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Watershed Health Assessment Using GIS and AHP Methods: Application in Stung Sen River Basin, Cambodia

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Abstract

The watershed assessment provides information about the condition of water quality and biological integrity to identify the source of stressors and their impacts. In the present decades, different watershed assessment method has been established to evaluate the cumulative impacts of human activities on watershed health and aquatic systems. This study proposes a new approach for assessing watershed vulnerability to contamination based on spatial analysis using the Geographic Information System (GIS). and Analytic Hierarchy Process (AHP) methods. This new procedure designed to identify vulnerable zones depends on seven basic factors representing watershed characteristics: land use/land cover, sediment load, nitrate load, phosphorus load, soil type, average annual precipitation, and slope. The new watershed vulnerability assessment technique was used to create a map showing the relative vulnerabilities of specific sub-watersheds in the Sen River Basin, the largest sub-basin of the Tonle Sap Lake. The results showed a remarkable difference in watershed susceptibility between the sub-watersheds in their vulnerability to pollution. The approximate area of 10,846 km^2 (76%) in the Northwest part and the long distance from the river of the study area were categorized in a range from moderate, low, and very low watershed vulnerability. However, consisting 3,341 km^2 (24%) located downstream and near distance from the river were displayed as a very high and high vulnerability to pollution in the watershed. Furthermore, the results of the evaluation of the predictive reliability of the watershed vulnerability assessment method revealed that the proposed approach is suitable as a decision-making tool to predict watershed health. The process of this study indeed provides an application performance for the Sen River Basin and calls for action to sustain the water ecosystem and use.

Keywords: Analytic Hierarchy Process (AHP), Sen River Basin, Geographic Information System (GIS), Vulnerability zones, Watershed health assessment.

1. Introduction

Watershed health assessment is one of the greatest methods of evaluating the dynamics and health of a watershed (Mosaffaie et al., 2021). The significance of measuring risks to evaluate the health of watersheds is being recognized by ecologists and hydrologists even more (Ahn et al., 2019). Hydrologists and ecologists looking to advance sustainable practices, the evaluation of watersheds in the context of human and ecological health is a topic of great interest (Hoque et al., 2012). Climate, soils, hydrology, geomorphology, land use, and land cover (LULC) are some of the factors that have an impact on the health of watersheds (Jabbar et al., 2020). Healthy watersheds play a key role in providing habitat for wildlife, clean water for healthy aquatic ecosystems, safe drinking water (Alilou et al., 2019), and contributing to sustainable development (Sophocleous & Mario, 2000). In these relevant details, Sen River is one of the main tributaries of Tonle Sap Lake. This catchment is a resource supplier by bringing Tonle Sap a variety of fish and other aquatic life, sediment, and chemical components including nutrients annually (Nagumo et al., 2017). Insufficient knowledge about the vulnerability of watershed health in this area could result in serious problems, affect the ecosystem as a whole, and delay the resolution of existing problems. Thus, watershed health assessment plays a significant role that must be constantly monitored for adopting natural resources and carry out proper watershed management.

With the advancing technology of one generation, numerous techniques were created and improved upon to more effectively address all the objects, and numerous hydrology modeling was also established. In the present investigation, we support a method for determining a watershed vulnerability to infections that are entirely based on spatial analysis using the Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) techniques. This process relies on seven simple elements that constitute watershed characteristics: LULC, sediment, nitrate, phosphorus, soil type, rainfall, and slope. The purpose of this research is to identify vulnerable zones on a watershed map including the relative vulnerabilities of specific sub-watersheds in Sen River Basin and can help experts in the field of environmental planning and management make more informed decisions.

2. Materials and Methods

Sen River Basin

The biggest freshwater lake in Southeast Asia, Tonle Sap lake located in the central floodplain of Cambodia (Campbell et al., 2006). In the catchment of Tonle Sap Lake, there are 11 sub-basins with a total area is 67,600 km^2. Among these sub-basins, the Sen River Basin is the largest sub-basin located in the north-eastern part of the Tonle Sap Lake of Cambodia. The Sen River Basin locates on the mountainous Cambodia and Thailand border in Preah Vihear province which lies between latitudes 12°30′ and 14°30′ North and longitudes 104°00′ and 105°30′ East (Figure 1).

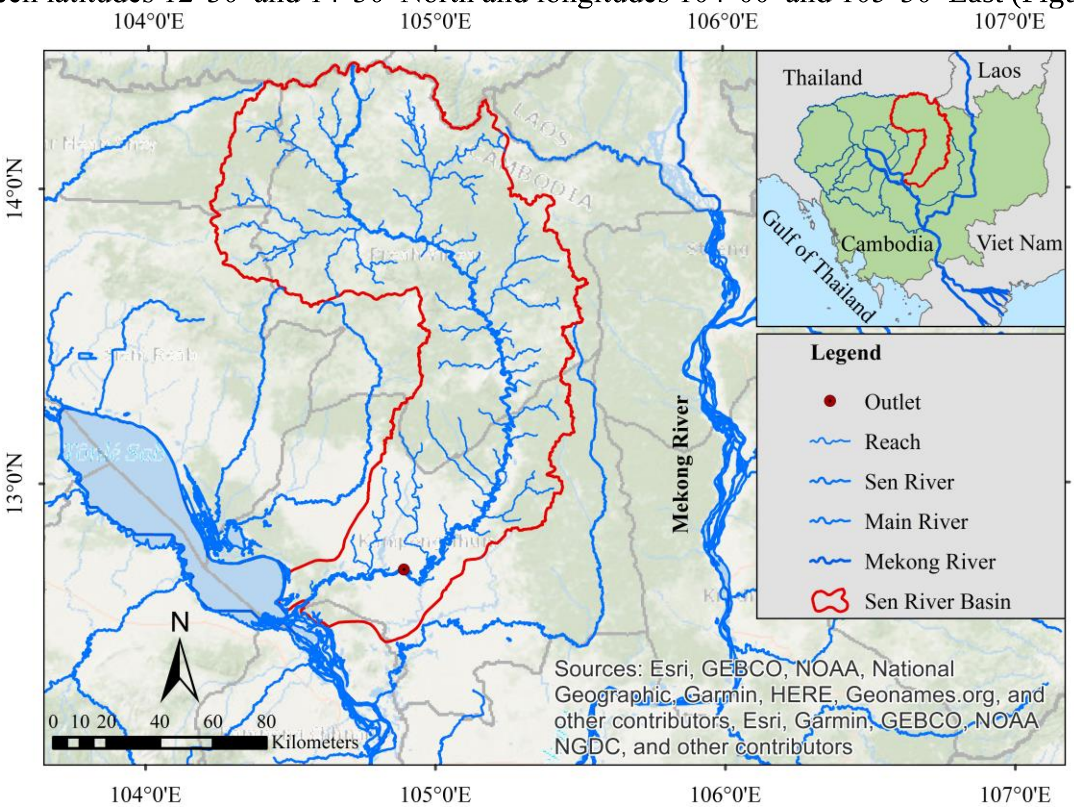

Figure 1. Sen River Basin

The total length of the Sen River is about 500 km and is controlled by the water level of the lake and originates from the highest elevation of approximately 790 m (Nagumo et al., 2013). Based on the data from the Ministry for Water Resources and Meteorology, the total catchment area of the Sen River Basin is 16,000 km^2. However, the floodplain of the Sen River extends along the lower reaches between about 50 and 230 km upstream of Tonle Sap Lake (Nagumo et al., 2015) is not covered in this study, the actual drainage area covers only 14,000 km^2. The mean precipitation in the Sen River basin is about 1600 mm annually, and this river discharge varies from 10 m^3/s in the dry season and 700 m^3/s in the wet season (Nagumo et al., 2013). The average temperature is about 27.5 ^{o}C with maximum and minimum temperatures of 35 ^{o}C and 20 ^{o}C, respectively (Sun et al., 2009). The basin encompasses 487 villages with a total population of 318,000 in 1998 and 359,000 in 2003, and the total agricultural land of the basin is 165,000 ha (Serrat & Olivier, 2006).

Research framework

This process relies upon seven fundamental factors, which characterize watershed characteristics, and it is designed to perceive susceptible zones. The major objectives of this study can be achieved through this flow chart. To be able to reach AHP evaluation, input factors such as LULC, soil type, slope, sediment, nitrate, phosphorus, and precipitation were needed. These seven factors with the relative significance of every criterion are wanted before assigning weights. It uses pairwise comparisons that measure all factors (criteria and sub-criteria) matched to each other, then calculates indicator weights and checks the accuracy performance. If the model does not perform well, it is needed to recheck. However, if the model performs well after checking the accuracy, the watershed susceptibility assessment can assess. The watershed susceptibility assessment process will reclassify the factors based on their weight and apply weighted overlay analysis to achieve watershed vulnerability (Figure 2).

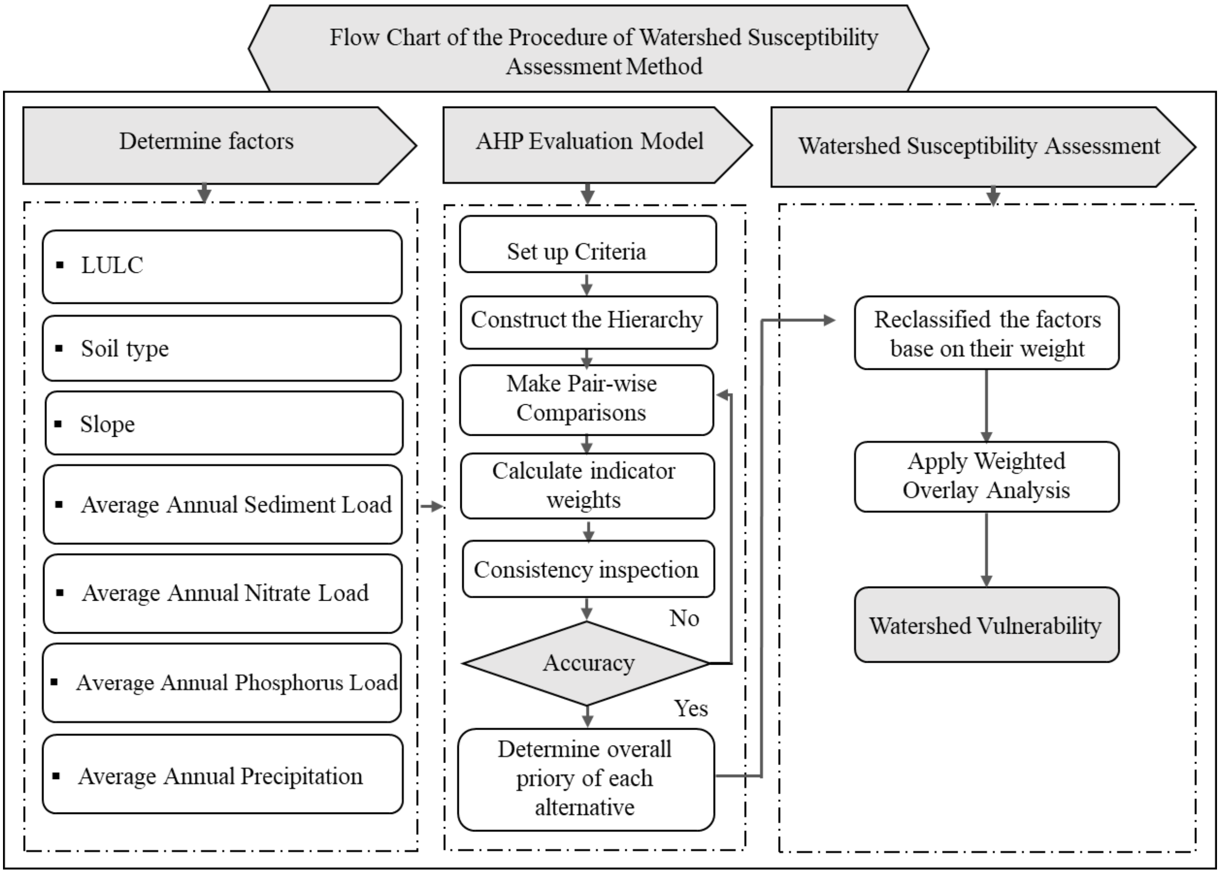

Figure 2. Flowchart of the procedures of AHP and watershed susceptibility assessment method

Data acquisition and processing

The primary data as shown in Table 1: the Digital Elevation Model is known as DEM were from USGS ASTER-GDEM2 with a spatial resolution of 30 m within Geographic coordinated latitude, and longitude with 16 bits in units of vertical meters. The source of LULC, and soil type, relied on the Mekong River Commission (MRC). In our analysis, classifications of LULC (Figure 3a) were reduced to the number of variables to create more meaningful LULC categories (Figure 3b). Furthermore, the average annual sediment load, nitrate load, and phosphorus load were simulated by the SWAT model with a good performance from the previous study (Lim et al., 2022) (Table 1 and Figure 4). These data have been analyzed using ArcGIS version 10.4.1, which also provided the averages of each parameter for every sub-watershed and were used to investigate key watershed characteristics.

Table 1. Description of the data requirement

Input Data	Period	Description Information	Sources
DEM	-	Spatial resolution 30 m, Geographic coordinated latitude, and longitude with 16 bits in units of vertical meters	USGS ASTER-GDEM2
LULC	2002	With the spatial resolution of 250 m, LULC is separated into 21 classes	MRC
Soil types	2002	Spatial resolution 250 m, soil type separated into 22 classes	MRC
Rainfall	1998-2019	Daily time step, 18 stations	TRMM
Sediment	2001-2015	Average annual sediment load (kt/year)	SWAT Simulation (Lim et al., 2022)
Nitrate	2001-2015	Average annual nitrate load (t/year)	SWAT Simulation (Lim et al., 2022)
Phosphorus	2001-2015	Average annual phosphorus (t/year)	SWAT Simulation (Lim et al., 2022)

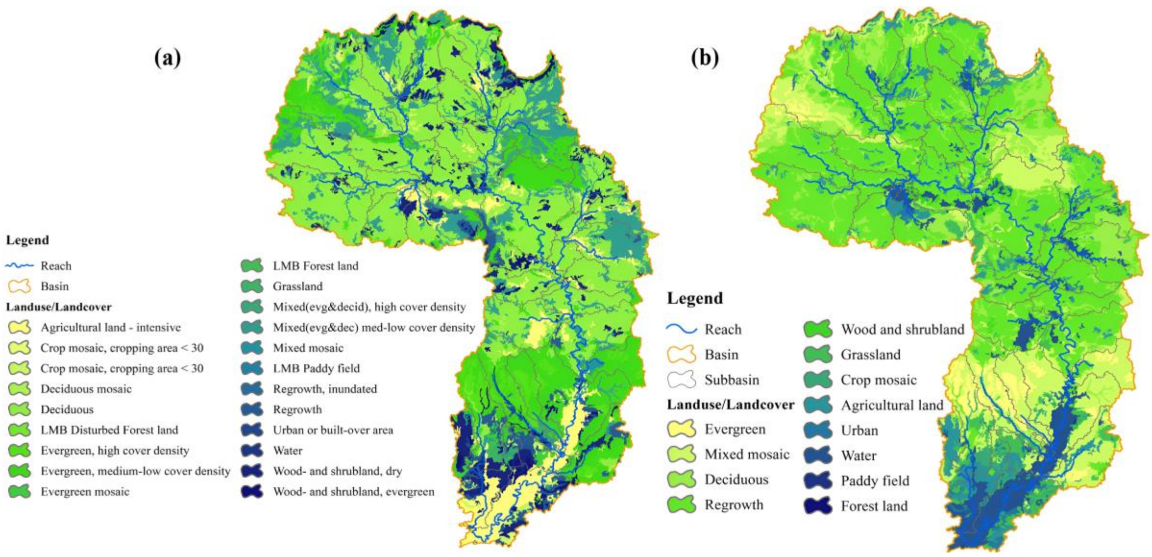

Figure 3. LULC categories (a) before re-classification and (b) after re-classification and aggregated into 12 categories

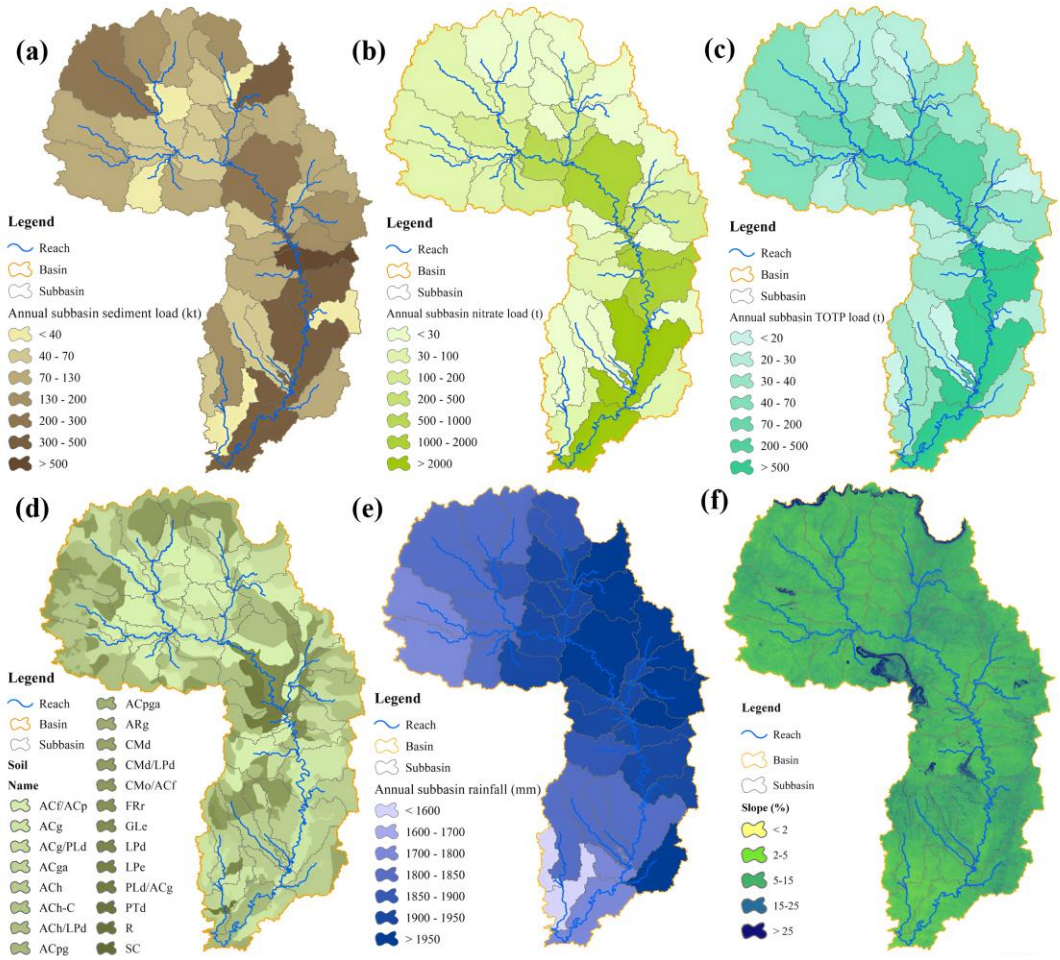

Figure 4. Thematic maps of the layers before rating value of (a) Sediment, (b) Nitrate, (c) Phosphorus, (d) Soil type, (e) Precipitation, and (f) Slope

Analytical Hierarchy Process evaluation model

The analytical hierarchy process (AHP) is an effective multi-criteria decision-making technique that can be used to set a systematic approach for evaluating and integrating the impacts of different factors, including some levels of qualitative and quantitative information (Saaty & Thomas, 1980). The AHP method can reduce problems between factors such as interrelationships and overlapping. The relative weight for each factor considered in this study was estimated using the methods of AHP and pairwise comparison matrix. It uses pairwise comparisons that measure all factors (criteria and sub-criteria) matched to each other. This method is founded on three major principles: (1) pairwise comparison judgments, (2) decomposition, and (3) synthesis of priorities. It was recommended using a scale from 1 to 9 to compare the factors, with 1 signifying that the criteria are equally important, and 9 signifying that a particular criterion is highly significant (Saaty & Thomas, 1980). The consistency ratio (CR) is calculated to assess the differences between the pairwise comparisons and the reliability of the measured weights. To be accepted, the CR should be less than 0.1. If not, subjective judgments should be rethought before recalculating the weights (Saaty & Thomas, 2008).

The structure of the decision-making problem for this study consisted of numbers represented by the symbols m and n. The values of a_{ij} (i = 1, 2, 3…, m) and (j = 1, 2, 3..., n) were used to represent the performance values matrix in terms of the i^{th} and j^{th} elements. The values of the comparison criterion above the diagonal of the matrix were used to fill the upper triangular matrix, and the lower triangular of the matrix used the reciprocal values of the upper diagonal. In the pairwise comparison matrix A, the matrix element a_{ij} indicates the relative importance of the i^{th} and j^{th} alternatives for criterion A, where a_{ji} is the reciprocal value of a_{ij}.

Below is an example of a decision matrix, which combines a typical comparison matrix for any problem with the relative importance of each criterion with the following formula:

$$A = \begin{pmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & a_{2n} \\ \dots & 1/a_{23} & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{pmatrix} \quad (1)$$

Where a_j; i, j = 1, 2… n is the element of row i and column j of the matrix, which is equal to the number of alternatives.

The geometric principles were used to calculate the eigenvectors for each row:

$$Eg_i = \sqrt[n]{a_{11} \times a_{12} \times a_{13} \times \ldots \times a_{1n}} \quad (2)$$

Where, Eg_i represents the eigenvector for row i, and n represents the number of elements in row i.

The priority vector (pr_i) was found by normalizing the eigenvalues to 1, the normalization is a method that is used to get numerical and comparable input data, using the following formula:

$$pr_i = Eg_i / \left(\sum_{k=1}^{n} Eg_k \right) \quad (3)$$

Lambda max (λ_{max}) was evaluated based on the summation of the result of multiplying each element in the priority vector with the sum of the column of the reciprocal matrix as show in formula below:

$$\lambda_{\max} = \sum_{j=1}^{n} \left(W_j \times \sum_{i=1}^{m} a_{ij} \right) \quad (4)$$

Where a_{ij} is the sum of the criteria in each column in the matrix; W_i is the value of the weight of each criterion corresponding to the priority vector in the matrix of decision; and where i = 1, 2 … m, and j = 1, 2 …n.

The consistency ratio (CR) can be found using the following formula:

$$CR = \frac{CI}{RI} \quad (5)$$

Where CI is the consistency index:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (6)$$

Where λ_{max} represents the sum of the products between the sum of each column of the comparison matrix and the relative weights, and n is the size of the matrix.

RI signifies the random index, which describes the consistency of the randomly generated pairwise comparison matrix. In this study, the decision matrix of this study and weighted scores for each factor were obtained using the AHP model with a similar method employed to obtain rating values for each sub-criteria within the watershed susceptibility assessment.

To calculate the watershed susceptibility values of the study area, the weighted overlay analysis was applied based on the following formula:

$$WS = \sum_{j=1}^{n} W_j \times C_{ij} \qquad (7)$$

Where *WS* represents the watershed susceptibility for the area i, W_j represents the relative importance weight of criterion, C_{ij} represents the grading value of area i under criterion j, and n represents the total number of criteria.

Table 2. Judgments scale and definitions for the pairwise comparison

Intensity of importance	**Qualitative definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgments slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Demonstrated importance	An activity is favored very strongly over another and dominance is demonstrated in practice
8	Very strong	The evidence favoring one activity over another is of the highest possible order of affirmation
9	Extreme importance	

3. Results and Discussion

The relative weights

The determination of factors, the development of ratings for each, and the ranking of the weights were based on a synthesis of previous studies which were conducted to investigate possible factors and their impacts on the surface water quality, as well as evaluation of factors correlating with environmental degradation watersheds (Hoorman et al., 2008; Jabbar et al., 2019). The general assumptions were considered in the study of watershed vulnerability based on the response of a watershed systematically to different contamination impacts and how the seven factors working together can affect the watershed health. A decision hierarchy was employed to assign the relative weight for each factor affecting the watershed's susceptibility. In this study, the weighted scores for each factor were obtained using the AHP model and weights based on the principal eigenvector of the decision matrix. with a similar method employed to obtain rating values for each sub-criteria within the watershed susceptibility assessment. In this study, the number of comparisons "n" equal "21", with consistency ratio "CR" equal "0.02%". These normalized weights of factors of these pair-wise comparisons are considered reliable since the value of consistency ratio CR = 0.02 < 0.1 was accepted, and a reliable level of consistency in the pairwise comparisons. Amount of these seven factors, LULC is the highest priority than another factor while their weight is 0.32 due to this factor is more effect on watershed health. After LULC, sediment load is a significant factor in watershed health vulnerability within 0.21 of their wight. Nitrate load and phosphorus load contain 0.14 and 0.11 of their weights. However, soil type, precipitation, and slope represent the lower weights (Table 3).

Table 3. Weights based on the principal eigenvector of the decision matrix

Factor	LULU	ST	AAP	AASL	AANL	AAPL	S	Weights
LULC	1	2	3	4	4	4	4	0.32
AASL	0.5	1	2	2	3	3	3	0.21
AANL	0.33	0.5	1	2	2	2	2	0.14
AAPL	0.33	0.5	0.5	1	2	2	2	0.11
ST	0.25	0.33	0.5	0.5	1	2	1	0.09
AAP	0.25	0.33	0.5	0.5	0.5	1	2	0.07
S	0.25	0.33	0.5	0.5	1	0.5	1	0.06
CR value = 0.02								

LULC (Land use/land cover), AASL (Average annual sediment load), AANL (Average annual nitrate load), AAPL (Average annual phosphorus load), ST (Soil type), AAP (Average annual precipitation), S (Slope).

Watershed susceptibility assessment factors

In this study, decision hierarchy was employed to assign the relative weight for each factor that contributed to affecting the watershed's susceptibility, which involves two steps. First, categories were created, using seven seemingly significant factors: LULC, soil type, precipitation, sediment, nitrate, phosphorus, and slope. Second, 66 sub-categories were created to assess the watershed health. This study integrated the opinions of survey researchers in this field with information related and accessible details about the review region to present each factor, which was then categorized into classes of sub-classifications. The results of the evaluation of the predictive reliability of the watershed vulnerability assessment method revealed that the proposed approach is suitable as a decision-making tool to predict watershed health. After the AHP analysis was completed, the maps needed for each layer were constructed as a shape file (vector) or raster. For each of the factors discussed below, the boundaries of each sub-watershed were used by GIS-based analysis on different data sets. The origins of each data set and manipulations of these data set to obtain the desired parameters. Therefore, the ratings of each of the seven parameters considered: LULC, sediment, nitrate, phosphorus, soil type, precipitation, and slope are shown below the result. Then, a reasonableness rating value was given to each subcategory. Elements positioned somewhere in the range of 1 (i.e., low scores) lightly affect water quality, while factors with high scores generally affect water quality. Sub-categories were rated from 1 to 10, with 1 meaning that there was a negligible effect on water quality, while high scores correlated with having a very high effect (Table 4 and Figure 5).

LULC

LULC directly affects the watershed hydrology components, such as evapotranspiration, surface runoff, groundwater, streamflow, flood frequency, flood severity, base flow, and annual discharge (Melesse et al., 2016). LULC changes pertain to variations in surface roughness, soil aggregate structure, and soil organic content and nutrients, including nutrient input from manure and fertilizer. The adverse effects of soil erosion include water pollution and siltation, crop yield depression, organic matter loss, and reduction in water storage capacity, which may lead to fundamental social challenges such as land abandonment and the decline of rural communities (Bakker et al., 2005). Urban lands can produce great effects on surface water quality because they contain substantial amounts of point and nonpoint source contaminants (Wilson & Weng, 2010). Contamination from nutrients, organic matter, and bacteria often result from the waste generated by city wastewater treatment plants as well as from a variety of anthropogenic sources (Chang et al., 2010). Based on their impact on watershed health, for this study, the LULC was separated into twelve categories. Consequently, LULC is the most severe factors mount factor. Agricultural LULC with the highest impact was rated "10" while LULC classified as "water" received the lowest rating or "1".

Sediment

Sedimentation transport is the movement of particles that may be purely due to gravity. Sediment load was carried entirely in the suspended state, and it covers the soil bed during the soil erosion process shielding the soil from the forces of flow. Thus, the sediment load exiting the rill and deposition along the rill were measured (Merten et al., 2001). The motive of sedimentation, such as transport or disposition in the stream, is led to cause issues or something providing benefits through the specific load of its dynamic (Merten et al., 2001). In this study, sediment load was classified into 7 groups as each sub-criterion. The rating scores of all sub-criteria corresponding such as annual sediment load < 40 kt/year were valued at "2" while the highest sediment load classification > 500 kt/year were valued to "10" of their rating score.

Nitrate

Nitrate is an important nutrient in the aquatic environment and is regarded as the key factor in determining the ecological status of aquatic ecosystems (Conley et al., 2009; Elser et al., 2007). Over the past century, intensified human activities have profoundly altered the supply of nitrate into the water bodies. Thus nitrate is causing a severe deterioration in water quality and frequent eutrophication incidents around the world (Varol et al., 2012). Increasing nitrate will be toxic to aquatic and water quality when the concentrations of nitrate increase and exposure times. Likewise, Nitrate is one of the factors that anxiety into the environment of watershed quality and watershed health. The matching rating scores for all sub-criteria, such as annual nitrate load < 30 t/year correspond to a value rating as to "2" of their rating score, respectively. While the highest annual nitrate load > 2,000 t/year was rated as "10" of their rating value.

Phosphorus

The transfer of phosphorus from the river is influenced by multiple factors of water pollution (Søndergaard et al., 2013). Moreover, stored sedimentary phosphorus may be regenerated and released back to the overlying waters with changing environmental conditions. Resulting in a decrease of phosphorus in water quality and internal source triggered eutrophication within the dynamics of a specific water body and its effect on watershed health (Grüneberg et al., 2015). Annual phosphorus load was also classified into seven classifications which vary from < 20 t/year to > 500 t/year and correspond to a value lowest is "1", and the highest value is "10".

Soil type

Soil types were grouped into 21 soil classifications relative to their impact on water quality. Most soil type covered in this catchment is Haplic Acrisol/Dystric Leptosol about 20.6%, followed by Gleyic Acrisol/Dystric Planosol 18.8%, Ferric Acrisol 16.84%, Ferreatic Cambisol/Ferric Acrisol 10.26%, Haplic Acrisol 10.23% of their total area and other. Ferric Acrisol and Ferric Cambisol/Ferrasol Acrisol were valued at "10" because of their favorable aggregate structure and high content of weatherable minerals (Chappell et al., 2007). They usually can be exploited for agriculture subject to the limitations of terrain and climate.

Precipitation

Precipitation and increasing pollution levels in surface water are usually assumed to be directly related. For example, surface runoff of pollutants increases with rapid precipitation and can degrade the water quality of rivers and streams (Göbel et al., 2007).The high correlation of precipitation with watershed health results from the impact of rainfall magnitude and intensity on sediment and nutrient loading. Thus, precipitation was classified into seven groups, with the highest amount of annual rainfall corresponding to a value of "10," while the lowest precipitation was given a value of "1".

Slope

High slopes have a considerable effect on the infiltration rate to groundwater, the number of infiltration increases as the slope increases (Fox et al., 1997). Therefore, this study formed five categories of slope to take into account their impact on the amount of rainfall that becomes overland flow, where it eventually either connects to the surface water or adds to the amount of groundwater by infiltration. In these new categories, gentle slopes are given a value of "1" while steep slopes were valued at "10".

Table 4. The relative weights and rating scores of the factors and sub-criteria used for watershed susceptibility assessment

Factor	Weighting	Sub-criteria	Rating
Land use/land cover	0.32	Water	1
		Regrowth	2
		Grassland	3
		Evergreen mosaic	4
		Forest land	5
		Wood- and shrubland	5
		Deciduous	6
		Mixed mosaic	6
		Paddy field	7
		Crop mosaic	8
		Urban or built-over area	9
		Agricultural land	10
Average annual sediment load (kt/year)	0.21	< 40	2
		40 - 70	3
		70 - 130	5
		130 - 200	7
		200 - 300	8
		300 - 500	9
		> 500	10
Average annual nitrate load (t/year)	0.14	< 30	2
		30 - 100	3
		100 - 200	4
		200 - 500	5
		500 - 1000	7
		1000 - 2000	9

		> 2000	10
Average annual phosphorus load (t/year)	0.11	< 20	1
		20 - 30	2
		30 - 40	3
		40 - 70	5
		70 - 200	8
		200 - 500	9
		> 500	10
Soil type	0.09	Slop complex	1
		Haplic Acrisol	2
		Haplic Acrisol-skeletic	2
		Haplic Acrisol/Dystric Leptosol	2
		Eutric Gleyysol	3
		Dystric	3
		Eustric Leptosol	3
		Areni-gley	4
		Gleyic	4
		Dystric Leptosol	5
		Dystric planosol/Gleyic Acrisol	5
		Dystric Cambisol/Dystic leptosol	6
		Gleyic Acrsol	7
		Rhodic Ferrasol	7
		Gleyic-plinthic	7
		Gleyic Acrsol/Dystric Planosol	7
		Rock out crop	8
		Gleyic-plinthic	8
		Dystric Pintosol	8
		Ferric Acrisol	9
		Ferric Cambisol/Ferrasol Acrisol	10
Average annual precipitation (mm)	0.07	< 1600	2
		1600 - 1700	4
		1700 - 1800	6
		1800 - 1850	7
		1850 - 1880	8
		1880 - 1900	9
		> 1900	10
Slope	0.06	< 2	2
		2-5	4
		5-15	6
		15-25	8
		> 25	10

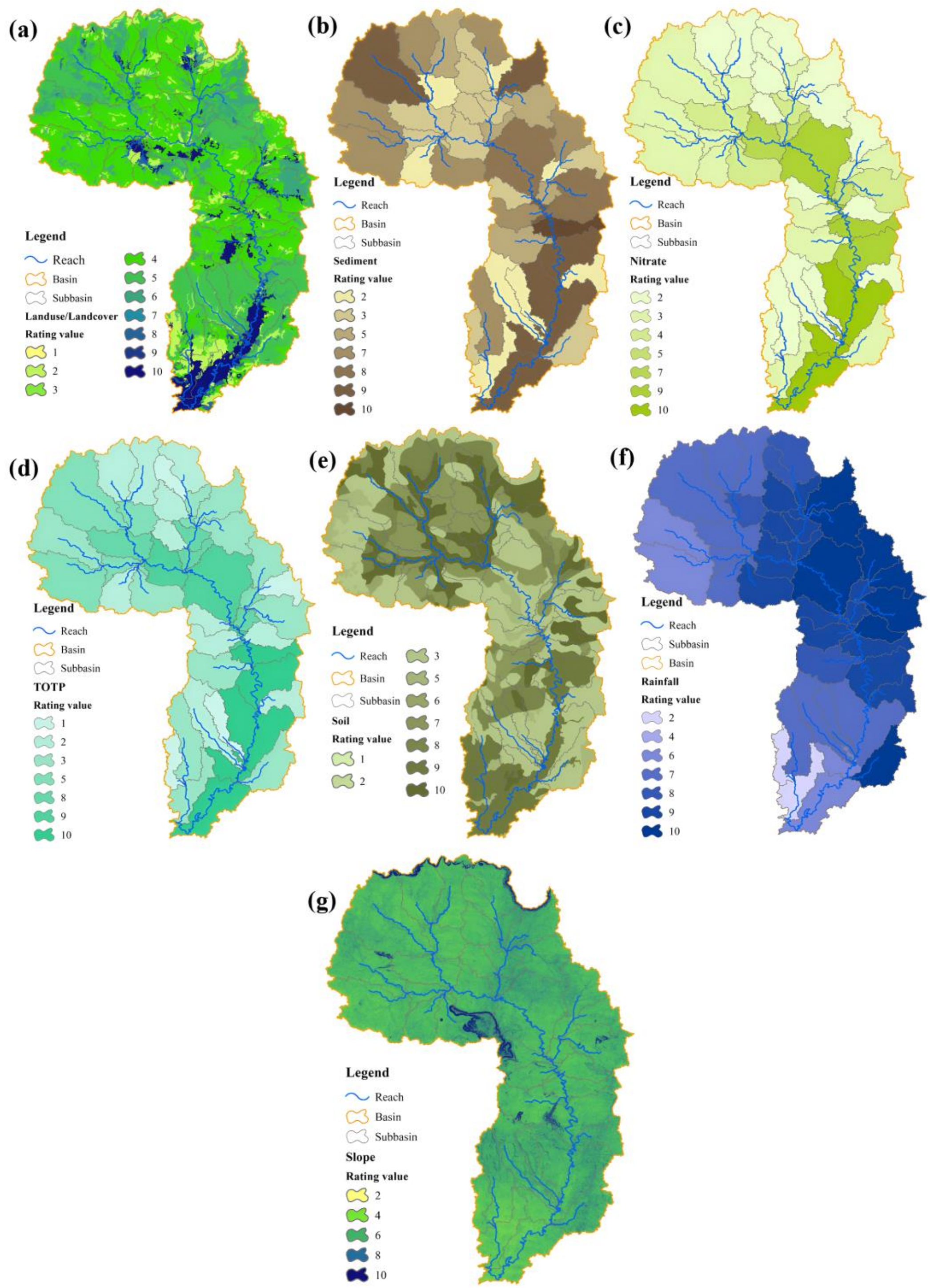

Figure 5. Thematic maps of the layers after rating value of (a) Sediment, (b) Nitrate, (c) Phosphorus, (d) LULC, (e) Soil, (f) Rainfall, and (g) Slope

Watershed vulnerability assessment

This study uses a watershed vulnerability assessment tool that allows calculating a unique vulnerability index value for the studied watershed, using simple characteristics that are weighted with their impact on surface water pollution. Based on the index, the vulnerability to pollution can be determined. The susceptibility categories for the watershed are as follows: very high (7–10), high (6–7), moderate (5–6), low (4–5), and very low (0–4). After evaluating each watershed for its vulnerability, the Sen River Basin generated displayed the relative vulnerabilities of each sub-watershed. The results showed a remarkable difference in watershed susceptibility between the sub-watersheds in their vulnerability to pollution. Approximately area of 959 km^2 (6%) and 2,382 km^2 (17%) where lies the downstream and near distance from the river body displayed very high and high watershed vulnerability. However, consisting area of 3,348 km^2 (24%), 5,483 km^2 (39%), and 2,015 km^2 (14%) located upstream and a long distance from the main river was demonstrated to be a moderate, low, and very low watershed vulnerability, respectively (Figure 6).

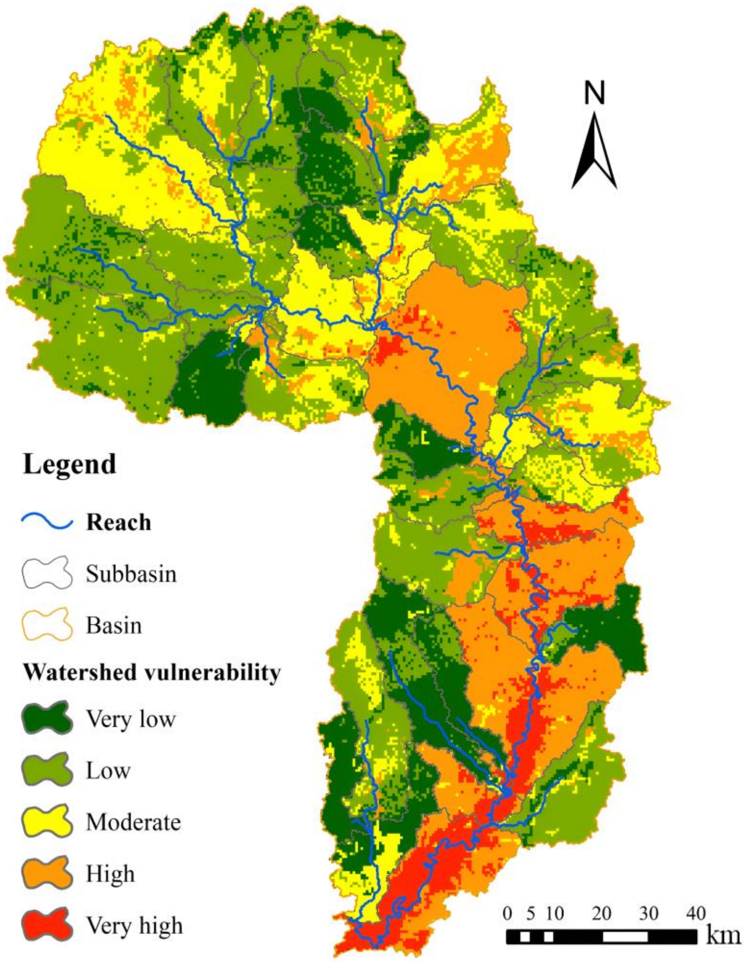

Figure 6. Watershed vulnerability distribution of the Sen River Basin

The greatest susceptibility to contamination is found near the river from the upstream to downstream of the watershed, by the reason of mainly in agricultural areas around 7% of the total area located downstream. The areas predicted to have very high vulnerability are primarily agricultural, so this high vulnerability is to some degree the result of agricultural run-off. The difference from LULC change between the top and bottom of the Sen River Basin showed a significant influence on sediment load. A high concentration of suspended solids in the top, middle and lower parts of the basin can be seen as an indicator that the greatest erosion and transport capacity has occurred in these areas of the basin, where a large amount of sediment is transported in the basin. In addition, both nitrate load and phosphorus load exhibited a similar trend of increase. The high sources of nitrate load and phosphorus load have been regarded as the major contributor along the river in the sub-watershed and eutrophication in water bodies. Thus, the lower portion of the watershed was likely to have a very high and high vulnerability at the outlet (downstream) of Sen River. These main factors confirmed the high potential watershed vulnerability in Sen River Basin. The results of the evaluation of the method to assess the vulnerability of watersheds showed, that the proposed approach is suitable as a decision aid to predict the status of watersheds.

Therefore, information on this watershed health assessment is a practical approach for evaluating the status and dynamics of the Sen River Basin.

4. Conclusion

Assessing watershed vulnerability based on spatial analysis by using the GIS and AHP technique. There are seven factors such as LULC, sediment load, nitrate load, phosphorus load, soil type, precipitation, and slope that were used to assess the watershed vulnerability. The process reclassifies the factors based on their weight and applies weighted overlay analysis to achieve watershed vulnerability zones. Hence, the evaluation of the predictive reliability of the watershed vulnerability assessment method revealed that the proposed approach is suitable as a decision-making tool to predict watershed health. This method showed a significant difference between the basins in their vulnerability to pollution. The basins in the lower portion of the study area were identified as highly vulnerable to contamination based on their average value of vulnerability. The results of watershed health demonstrated a very high and high watershed vulnerability to a pollution area of about 3,341 km^2 (24%) located downstream and near a distance from the river. Furthermore, approximately an area of 10,846 km^2 (76%) in the Northwest part and a long distance from the river of the study area was categorized in a range from moderate, low, and very low watershed vulnerability. Hence, the results of the evaluation of the watershed vulnerability assessment method revealed that the proposed approach is suitable as a decision-making tool to predict watershed health including the relative vulnerabilities of watersheds in the Sen River Basin. These are the essential sources of evidence that call for actions like sustainable land use planning and management or pollution control to guarantee the water environment and use in this research location.

5. Acknowledgments

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