimum and maximum guideline is given, the excursion equation must be run as above as well as in reverse i.e. guideline value/failed test value.

Second, the normalized sum of excursions (nse) is calculated as follows:

$$nse = \left(\frac{\sum excursion}{total\ \#\ of\ tests}\right)$$

Table 3. Reference/Target Values for water quality and EPT proportion*.

Parameters	Reference/Target Value			Reference
Response Parameters	**Unit**	**Minimum**	**Maximum**	
I. Water Quality				DAO-34 and LLDA
pH		6.8	8.5	
Cadmium	mg L^{-1}	-	0.01	
Lead	mg L^{-1}	-	0.05	
Chla	ug L^{-1}	-	50	
Total Suspended Solids	mg L^{-1}	-	30	
Surfactants	MBAS mg L^{-1}	-	0.5	
Temperature Difference (Air temperature and water temperature)	^{o}C	-	3	
DO	mg L^{-1}	5		
BOD	mg L^{-1}	7	10	
Oil and Grease	mg L^{-1}	-	2	
Total Coliform	MPN 100 mL^{-1}	-	1000	
Fecal Coliform	MPN 100 mL^{-1}	-	200	
Phosphorus	mg L^{-1}	-	0.04	
Conductivity	microS cm^{-1}	150	500	
Total Kjeldahl Nitrogen	mg L^{-1}	0.26	0.4	
II. EPT Proportion	148/410 individuals or 36.09%			*Romero and Labuguen* (*2010*) Diden River

*blank values indicate absence of minimum or maximum target values

F3 is then calculated using a formula that scales the nse to range between 1 and 100:

$$F3 = \left(\frac{nse}{0.01nse + 0.01}\right)$$

EPT proportion. EPT index or EPT richness is the total number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) found in thorough stream collections. The three orders are considered clean water taxa and indicative of quality aquatic environments: the greater the diversity of these orders the better the rating of the aquatic environment (*Lenat 1988*). To present the score of this parameter from 1-100, the following formula, modified from the scoring system used by US EPA health programs was used:

Pressure Parameters

Riparian cover proportion. The riparian zone is the buffer between the river and the surrounding terrestrial ecosystems. It can serve to filter potentially harmful inputs from the terrestrial environment. For these functions, the riparian vegetation supports high levels of biodiversity that can provide food, shelter, and protection to aquatic and terrestrial organisms (*Galvin et al. 2009*).

For the purpose of this study, riparian cover was observed 20 m from each side of the river (modified from *Norris et al. 2001* and *USDA 1998*) and the proportion of the vegetated area was divided by the total riparian area (**Figure 3**). Same formula as the EPT richness was used to present the score in a 100-point scale.

Land use and infrastructure. The focus of this parameter is to provide a measure of anthropogenic changes that ultimately impact the river condition and the biota. Catchments influence a river through large-scale controls on hydrology, sediment delivery and chemistry (*Allan and Johnson 1997*). This study adopted the method used by *Norris et al.* (*2001*) in his assessment of Canadian Rivers. Land use activities and infrastructure can affect river health in a number of ways. All the possible impacts was listed (**Table 4**) and categorized as effects of land use activities, infrastructure, or both. With the help of scientists involved with land use change and riverine studies, impacts were ranked and ranked scores were averaged across the impact types to produce an overall ranking for each land use and infrastructure categories. The weights were derived from the average ranks by scaling them to a range of 0 to 0.7. Ranks were not scaled from 0-1 because a score of 1 implies that the impact cannot get any worse. The types of impacts were judged based on literature review and professional judgment.

The pressure generated by land use was assessed by the areal extent of each land use category within the reach catchment, adjusted by the weights applied to the different categories:

(Where LU = land use measure, F1 = fraction of the catchment that is category 1 land use, w1 = weight associated with land use 1, etc).

The pressure generated by infrastructure was assessed by the areal extent of the each infrastructure category within the reach catchment, adjusted by the weights applied to the different infrastructure types.

(Where I = infrastructure measure, I1 = fraction of the catchment of infrastructure category 1, w1 = the weight for infrastructure category 1 etc).

Land use, infrastructure, and riparian vegetation proportions were derived from a land use map developed for the subwatershed.

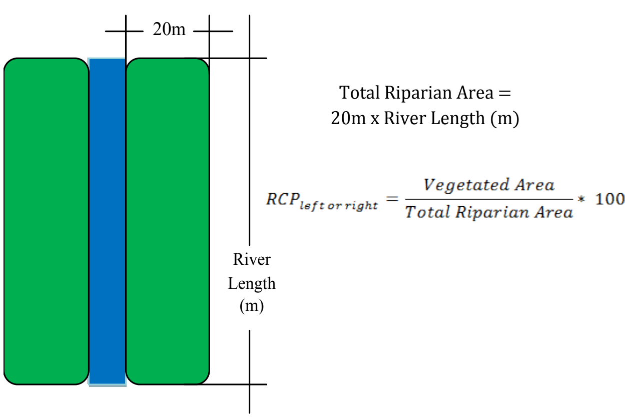

Figure 3. Riparian Cover Proportion will be computed by dividing actual riparian area by the ideal riparian area.

Table 4. Potential impacts of land use and infrastructure.

Types of Impact	Produced by Landuse or Infrastructure?
1. Augmentation of the nutrient supply to a stream	Both
2. Increase in salinity	Land Use only
3. Release of biocides (pesticides, herbicides and fungicides)	Both
4. Change to the hydrological regime	Both
5. Augmentation of the sediment supply to a stream	Both
6. Loss of native riparian vegetation	Land Use
7. Toxicants (including hydrocarbons and trace metals)	Both

Aggregating Parameter Scores for Overall River Health

The scores of the sub-indicators under the two component parameters were aggregated separately based on assigned importance values derived from literature and expert opinion. The aggregated values from the component parameters were combined to come up with a single value, which would indicate the overall river health. The response parameters were aggregated by averaging the values from water quality and EPT richness. On the other hand, the pressure parameters were aggregated by averaging the values from riparian vegetation proportion, land use, and infrastructure pressure. The response parameter value was multiplied by 60% while the pressure value was multiplied by 40% before they were added. Response parameters represented a higher percentage since they are assumed to be indicative of the current state of the river and the pressure parameters can be the factors that can aggravate the condition.

$$Response = \frac{WQI + EPT}{2}$$

$$Pressure = (RCP + LU + I)/3$$

$$Overall\ River\ Health\ (ORH) = (Response * 0.60) + (Pressure * 0.40)$$

The overall river health index was interpreted based on the river health classification by Roux in 2003 (**Table 5**).

Stella Calculator-like Interface

All the formulas used in determining the overall health score were embedded in a Stella model that has a calculator-like interface. The model was developed in a way that the user can change the weights of the parameters in case the model will be used in another region or river.

Sensitivity Analysis

Several sensitivity analyses were done to test how the model behaves. The first set of sensitivity analyses were done only with the water quality index in the response parameter of the model. The first test involved reducing the number of water quality parameters by randomly removing indicators until only six remain. This method was modified from how CCME did the sensitivity analysis for their water quality index. The order of removal was Cd, Pb, Chl a, surfactants, air and water temperature difference, BOD, P, OG, and total coliform. The second test involved setting up different combinations of the parameters by removing one parameter at a time. Independent sample t-tests were used to determine if the resulting river health scores differed significantly or not.

The second set of sensitivity analyses involved varying the weights of the individual parameters of the model: water quality and EPT score, land use, infrastructure and riparian vegetation, and the collective response and pressure parameters. The collective response parameter and pressure parameter were turned off one at a time to check how the model responds.

RESULTS AND DISCUSSION

Niyugan River Subwatershed

Land Use and Infrastructure. Grasslands and croplands had the highest percentage in land use, covering about 27 % each of the whole subwatershed area. Built-up areas, composed of residential and industrial/commercial areas took up 34%. Barren areas cover 4% of the subwatershed. For infrastructure, sealed roads cover 2% of the subwatershed, followed by unsealed roads and railways covering 0.14 and 0.10%, respectively (**Table 6** and **Figure 4**). The Comprehensive Land Use Plan of Cabuyao (2010) compares land use percentages in 1979 and 1999 (**Tables 7** and **8**). Rapid industrialization has pushed the conversion of agricultural areas to built-up areas. Built-up areas continually expanded because of increased demand for residential, commercial, industrial, and institutional uses. Conversion to commercial and industrial land uses is continually being favored since the city revenues mainly come from business taxes followed by the Internal Revenue

Table 5. The Qualitative Interpretation on River Health Score.

Score	Qualitative Equivalent	Management Perspective
81-100	Natural	Protected rivers; relatively untouched by human hands; no discharges or impoundments allowed. Some human-related disturbance, but mostly of low impact potential.
61-80	Good	Multiple disturbances associated with need for socio-economic development, e.g. impoundment, habitat modification and water quality degradation.
41-60	Fair	
21-40	Poor	Often characterized by high human densities or extensive resource exploitation. Management intervention is needed to improve river health, e.g. to restore flow patterns, river habitats or water quality.
1-20	Artificial	Modified beyond rehabilitation to anything approaching a natural condition. Example: canalized rivers in urban environments.

Table 6. Niyugan River Subwatershed Land uses and Infrastructure.

Land use/Infrastructure	Area in m^3	Area in ha	Proportion (%)
Grassland	7983055.787	798.305579	27.145919
Cropland	7943628.679	794.362868	27.011849
Residential	7279607.89	727.960789	24.753885
Commercial or Industrial	3423990.933	342.399093	11.643083
Barren	1375803.711	137.580371	4.6783408
Sealed Road	598565.3592	59.856536	2.0353868
Unsealed Road	43208.98138	4.320898	0.1469296
Railway	27249.77074	2.724977	0.0926613

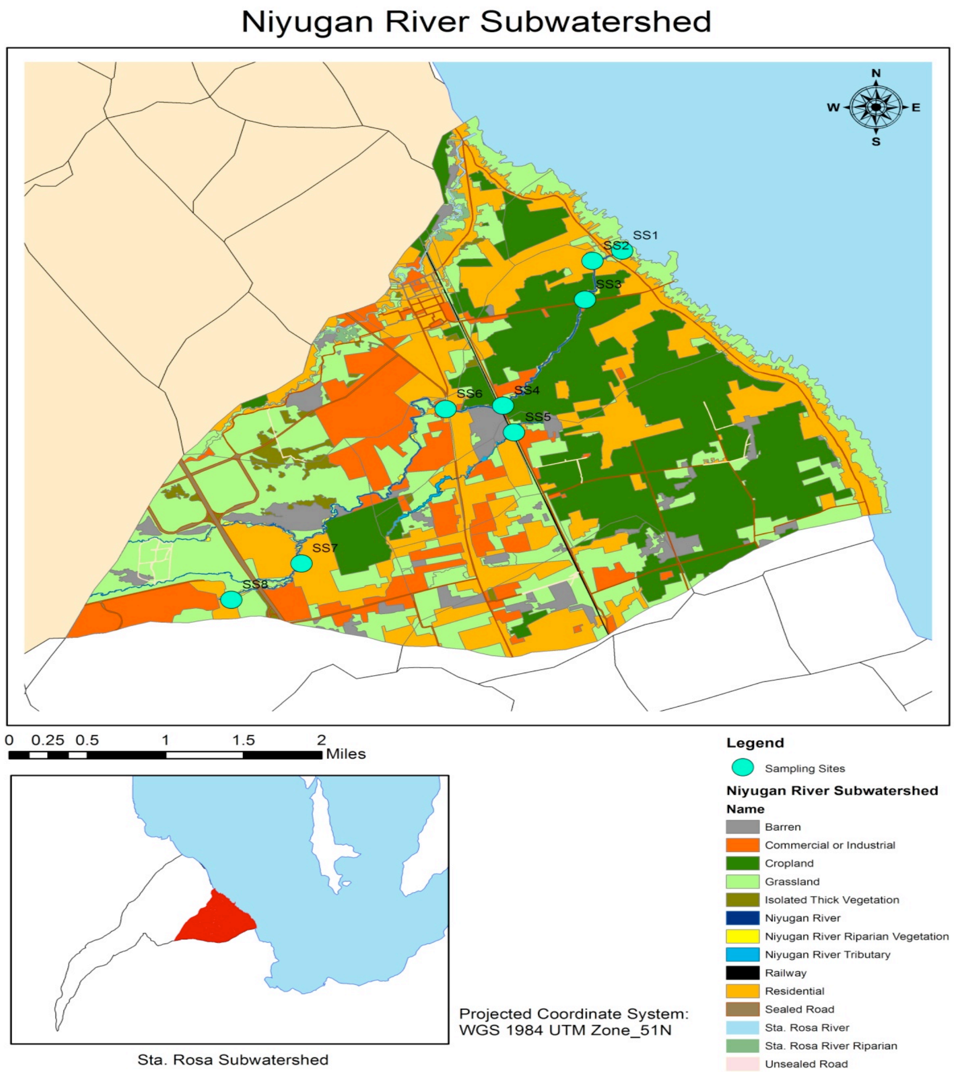

Figure 4. Niyugan River Subwatershed has five major land uses: barren lands, commercial and industrial, croplands, grasslands, and residential; and 3 infrastructure types: railways, sealed and unsealed roads.

Allotment (IRA) and taxes from the Real Property. The increase in residential areas is driven not only by the natural population increase but by the influx of migrants coming to the area for work. Presently, grasslands have the highest percentage possibly because of agricultural areas that have been sold and are to be developed into another type of land use.

Niyugan River Water Quality

Fifteen (15) water quality parameters were tested on the samples collected from the sampling stations: pH, Cd and Pb concentrations, Chl a, TSS, surfactants, air and water temperature difference, DO, EC, BOD5, Phosphorus, TKN, OG, Total Coliform, and Fecal Coliform. The results of the analysis were compared with the reference or target

Table 7. Cabuyao City Land Use in 1979 and 1999.

Land use (ha)	1979		1999		Change in Area (%)*
	Area	%	Area	%	
Agricultural	3,676.8648	85.67	2,404.00079	56.02	- 29.65
Built–up	529.7000	12.34	1,729.58115	40.30	+ 27.96
Open Spaces	85.0000	1.98	4.80037	0.11	- 1.87
Other Uses	-	-	1,543.10428	3.57	-
Total	4,291.5648	100.00	4,291.5648	100.00	

*+ increase, - decrease

Table 8. Cabuyao City Built-up areas in 1979 and 1999.

Built–up Area (ha)	1979		1999		Change in Area (%)*
	Area	%	Area	%	
Residential	252.1298	50.43	829.249	47.95	- 2.48
Commercial	.5506	0.11	5.90625	0.34	+ 0.23
Industrial	231.3532	46.27	878.215	50.77	+ 4.5
Institutional	15.926225	3.19	16.2109	0.94	- 2.25
Total	499.959	100.00	1,729.58115	100.00	

*+ increase, - decrease

values for each parameter. A site fails in a parameter if the observed values did not meet the minimum or the observed values exceeded the maximum threshold (**Table 9**).

Sampling station 5, a tributary of Niyugan River, receiving water from surrounding residential and industrial areas, failed ten (10) out of fifteen (15) parameters. Sampling station 5 had very high levels of TSS, surfactants, BOD, TKN, and OG. The high levels of these parameters might have resulted from the station's location, being at the end of a tributary before water mixes with the main stem of Niyugan River. All the pollutants might have been carried and concentrated in this station. A major dairy food processing industry, located upstream this tributary, is also suspected to be the major contributor of the pollutants. This is because according to *Western Australia Department of Environment* (*2004*), dairy processing wastewater containspredominantly milk and milk products, such as whey, which have been lost from the process, as well as detergents, sanitizers, acidic and caustic cleaning agents, nutrients (e.g., Nitrogen, Phosphorus), dissolved solids including sodium chloride and small amounts of lubricants. The very high TSS levels in the tributary might have come from the colloidal particles of milk and whey; high surfactants levels, from the detergents, sanitizers, cleaning agents, and emulsifiers; high levels of BOD and TKN, from organic matter loads; and high OG levels, from dissolved animal fats and lubricants used in the industry.

Sampling station 4 failed nine (9) parameters. Sampling stations 1, 2, and 3 failed eight (8) parameters, sampling stations 6 and 7 failed seven (7) parameters and station 8 failed six (6) parameters.

Macroinvertebrates

In Niyugan River, only stations 7 and 8 had representatives under the orders Ephemeroptera (mayflies) and Plecoptera (stoneflies). These orders, together with Trichoptera (caddisflies), are indicators of water quality. High proportions of these pollution-sensitive organisms indicate good water quality. Station 7 had 3 stoneflies out of the 60 individuals that were caught (EPT richness: 3). Station 8 had 3 stoneflies and 9 mayflies out of the 27 individuals that were caught (EPT richness: 12) (**Table 10**). Stations 7 and 8 are the upstream stations where the riparian vegetation is maintained. Because of the richness of the two stations in macroinvertebrates, river water in these two stations is considered less polluted. Station 7 is in an exclusive subdivision while station 8 is in Sta. ElenaGolf course, where an efficient waste management system can be assumed. No industrial effluents drain to these stations (**Figure 5**).

Computed Simpson's biodiversity indices, 1-D (**Figure 6**) showed that stations 7 and 8 have the highest diversity of macroinvertebrates. Sites 4, 5, and 6 had zero (0) diversity index because only one macroinvertebrate order was found to be thriving in these stations. Only a single species under the order Oligochaeta was found in polluted sampling stations 4, 5, and 6. This species, commonly known as sludge worms are known to be pollution insensitive macroinvertebrates that can inhabit waters with very low dissolved oxygen and high amounts of organic matter (*Siborowski 2009*). Species from orders Bivalvia and Gastropoda are distributed among the sampling stations, indicating that they are not as sensitive as the species under Ephemeroptera, Plecoptera, and Trichoptera. Species under

Table 9. Summary Results of the water quality indicators from the eight (8) sampling stations in Niyugan River*.

Parameters	Unit	Reference		Sampling Stations							
		Min	Max	1	2	3	4	5	6	7	8
pH		6.80	8.50	7.20	7.45	7.60	7.70	7.01	7.72	7.99	8.30
Cadmium	mg L^{-1}	-	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead	mg L^{-1}	-	0.05	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Chla	mg L^{-1}	-	50	5.10682	6.56100	4.37535	1.07000	2.29477	2.93109	0.10565	
Total Suspended Solids	mg L^{-1}	-	30	15	8	8	19	190	21	10	14
Surfactants	MBAS mg L^{-1}	-	0.5	0.02	0.1	<0.01	<0.01	1.55	<0.01	<0.01	<0.01
Temperature Difference	°C	-	2	0.5337	0.2	0.011	3.6	0	2.25	4.25	2.2
DO	mg L^{-1}	5		2.39667	0.28	2.91333	4.54	2.33	7.45	6.42	
Conductivity	microScm^{-1}	150	500	849.081	833.652	811.586	730.114	990.724	741.541	366.603	400.980
BOD	mg L^{-1}	7	10	24	17.9	13.1	11.1	224.3	9.7	1.1	6.5
Phosphorus	mg L^{-1}	-	0.04	1.88	2.14	2.39	2.17	1.27	1.46	0.2	0.11
Total Kjeldahl Nitrogen	mg L^{-1}	0.26	0.4	9.86	7.46	5.86	5.6	23.32	6.93	5.33	5.46
Oil and Grease	mg L^{-1}	-	2	9.6	8.6	10.1	10.2	21	8.1	9.6	10
Total Coliform	MPN 100 mL^{-1}	-	1000	90000	160000	≥160000	≥160000	≥160000	≥160000	160000	14000
Fecal Coliform	MPN 100 mL^{-1}	-	200	90000	160000	≥160000	≥160000	≥160000	≥160000	160000	14000
Total Number of Failed Parameters				8	8	8	9	10	7	7	7

*Red values failed, blank fields had no results

Table 10. Abundance of benthic macroinvertebrates in the 8 sampling stations in Niyugan River.

Orders	Sampling Stations							
	Abundance							
	1	2	3	4	5	6	7	8
Bivalvia	4	0	0	0	0	0	28	11
Gastropoda	6	4	6	0	0	0	17	1
Oligochaeta	0	7	7	11	14	15	0	0
Odonata	0	0	0	0	0	0	12	0
Plecoptera	0	0	0	0	0	0	3	3
Ephemeroptera	0	0	0	0	0	0	0	9
Diptera	0	0	0	0	0	0	0	3
TOTAL	10	11	13	11	14	15	60	27
EPT Richness	0	0	0	0	0	0	3	12

order Diptera are also known to be pollution insensitive.

Sampling stations 5 and 6 are the most similar among the stations (95.55% similarity) because both of the stations only have organisms under order Oligochaeta (**Table 11**). Sampling stations having no shared macroinvertebrate order had zero percent similarity (**Figure 7**).

It can be observed from the dendrogram that the sampling stations tend to cluster based on their relative topographical positions in the river system as upstream (SS8 and SS7), midstream (SS4, SS5, and SS6), and downstream (SS1, SS2, and SS8). This means that the

Figure 5. The sampling stations had representative macroinvertebrates from the orders Ephemeroptera (A), Plecoptera (B), Gastropoda (C), Odonata (D), and Bivalvia (E).

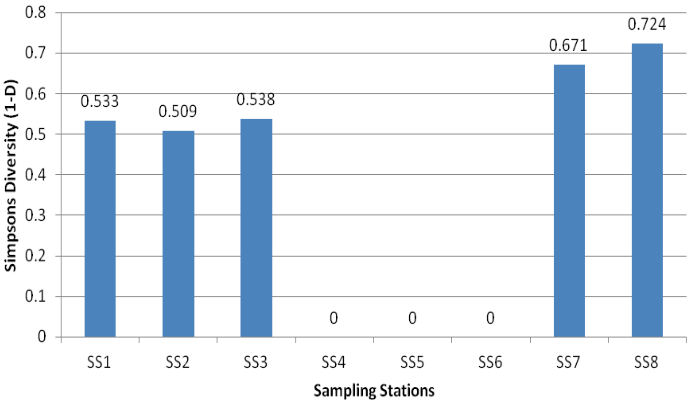

Figure 6. Simpson's Diversity indices of the eight (8) sampling stations in Niyugan River varied from upstream to downstream.

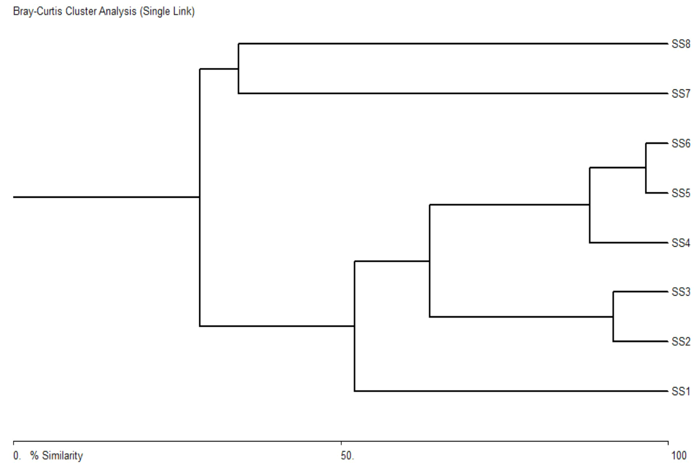

Figure 7. Bray-Curtis Cluster Analysis dendrogram is generated with BioDiversity Pro software on the basis of the benthic macroinvertebrate abundances in the eight (8) stations of Niyugan River.

stations from each topographical position share similar species of macroinvertebrates and could have similar health conditions.The similar health conditions might have resulted from the similar land uses that surround the sampling stations (**Figure 4**): SS1, SS2, and SS3 are surrounded byagricultural and residential areas; SS4, SS5, and SS6 are surrounded by residential and industrial areas; and SS7 and SS8 are surrounded by residential and commercial areas.

Computing Parameters for the Model

Response Parameters

Water Quality Index. The water quality index in the model was computed based on the formula given by the CCME in 2001. The first element, F1, was computed using the number of parameters that had a fail value (11) and the total number of parameters (15). The second element, F2 was computed using the number of tests failed (64) and the total number of tests (118). For the third element, F3, excursions of each test that failed were computed and then normalized. The water quality index resulted to a score of 22. 57.

EPT proportion. The EPT proportion of Niyugan River was computed by dividing the number of mayflies, stoneflies, and caddisflies collected from the stations (15) by the total number of individuals collected (161). The computed EPT score was 25.81.

Pressure Parameters

Riparian cover proportion. The ideal riparian cover of Niyugan River was computed by multiplying the total length of the river (14,020 m) by 20 m in each side of the river. The observed riparian vegetation (560,800 m^2) was then divided by the ideal riparian cover (104,095 m^2) and multiplied by 100. Same formula as EPT score was used to get the Riparian Cover Score. The computed value was 18.56.

Land use and infrastructure. Land use and infrastructure proportions were derived from the created land use map for the area. These proportions were then multiplied with their weights, computed from summarized ratings from interviewed experts on the contribution of each land use and infrastructure for the listed impacts (**Tables 12** and **13**). The computed land use and infrastructure scores were 51.58 and 99.1, respectively.

Table 11. Bray-Curtis similarity indices of the eight (8) sampling stations of Niyugan River from BioDiversity Pro software, computed from macroinvertebrate abundance of the stations.

	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8
SS1	*	38.0952	52.1739	0	0	0	28.5714	27.027
SS2	*	*	91.6667	63.6364	56	53.8462	11.2676	5.2632
SS3	*	*	*	58.3333	51.8519	50	16.4384	5
SS4	*	*	*	*	88	84.6154	0	0
SS5	*	*	*	*	*	96.5517	0	0
SS6	*	*	*	*	*	*	0	0
SS7	*	*	*	*	*	*	*	34.4828
SS8	*	*	*	*	*	*	*	*

Table 12. Weights of different land uses in Niyugan River Subwatershed.

Land use	Augmentation of Nutrient Supply to River	Increase in Salinity	Release of Biocides	Change to Hydrological Regime	Augmentation of the River	Toxicants	Mean Rank	Weight
Barren Land	1.75	1.75	1	2	4.25	1	2.15	0.23889
Cropped Land/ Arable Land	6	5.25	6.25	5	5	5.5	5.5	0.61111
Forests	3.75	3.75	2	3.5	2.5	1.75	3.1	0.34444
Grasslands	2.5	2.75	2.25	2.5	3.5	1.75	2.7	0.3
Industrial/ Commercial	5.5	7	6.75	6.25	6	7	6.3	0.7
Residential	5.5	5.75	4.5	6	4.75	5.75	5.3	0.58889
Agroforests	4.25	4	4.5	4.5	3.75	4.25	4.2	0.46667

Table 13. Weights of different infrastructure in Niyugan River Subwatershed.

Infrastructure	Augmentation of Nutrient Supply to River	Release of Biocides	Change to Hydrological Regime	Augmentation of the Sediment Supply to River	Toxicants	Mean Rank	Weight
Sealed Roads	1.25	1.75	1.25	1	1.25	1.3	0.37143
Railway	1	1	1.5	1.25	1.25	1.2	0.34286
Unsealed Roads	3	1.75	2.5	2.75	2.25	2.45	0.7

Overall River Health Index

To get the overall river health index, the individual scores of the indicators within the response and the pressure parameters were averaged. The average response score was multiplied by 60% and the average pressure score was multiplied by 40% before they were added. The overall river health score was 37.07, which has a qualitative equivalent of "poor" (**Table 5**). This river score corresponds to rivers that are largely influenced by human densities. From the management perspective, this river needs restoration of flow patterns, river habitats, and water quality. Several factors might have caused the degradation of the river:

Discharge of Untreated Sewage and Effluents and Storm Water Runoff into the River. Cabuyao City shoulddevelop a sewage treatment facility. Though it might require high investment, this would improve the water quality of the all other rivers within the city, including San Cristobal River, which is considered as one of the most polluted rivers draining into Laguna Lake. Effluents from all industries in Cabuyao City should also be monitored regularly. This is to make sure that industries follow effluent quality standards. Cabuyao City should establish a buffer zone for riparian vegetation, so that storm water runoff, carrying sediments and other chemicals and nutrients from different land uses, would not drain directly into the river.

Inefficient/Absence of Solid Waste Management System. Cabuyao City should develop and strictly implement solid waste management system to prevent the disposal of garbage in the river. River cleanup projects should be started to improve the flow regime of the river.

Inefficient/Absence of Zoning Plans. Cabuyao city should create an efficient zoning plan that would consider possible environmental consequences of industries, residential areas, and farms. An environmental impact assessment should strictly be done before any type of project can be implemented. Stakeholder participation should be given importance in this matter.

Presence of Informal Settlements along the Banks of the River. Relocation sites should be prepared for the informal settlers along the riverbanks of the river. Re-establishment of riparian vegetation should immediately follow the removal of the settlements.

Stella Calculator-like Interface

The calculator interface was made using a save-disabled trial version of Stella modelling software. All the formula was embedded into the model for efficient calculation of the index and sensitivity analyses (**Figure 8** and **Figure 9**).

Sensitivity Analysis

It can be noted that water quality and the river health scores were decreasing continuously until parameters having more failed values (BOD, P, OG, and total coliform) were removed (**Figure 10**). On the other hand, results of varying the combination of indicators by removing oneparameter at a time showed that water quality and river health scores

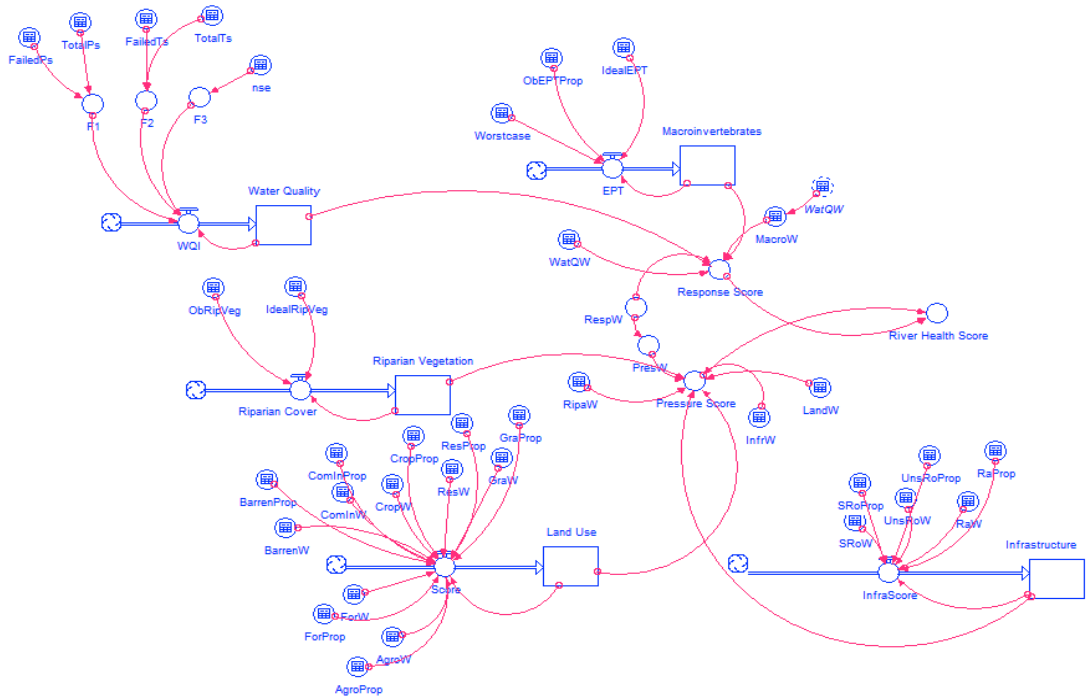

Figure 8. Response and pressure parameter formulas were embedded in the model.

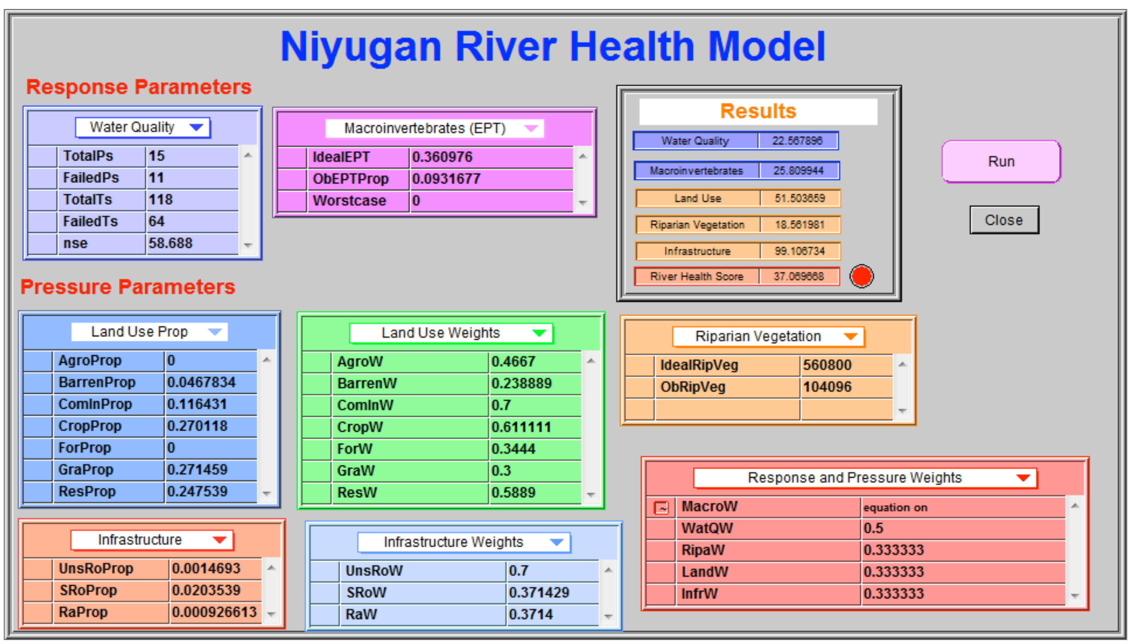

Figure 9. Calculator-like interface was created with Stella software.

decreased when parameters having none or few failed values were removed; the scores increased when parameters having more failed values were removed (**Figure 11**).

An independent-sample t-test of the scores from varying the number of indicators indicated that the scores were not significantly different from each other, t (8) = 1.271, p = 0.240. Another independent-samples t-test of the scores from the different combination of indicators indicated that the scores were significantly different, t (8) = 1.937, $p < 0.05$. This would mean that the river health score is influenced, at a greater extent of the different combinations of water quality indicators, rather than the number of indicators used.

It can be noted from the results that river health score decreased when weights of the parameters having low values were increased (**Figure 12**). Same observation was noted as the weight of land use was increased (**Table** 14).

In the case of Niyugan River the combination of pH, TSS, DO, conductivity, TKN, and fecal coliform can give a river health score with the same descriptive interpretation as having all other parameters. This might not be the case

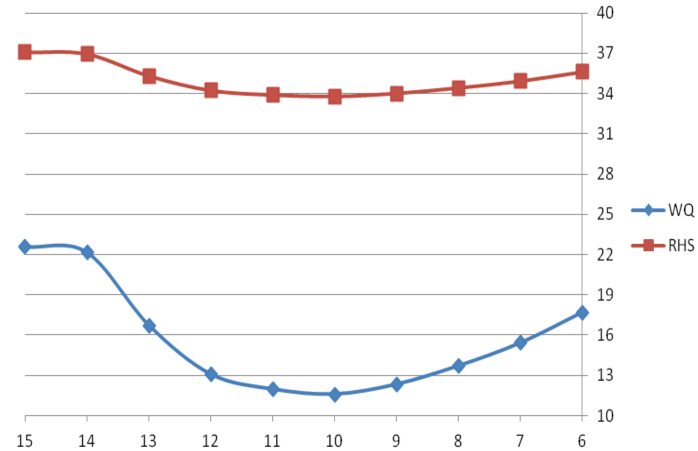

Figure 10. Water Quality Score (WQ) and River Health Score (RHS) responds to the number of parameters used in the Water Quality Index (order of removal: Cd, Pb, Chla, surfactants, temperature difference, BOD, P, OG, and total coliform).

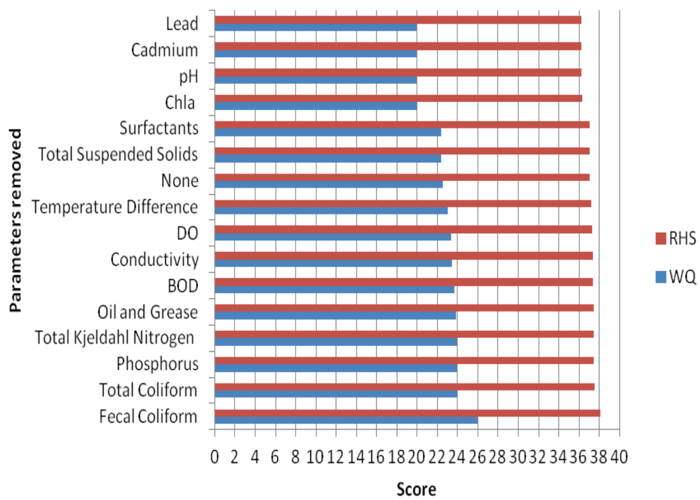

Figure 11. Water Quality Score (WQ) and River Health Score (RHS) vary with different combinations of parameters.

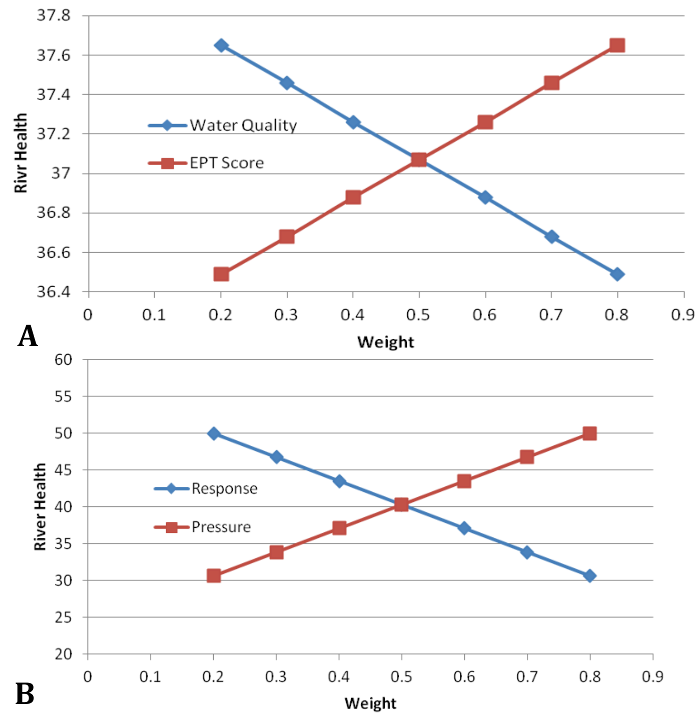

Figure 12. (A) River Health Score changes with varying Water Quality and EPT Proportion weights; (B) River Health Score changes with varying Response and Pressure weights.

for other rivers. The magnitude of the collective response and pressure scores influenced the river health scores when their weights were changed. The model should be used with data sets coming from other Laguna Lake tributaries to further investigate its sensitivity.

CONCLUSIONS AND RECOMMENDATION

The Niyugan River Subwatershed is composed of 13 barangays with a total area of 2949.5 has. Grasslands and croplands dominate the area, covering more than 50% of the entire subwatershed. Niyugan River is one of the least

Table 14. Model sensitivity scenarios and results.

Case 1: Varying Weights of the Response Parameters									
Water Quality	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0	1	0
EPT Score	0.8	0.7	0.6	0.5	0.4	0.3	0.2	1	0	0
River Health Score	37.65	37.46	37.26	37.07	36.88	36.68	36.49	38.04	36.1	22.55
Case 2: Varying Weights of the Pressure Parameters										
Land use	0.33	0.25	0.3	0.6	0.4	0	1	0		
Infrastructure	0.33	0.25	0.2	0.1	0.1	0	0	1		
Riparian	0.33	0.5	0.5	0.3	0.5	1	0	0		
River Health Score	37.07	33.29	32.33	33.07	30.43	21.94	35.11	54.16		
Case 3: Varying Weights of Collective Response and the Pressure Parameters										
Response	0.2	0.3	0.4	0.5	0.6	0.7	0.8			
Pressure	0.8	0.7	0.6	0.5	0.4	0.3	0.2			
River Health Score	49.95	46.73	43.51	40.29	37.07	33.85	30.63			

studied river tributaries of the Laguna Lake. It extends 14.02 km from Barangay Don Jose in the upstream to Barangay Marinig near the lake. Eight sampling stations, chosen based on the surrounding dominant land use were established to represent the health of the river. Fifteen parameters (15) were tested to determine the quality of the water in the river. Based on the water quality data, sampling station 5 (tributary of the Niyugan River), located in the middle of industrial, commercial, and barren lands, was the most degraded part of the river. It failed 10 out of the 15 water quality parameters. Benthic macroinvertebrates were collected from the stations and the proportion of pollution- sensitive orders, Ephemeroptera, Plecoptera, and Trichoptera was determined. Only the upstream stations, 7 and 8, had these organisms. Riparian vegetation is almost absent in most part of the river.

The developed model is comprised of two categories of parameters, response and pressure. The response parameters, water quality index and EPT proportion are meant to demonstrate the present condition of the river; the pressure parameters, land use and infrastructure and riparian cover proportion are meant to reflect factors that can aggravate or worsen the health of Niyugan River. The model was given a calculator-like interface using Stella software for efficient computation and sensitivity analyses. The computed river health score for Niyugan River was 37.07, corresponding to "poor" health condition. Restoration of flow regimes, riparian vegetation, and removal of solid waste in the river should be done to improve its health. Effluents draining from surrounding industries should also be monitored to make sure that they meet effluent quality standards.

The combination of water quality indicators affects the river health score greater than the number of indicators used. River health score also seemed to be influenced by the magnitude of separate indicators within a parameter category.

For this reason, the model should be used with data from other rivers. It will also be of value to assess the categorization of the descriptive equivalents of the river health score.

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