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Vulnerability Assessment of Irawan Watershed in Puerto Princesa City, Philippines using the GeoREVIEW Model

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ABSTRACT

Vulnerability assessment is a rapid planning and decision–making tool to address issues on the vulnerability of a system and minimize the risk to environmental disasters. Amidst its importance as a requisite for empirical–based strategies for adaptation from the impacts of climate change, applicability of vulnerability assessment models however must be tested across the varying regional conditions of systems before their wide usage. The study was conducted to assess the level of vulnerability of the Irawan watershed in Puerto Princesa City, Philippines due to climate change using the GeoREVIEW model. Secondary data were used for each indicator except for the soil. Soil data were obtained through field sampling. Weights of indicators were determined through pairwise comparisons. All the indicators under the three components of vulnerability were characterized except for the biomass potential due to the absence of forest inventory data of varying periods. Values for each indicator of vulnerability were generated and their equivalent vulnerability scales ranging from 1 to 5 were determined. Ten (10) thematic maps were generated with a 30 m x 30 m resolution. Indicators representing the biological components of the watershed had the highest weight while climatic indicators were rated as the lowest. The overall vulnerability map generated a scale ranging from 1.90 to 2.99 placing the watershed at a moderately vulnerable level within its varying regions with an overall vulnerability point to climate change and anthropogenic hazards of 48.96. Adequate interventions must be developed to avoid further aggravation of the present condition of the watershed due to climate change.

Keywords: GeoREVIEW Model, vulnerability assessment, vulnerability map

INTRODUCTION

Philippine watersheds are adversely to be affected by climate change effect due to their present critical stage and the varying stages of deterioration experienced (Lasco *et al*. 2011). Because of these unprecedented incidents, the need for vulnerability assessment becomes more imperative. Vulnerability study has been deemed as one of the important components in creating the framework strategy on climate change for the country.

Although many vulnerability assessments tools have been developed and conducted for watersheds in the Philippines, most of the methods used are focused on hazard identification that includes flooding, landslide/erosion, forest/grass fire, water pollution, deforestation/illegal logging and biodiversity loss, critical factor analysis through a GIS–based analysis in formulating mitigation measures such as those conducted by Lanuza (2008), Lopez *et al*. (2008), & Rimando (2009). The manual on vulnerability assessment of watersheds in the Philippines published by the ERDB (2011) used the same goals and methods.

Recently, a new approach to assess risks and vulnerability due to climate change in the country was developed, called the GeoREVIEW model by Tiburan *et al.* (2010). This model utilizes the integration of geospatial–based techniques and methods in the vulnerability assessment of watersheds to enhance the capacity in identifying vulnerable regions and areas of immediate concerns (Tiburan *et al*. 2010). The vulnerability concept of the model was based on the definition provided by the IPCC (2007) as "the degree to which a system is susceptible to and is unable to cope with adverse effects of climate change, including climate variability and extremes". Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2007). The model is comprised of 21 indicators that are classified into three different components namely exposure, sensitivity and adaptive capacity which are based on the description provided by the IPCC (2007). All of the information will play a significant role in the effective and efficient management of watersheds in the country as well as in integrating policy interventions associated with climate change (Tiburan *et al*. 2010). Likewise, the model has strong relevance to approaches that measure sustainability.

Since the GeoREVIEW model is new and there is not much study conducted as to its application except in the case of Mt. Makiling where the model was tested (Tiburan *et al.* 2011), weaknesses could not yet easily be pointed out. However,

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Tiburan *et al.* (2010) recognized that threshold calibration has not been clearly established. Hence, additional databases to represent differences of regional watershed ecosystems in the country and increase in the number of samples for statistical analysis in some of the indicators of its scale is necessary for its further development and/or general applicability. Another is the need to introduce a weighing scheme between its components or among its indicators because currently, all indicators are treated with equal weights in the entire process.

Irawan watershed is part of the Palawan Flora, Fauna and Watershed Reserve (PFFWR) and it is the major source (51%) of water supply being utilized by the Puerto Princesa City Water District (PPCWD) for domestic use of the entire City of Puerto Princesa. Despite its being declared as a reserve, overlapping tenurial instruments and gathering of non–timber forest products such as bamboos, rattan and wood for charcoal making are common in the area. Furthermore, problems like soil erosion; seasonal drying up of river and flooding are also being felt recently, while slash and burn cultivation and land conversion continue to worsen the condition of the watershed as aggravated by encroachment and population increase in the past. The impacts of climate change are expected to worsen the condition of the watershed.

Climate change adaptation is crucial to ensure that the services delivered by the watershed would still be available under future climate and to reduce vulnerability of forest communities to adverse impacts (Seppala *et al*. 2009a). Vulnerability assessment of the Irawan watershed is therefore essential in providing information on the magnitude and/or degree of vulnerability of the watershed to natural and anthropogenic hazards. It is envisioned to shed light on the means of acquiring adequate protection from the environmental hazard, formulation of interventions to reduce possible damage or enhance the coping capacity of the Irawan watershed system. It is also an avenue to test the applicability of the GeoREVIEW model in assessing the vulnerability of ecosystem characterizing the Irawan watershed due to the impacts of climate change and anthropogenic hazards. Hence, this study specifically aimed to: (1) develop a weighted distribution of indicators of vulnerability; and (2) determine the degree of vulnerability within the varying regions of the watershed and its overall vulnerability to climate change and anthropogenic hazards.

METHODOLOGY

Study Area. The watershed area is located within $9^0 47'$ to $9^0 53'$ in the north latitude and $118^0 37'$ to $118^0 43'$ in the east longitude (Figure 1), around 14 km from the City proper and 580 km from Manila. It has an approximate area of 3,679 ha. situated within the political boundary of barangay Irawan and a little part of barangay Bacungan, in Puerto Princesa City. The area has 7 sub–watersheds with defined stream channels which are generally perennial. The watershed is currently under the management of the Puerto Princesa City Water District (PPCWD).

The watershed has Type III climate, characterized by having seasons not very pronounced, relatively dry from December to April and wet during the rest of the year. Based on the past 5–year (2007–2011) record from Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) Puerto Princesa City station has rainfall ranging from 1,489.6 to 2,338.3 mm with an average of about 1,769.14 mm. Temperature on the other hand was averaged at 28.32 ^{0}C. Occurrence of typhoons in the City is very minimal.

Barangay Irawan has a population of 4,652 persons in 2007 with a population density of 2 persons ha^{-1}. Population growth rate from 1995 to 2000 (PAMB–PFFWR 2002) was estimated at 6% per year.

Based on a SPOT image taken in 2005, the entire watershed area is dominated by primary forest cover with a total area of 2,859 ha (77.72%). Brushland, grassland, agricultural, and built–up/residential on the other hand have approximate areas of 621 ha (16.89 %), 14 ha (0.37 %), 123 ha (3.33 %), and 62 ha (1.69 %); respectively. The elevation of the watershed ranges from 0 to 1,080 meters above sea level.

The forest of the Irawan watershed is characterized by ultramafic soil on the upper elevation and alluvial at the lower. Based on the survey report of PCSDS (2006), majority of the fauna species in the area are birds (40 species or 65.57%), while mammals, amphibians and reptiles have 15 (24.59%), 4 (6.56%) and 2 (3.28%), respectively. The area has a total species richness (R) value of 3.91, and diversity index (H') value of 1.40. For trees, some of the noted endemic species of high commercial value in the area include Ipil (*Intsia bijuga*), Philippine ebony (*Diospyrus philippinensis*) and Almaciga (*Agathis philippinensis*) (PAMB & PFFWR 2002). The primary forest is dominated by Almaciga (*Agathis philippinensis*) and Apitong Baboy/Rumaraw (*Dipterocarpus* sp.), which are found growing above 700m. Other premium

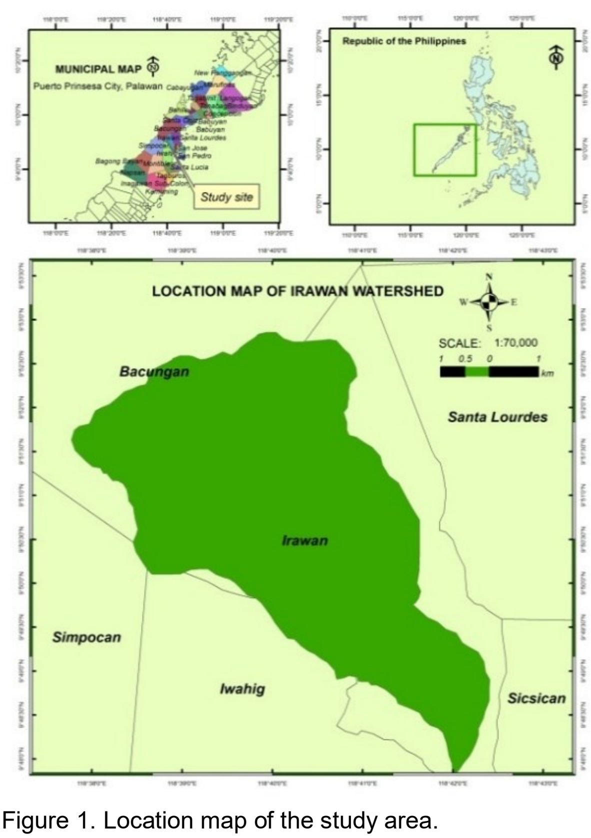

Figure 1. Location map of the study area.

timber species are: Ipil (*Intsia bijuga*), Kamagong (*Diospyrus philippinensis*), Amugis (*Koordersiodendron pnnatum*), Apitong (*Dipterocarpus grandflorus*), and Kalantas (*Toona calantas*). Dipterocarps and some species under the family Moraceae are also abound in the area including rattan (*Calamus, Plectocomia* and *Daemonorops*).

Components of the GeoREVIEW. Twenty (20) of the 21 indicators under three major components (exposure, sensitivity, and adaptive capacity) in the GeoREVIEW model were considered in assessing the general vulnerability to climate change of the Irawan watershed. The potential biomass indicator was not included because of the unavailability of forest inventory data at varying periods in the watershed.

Threshold Level. Threshold levels of indicators in the GeoREVIEW model were determined and calibrated using the Kolmonorov–Smirnov (K–S) statistical test, spatial–based techniques, indices and previous researches (Tiburan *et al.* 2010). Eleven (11) of the twenty (20) indicators in this study were based on the calibrated and statistically tested (K–S test) threshold values which are as follows: wet season, dry season, minimum temperature, maximum temperature, maximum wind, elevation, watershed area, land use change, population growth, population density, and road density.

Threshold values for the other six (6) indicators were based on the assessment conducted by Tiburan *et al.* (2010) using existing spatial–based techniques, indices and previous researches. This includes the following indicators: Shannon–Weiner diversity (H') index for biodiversity, the Strahler's method for channel size, and the Human Development Index (HDI) as a measure of human development. Proxy measures used involve soil organic matter content for soil quality, density for threatened species, and different land cover types for vegetation cover.

The threshold level for the last three (3) indicators namely, number of tourist, ecosystem greenness, and erosion potential were generated in this study based on the specific conditions of the Irawan watershed. The number of tourist was based on the physical carrying capacity of the tourist attraction in the area after Huttche *et al.* (2002) and Mowforth and Munt (1998) as shown in equation 1. Tourist records The derived tourist carrying capacity values were evenly distributed in accordance to the 1 to 5 scale of vulnerability in the GeoREVIEW, hence, its threshold levels.

Tourist carrying capacity:
(1)

$$Carrying\ capacity\ = \frac{Area\ used\ by\ tourist\ (\mathrm{m2}\ )}{Average\ individual\ standard\ or\ Area\ tolerance\ for\ visitations} \times Rotation\ coefficient$$

Where:

$$Rotation\ Coefficient\ = \frac{Number\ of\ daily\ hours\ area\ is\ open\ for\ tourists}{Average\ time\ of\ one\ visit}$$

Average individual standard = 1 person per m^2
Number of daily hours area is open for visit = 10 hours
Average time of one visit = 30 minutes
Area used by tourist = 2.5 m x 2.5 m (based on platform size used in the zipline)
Estimated total area covered by the zipline = 3 ha
For the ecosystem greenness, ranges of values of vegetation index to signify the indicator's degree of vulnerability were based on the natural breaks of the resulting indices as analyzed in the GIS software used. According to Weier and Herring (2000), calculations of NDVI for a given pixel always result in a number that ranges from minus one (–1) to plus one (+1); however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8–0.9) indicates the highest possible density of green leaves.

Lastly, a modification on threshold levels for erosion potential was made. Threshold levels were based on the soil loss tolerance limit after Bantayan (2006) with a little modification. Accordingly, soil tolerance values based on the soil loss intensity can be divided into two major categories: acceptable soil loss which would have an intensity below zero, and unacceptable soil loss which would be those at or above zero (Table 1). Hence, vulnerability scale from these threshold levels with < –0.75 being the lowest (very low vulnerability) while > 1.0 being the highest (very high vulnerability).

Table 1. Threshold levels for erosion potential of Irawan watershed.

Soil Loss Intensity	Tolerance	Scale	
		Nominal	Descriptive
<–0.75	Acceptable	1	Very low vulnerability
> –0.75 – < –0.25	Acceptable	2	Low vulnerability
> –0.25 – < 0.0	Acceptable	3	Moderate vulnerability
> 0.0 – < 1.0	Unacceptable	4	High vulnerability
> 1.0	Unacceptable	5	Very high vulnerability

Vulnerability Scale. The vulnerability scales in this study employed the 5–point scale rating (Table 2) following the scale developed by ERDB (2011) in conjunction with the GeoREVIEW scaling system developed by Tiburan *et al.* (2010). A scale of 1 indicates a very low vulnerability or high resilience of the watershed to the risks of damage in the past, recent and future events. A scale of 5 on the other hand indicates very high vulnerability or a high risk of damage from future conditions, some of which may be related to damage in the past and may therefore be a more appropriate measure for adaptive management.

Table 2. Vulnerability scale for the Irawan watershed.

Vulnerability Scale	Description
5	Very high vulnerability
4	High vulnerability
3	Moderate vulnerability
2	Low vulnerability
1	Very low vulnerability

Data Collection. This study employed the collection of primary and secondary data needed in characterizing the socio–biophysical components of the Irawan watershed, in generating thematic maps based on the 20 indicators selected for exposure, sensitivity and adaptive capacity components of the Irawan watershed, and in determining the degree of vulnerability. The soil data were obtained through a field sampling employing a grid cell method with an area of 225 ha each cell. Five pits with 30 cm width and 30 cm depth per pit were sampled per grid cell with a total of 55 samples.

Data Organization, Processing and Analysis. Composite soil samples were processed by pulverizing and sieving to meet the required size of soil granules and brought to the Soil Science Laboratory of the College of Agriculture, University of the Philippines Los Baños, Laguna for pH, organic matter, and texture analysis.

Primary (number of tourists, ecosystem greenness, erosion potential, and soil quality) and secondary (wet season, dry season, minimum temperature, maximum temperature, maximum wind, elevation, watershed area, channel size, land use change, threatened species, biodiversity, human development, population growth, population density, road density, and vegetation cover) data were processed (Table 3 to 5) to generate values necessary in the determination of scale of vulnerability of the Irawan watershed through geospatial–based techniques. Thematic maps of the socio–biophysical characteristics of the watershed were

Table 3. Exposure component of vulnerability assessment.

Indicator	Description
Wet Season	Average annual rainfall excess (mm) over the past 5 years for all months with 20% higher than the 30–year monthly average. It accounts for flooding and effects of storms to ecosystem disturbance
Dry Season	Average annual rainfall deficit (mm) over the past 5 years for all months with 20% lower than the 30–year monthly average. It describes vulnerability to drought and other problems ion water
Minimum Temperature	Average annual heat deficit (^{0}C) over the past 5 years for all months with 2^{0}C lower than the 30–year monthly minimum average. It relates to temperature stress, productivity, and reproduction
Maximum Temperature	Average annual heat excess (^{0}C) over the past 5 years for all months with 2^{0}C higher than the 30–year monthly maximum average, with 2^{0}C higher than the 30–year monthly minimum average. It can provide stress to forest growth and biodiversity survival
Maximum Wind	Average annual excess wind over the past 10 years for all months with 20% higher than the 30–year maximum wind speed average for that month. It affects storm surges, fire spread and damage to forest
Elevation	Topographic relief of the area. It has significant effects on the variety of ecosystems and it can be attributed also to pollution, flooding, human disturbance, and exploitation of natural resources.
Watershed Area	Extent of the boundary of watershed which may also capture the richness of habitats and diversity present in the site

Source: Tiburan et al. (2010).

Table 4. Sensitivity component of vulnerability assessment.

Indicator	Description
Channel Size	Stream order of the watershed based on Strahler's method. It explains the relative channel size and to some extent, water supply and the stream types present
Land use Change	Mean annual percentage of forest cover change over at least the last 5 years. It has effects on landscape integrity, biodiversity and carbon storage
Threatened Species	Number of species based on PAWB. National Red List of Philippine Wild Fauna. It has effects on biodiversity and ecological interaction
Biodiversity	Number and evenness of floral species using the Shannon–Weiner index. It describes the type of ecosystems present in the watershed
Ecosystem Greenness	NDVI values provide information on greenness of plants and vegetation quality. It can be correlated also to vegetation productivity, CO_2, fluxes, biomass and pest and diseases attacks
Erosion Potential	Erosion potential estimates of the area using the Revised Universal Soil Loss Equation (RUSLE) as applied to developing countries. It captures hazards to landscape and habitat disturbance

Source: Tiburan et al. (2010).

Table 5. Adaptive capacity component of vulnerability assessment.

Indicator	Description
Human Development	The index is generated using GDP, life expectancy, and education. It reflects the achievement and development of people and/or communities within or adjacent the watershed
Population Growth	Annual population growth rate based on two consecutive census data. It captures possible exploitation of natural resources, disposal of wastes and poverty incidences
Population Density	Population density of communities within the boundary of the watershed. It may increase pressure to the environment such as habitat damage and resource use
Number of Tourists	Annual tourists over the past year in the area. This includes international and local visitors. It has significant impacts on carrying capacity and pollution.
Road Density	Road density calculation only includes primary and secondary roads. It affects the contiguousness of species habitats and may provide access to resource exploitation and infrastructure development
Vegetation Cover	Land cover classification of the area using satellite images. It highlights the importance of forest cover to species composition and ecosystem types, and reflects biomass and carbon contents
Soil Quality	Soil organic matter is used as proxy measure because of its affinity to nutrients, aggregation and other important soil parameters

Source: Tiburan et al. (2010) .

then generated after deriving values of all indicators (Table 6). The values for each indicator generated and reclassified were compared to the established threshold level and range of values to determine their degree of vulnerability based on the 5–point scale used in the model. Scales were further reclassified to incorporate the derived weights of indicators.

A pairwise comparison was applied to determine the relative importance and rank of each indicator of vulnerability through experts and stakeholders' judgments after Mendoza *et al.* (1999), and Haas & Meixner (1990). Local experts were purposively chosen. Local experts such as social scientist, environmentalists, biologist, forest management specialist, academician, watershed management specialist, and meteorologist were purposively chosen. Rating of relative importance of indicators was administered through pairwise comparison rating forms. Prior to the rating of indicators' relative importance, a brief background of the study and instruction on how the rating must be undertaken were discussed for each rater aside from the written documents provided. Importance is rated through a 9–point scale (Table 7) for an indicator over the other as they are arranged in a matrix.

The indicators associated with climate, environment, and disaster or even with demographic impacts on the watershed were categorized under the three aspects of vulnerability namely: hazard, resistance and damage. Vulnerability points (VP) for sub–indices which have policy–related importance particularly on issues regarding natural disasters and environment besetting the watershed like flood, drought, biodiversity loss, and erosion and landslides were determined using equation 2, 3, 4, and 5 respectively based on the work of Tiburan *et al.* (2010). The scales of indicators used in the vulnerability assessment of the Irawan watershed are summarized in Table 8.

(2)

$$VP_F = \frac{\frac{1}{n}\sum_{f=1}^{n} S_f}{S_{max}} \times 100 \quad \text{(for flood)}$$

(3)

$$VP_D = \frac{\frac{1}{n}\sum_{d=1}^{n} S_d}{S_{max}} \times 100 \quad \text{(for drought)}$$

(4)

$$VP_B = \frac{\frac{1}{n}\sum_{b=1}^{n} S_b}{S_{max}} \times 100 \quad \text{(for biodiversity loss)}$$

(5)

$$VP_E = \frac{\frac{1}{n}\sum_{e=1}^{n} S_e}{S_{max}} \times 100 \quad \text{(for erosion and landslide)}$$

Table 6. Thematic maps sourced/generated for the Irawan watershed.

Maps	Inputs	Operation
1.Location map	Watershed boundary shape, Philippine shape, PPC–barangay shape	Overlay, reclassify attribute table, layout
2.Elevation map	Watershed boundary shape, contour map	Clip, reclassify attribute table, overlay
3.Drainage map	Watershed boundary, streams and river shape, sub–watershed shape	Overlay, reclassify, layout
4.Slope map	Watershed boundary shape, slope shape	Clip, overlay, reclassify, layout
5.Land use map (1998 & 2005)	2005 and 1998 land cover shapes	Merge, reclassify, layout
6. Soil map	Watershed boundary shape, textural grade for each sample points	Krigging, reclassify, layout
7. Soil erosion potential map	Watershed boundary shape, RKLS values	Reclassify, layout
8. Soil erosion map	RKLSC values	Overlay, interpolate, layout
9. Ecosystem Greenness Map (NDVI)	2007 SPOT image, watershed boundary shape	Overlay, clip, ana-lyze, reclassify, layout
10. Soil quality map	Watershed boundary shape, OM values	Krig, reclassify, layout
11. Overall vulnerability map	All 20 indicators	Overlay, reclassify, layout

Table 7. Numerical scale for comparative judgment of indicators.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Moderately more Important	Experience and judgment slightly favor one over the other
5	Strongly important	Experience and judgment strongly favor one over the other
7	Very strongly important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice
9	Extremely more important	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed

Table 8. Summary of all indicators of vulnerability

Indicator	Aspect	Sub–Index[a]	Unit	Scale 1	2	3	4	5
				Exposure Component				
Wet Season	Hazard	E, F	mm yr^{-1}	<286.7	286.7–430.7	430.7–646.9	646.9–971.7	>971
Dry Season	Hazard	D, E	mm yr^{-1}	<349.7	349.7–535.8	535.8–721.9	721.9–908.1	>908
Minimum Temperature	Hazard	B	$^0C\ yr^{-1}$	<0.20	0.20–0.60	0.60–1.40	1.40–2.99	>2.99
Maximum Temperature	Hazard	B, D	$^0C\ yr^{-1}$	<0.19	0.19–0.53	0.53–1.16	1.116–2.35	>2.35
Maximum Wind	Hazard	B, E	km hr^{-1} yr^{-1}	<11.26	11.26–23.5	23.50–40.21	40.21–61.37	>61.3
Elevation	Resistance	B, F	masl	>2393	1,853–2,393	1,313–1,853	773–1,313	<773
Watershed Area	Resistance	B	ha	>16153	2,241–16,153	311–2,241	43–311	<43
				Sensitivity Component				
Channel Size	Resistance	E, F	order	≥5	4	3	2	1
Land use Change	Damage	B, D, E, F	% cover	>2	0–2	0	0 – -2	<-2
Threatened Species	Damage	B	no. of species km^{-2}	0	0–5	5–10	10–15	>15
Biodiversity	Damage	B	H value	>2.0	1.50–2.0	1.0–1.50	0.5–1.0	<0.5
Ecosystem Greenness*	Damage	B, D	NDVI value	<0.3702	0.3702–0.5747	0.5747–0.6908	0.6908–0.7627	>0.7627
Erosion Potential**	Hazard	B, E	ton ha^{-1} yr^{-1}	< –0.75	> -0.75 – < -0.25	> -0.25 – < 0.0	> 0.0 – < 1.0	> 1.0
				Adaptive Capacity Component				
Human Development	Resistance	B, D, E, F	HDI value	>0.74	0.68–0.74	0.62–0.68	0.56–0.62	<0.56
Population Growth	Damage	B, E	% growth	<0	0	0–0.62	0.62–1.74	>1.74
Population Density	Damage	B, E, F	person km^{-2}	<127	127–308	308–633	633–217	>1217
Number of Tourists***	Damage	B, E, F	person km^{-2}	<307	307–615	615–922	922–1,240	>1,240
Road Density	Damage	B, E,	m ha^{-1}	<1.44	1.44–1.74	1.74–2.18	2.18–2.93	>2.93
Vegetation Cover	Resistance	B, D, E, F	land cover	forest	brushland	Agroforestry	grassland	bare/built–up
Soil Quality	Resistance	E, F	% OM	>4	3–4	2–3	1–2	<1

[a] Policy relevant sub–indices include biodiversity loss (B), drought (D), erosion and landslide (E) and flood (F)
*Threshold levels were derived based on the NDVI natural breaks of the Irawan watershed
**Threshold levels were derived based on soil loss tolerance.
*** Threshold levels were derived based on the tourist carrying capacity of the Irawan watershed

Where:

VP_F = Vulnerability points for flooding
VP_D = Vulnerability points for drought
VP_B = Vulnerability points for biodiversity loss
VP_E = Vulnerability points for erosion and landslide
Sf = scale of indicator associated with flood
Sd = scale of indicator associated with drought
Sb = scale of indicator associated with biodiversity loss
Se = scale of indicator associated with erosion and landslide
Smax = maximum scale
n = total number of indicators

The overall vulnerability classification and category assignment (Table 9) were determined to describe the general vulnerability of the study site based on its 20 indicators used based on the equation (equation 6) developed by Tiburan *et al.* (2010).

Table 9. Overall vulnerability classification.

Category	Classification	Overall Point
5	Very high vulnerability	>90
4	High vulnerability	70–90
3	Moderate vulnerability	50–70
2	Low vulnerability	30–50
1	Very low vulnerability	<30

These parameters particularly represent the resilience and vulnerability of the Irawan watershed to climate change by way of computing the overall vulnerability point (OVP). This was evaluated from the cumulative weighted scales given for all the indicators divided by the maximum scale then multiplied by 100. It is denoted by the following equation:

$$OVP = \frac{\sum_{i=1}^{n} Wi\, S_i}{S_{max}} \times 100 \qquad (6)$$

Where: *Si* = scale of indicator i
Wi = weights
Smax = maximum scale
n = total number of indicators

RESULTS AND DISCUSSION

Exposure Component

Climatic Indicators. The watershed has 2,418.26 mm estimated excess total rainfall for the past five years (2007–2011) with an average annual excess of 483.65 mm. The derived value for excess annual rainfall falls under the scale of 3, which places the watershed at a moderately vulnerable level (Table 10). For the dry season, a total rainfall deficit over the past 5 years was estimated at 1,169 mm yr^{-1} with a mean of 233.89 mm. This value has an equivalent scale of 1 under the model. According to Lasco *et al.* (2011), the increase in rainfall at varying degrees from 25% will cause a total loss of all dry forest, decline in the rate of moist forest, and increase rainforests and wet forest cover. The results on rainfall imply that the area is at risk to ecosystem disturbance and flooding due to excessive amount of rainfall, while it is resilient to problems on water due to rainfall shortfall.

Table 10. Derived values for climate indicators and their equivalent vulnerability scales.

Climatic Indicators	Derived Values	Scale
1. Wet Season		
Past 30 years (1982–2011)		
Total for monthly average	1,533.81 mm yr^{-1}	
Mean	127.82 mm yr^{-1}	
Threshold	153.38 mm yr^{-1}	
Past 5 years (2007–2011)		
Total heat excess	2,418.26 mm	
Average annual rainfall excess	**483.65 mm yr^{-1}**	**3**
2. Dry Season		
Past 30 years (1982–2011)		
Total for monthly average	1,533.81 mm yr^{-1}	
Mean	127.82 mm yr^{-1}	
Threshold	102.25 mm yr^{-1}	
Past 5 years (2007–2011)		
Total heat excess	1,169 mm	
Average annual rainfall deficit	**233.89 mm yr^{-1}**	**1**
3. Minimum Temperature		
Past 30 years (1982–2011)		
Total for monthly average	265.85 ^0C yr^{-1}	
Mean	22.15 ^0C yr^{-1}	
Threshold	20.15 ^0C yr^{-1}	
Past 5 years (2007–2011)		
Total heat excess	0.00	
Average annual heat deficit	**0.00**	**1**
4. Maximum Temperature		
Past 30 years (1982–2011)		
Total for monthly average	400.58 ^0C yr^{-1}	
Mean	33.38 ^0C yr^{-1}	
Threshold	35.38 ^0C yr^{-1}	
Past 5 years (2007–2011)		
Total heat excess	0.34 ^0C	
Average annual heat excess	**0.07 ^0C yr^{-1}**	**1**
5. Maximum Wind		
Past 30 years (1982–2011)		
Total for monthly average	498.78 km hr^{-1}	
Mean	41.56 kmhr^{-1} yr^{-1}	
Threshold	49.88 km hr^{-1} yr^{-1}	
Past 10 years (2002–2011)		
Total heat excess	424.35 km hr^{-1}	
Average annual excess wind	**42.43 km hr^{-1} yr^{-1}**	**4**

The area has a minimum temperature of 22.15 ^0C yr^{-1} over the past 30 years (1982–2011). The results indicated that there was no heat deficit over the past 5 years having temperature lower than the threshold value, thus a scale of 1 was assigned. For the maximum temperature, a threshold value of 35.38 ^0C yr^{-1} was obtained. There was a total heat excess of 0.34 ^0C for the past five years (2007–2011) with an annual average of 0.07 ^0C. The resulting value for this indicator falls under a scale of 1 classified as very low vulnerability. If global temperature indicates an increase in the average temperature by more than 1.5–2.5°, there are projected major changes in local climates (Parry *et al.* 2007) which can modify the functioning and composition of forests (Djoghlaf 2007). However, the minimal heat excess over the past 5 years in the area indicates its resilience to such modification. For maximum wind, a threshold value of 49.88 km hr^{-1} was estimated with an average annual excess wind of 42.43 km hr^{-1} for the past 10 years (2002–2011). This gives the watershed a scale of 4 classified as highly vulnerable. These results imply that more strong winds occur more frequently in the study area. This may be due to geographic location of mainland Palawan where the study is located. It is surrounded by sea and a more or less flat terrain at the lower elevation and an abrupt increase of slopes as elevation increases towards its center.

Non–climatic Indicators. Elevation is one of the two non–climatic indicators under the exposure component of the GeoREVIEW model. Its inclusion as an indicator of vulnerability under the exposure component was based on the statement of Fussel and Klein (2006 as cited by Tiburan *et al.* 2010) that non–climatic factors such as environmental, economic, demographic, technological or even political factors play an important aspect in the system.

Most of area (3,564 ha or 97%) in the Irawan watershed has elevation below 773 meters above sea level (Figure 2) which falls under the vulnerability scale of 5. The remaining area of 115 ha (3 %) has elevation ranging from 773 to 1,080 meters above sea level with an equivalent scale of 4. These results indicate a composite scale of 4.97 for the watershed's elevation which is very highly vulnerable. The result on topographic relief indicates that most of the varieties of ecosystem of the area are highly vulnerable to pollution, flooding, human disturbance, and exploitation of natural resources. On the other hand, recent research shows according to the World Bank (2008) that climate change will be even more pronounced in high–elevation mountain ranges, which are warming faster than adjacent lowlands. Accordingly, the hydrological and ecological changes of this magnitude would result in a loss of unique biodiversity, as well as a loss of many of the environmental goods and services provided by these mountains, especially water supply, basin regulation, and associated hydropower potential.

Watershed area as an indicator on the other hand was classified under a vulnerability scale of 2 indicating low vulnerability of the watershed to climate hazards considering its size which captures the richness of habitats and biodiversity. Surface area and the number of endemic species have significant relationship for all species e.g. the case of vascular plants in five Malesian islands (Java, Sulawesi, Sumatra, Borneo and New Guinea) (Roos *et al.* 2004). The species area relationships and environmental diversity method which combines models of α diversity (richness) and ß diversity (compositional dissimilarity among communities) developed by Faith (2011) further explains that greater area captures greater environmental heterogeneity, and so also capture a greater number of species.

Sensitivity Component

Channel Size. The channel size of the Irawan watershed was determined on a sub–watershed basis (Table 11). Among the seven (7) sub–watersheds, Tagpangi has 4 stream orders (scale of 2) while Manlat, Tagkanarem, Pugad Lawin and Kalantiaw–Lalandeg have stream orders of 3 (scale of 3), while Impapay and Mananangeb have only stream order of 2 and 1 (scale of 4 and 5), respectively. The average vulnerability scale under

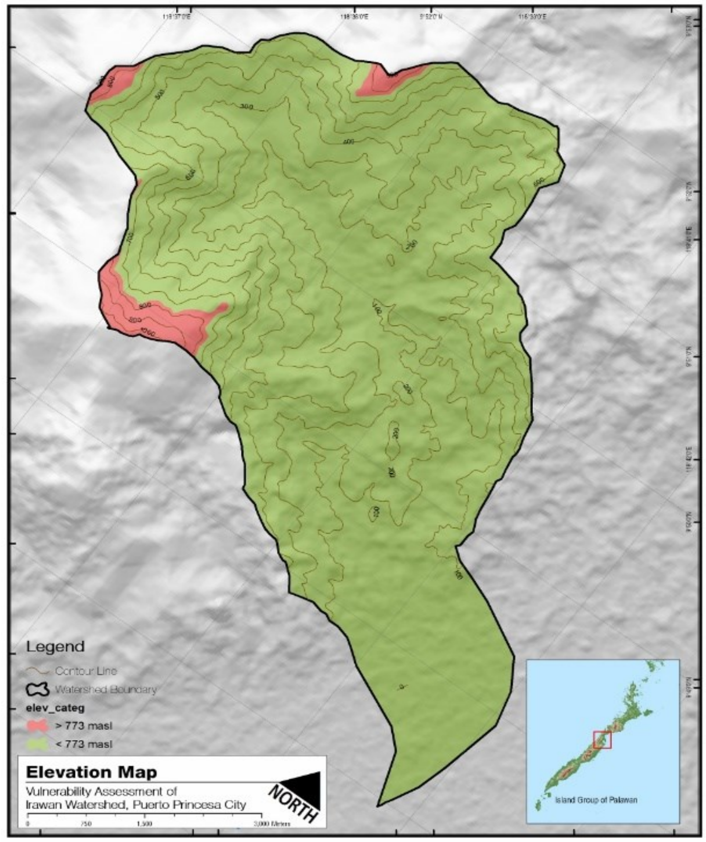

Figure 2. Elevation map of the study area.

channel size is 3.3 which is classified as highly vulnerable to natural and human related risks. Results imply that the watershed is highly vulnerable to climate change due to its limited number and short stream channels. The current and future state of water flow both surface and ground water from the watershed is crucial for the entire Puerto Princesa City which mainly derive water for its domestic use. This is compounded by its fragility due to steep topography, highly erodible soils, short rivers and impermeable soil, seasonal drying up and flooding of the Irawan river (PFFR–PAMB 2002), increasing population that is much higher than the national growth rate, and the adverse effects of climate change further aggravates its situation. If climate change leads to a reduction in rainfall and a rise in sea level, this would reduce the volume of potable water and the size of the narrow freshwater lens (IPCC 2001). If the current land use will be intensified on the other hand, it will only compound the problem, thus making the watershed highly vulnerable to climate change if no appropriate adaptation strategies will be developed.

Table 11. Stream order of Irawan watershed.

Sub–watershed	Stream Order	Scale
Impapay	2	4
Manlat	3	3
Mananangeb	1	5
Tagkanarem	3	3
Pugad Lawin	3	3
Kalantiaw–Lalandeg	3	3
Tagpangi	4	2

Land Use Change. Land use change was measured based on the derived land cover map for 2005 and 1998 from 2005 and 1998 SPOT images, respectively (Figure 3). The forest cover of the Irawan watershed in 2005 has decreased by 2.65 % (97 ha) with a mean annual forest cover change of 0.38 % (14 ha) (Table 12).

Table 12. Land use change in the Irawan watershed.

Land Cover Type	Area (ha)		Land Cover Change		Mean Annual Cover Change		Scale
	2005	1998	Ha	%	Ha	%	
Primary/old growth	**2,859**	**2,957**	**–97**	**–3**	**–14**	**–0.38**	**4**
Agricultural/ crop land	123	253	–131	–4	–19	–0.51	
Brushland	621	434	187	5	27	0.73	
Built–up areas	62	27	36	1	5	0.14	
Grassland	14	8	5	0.2	0.8	0.02	
Total	**3,679**	**3,679**					

Brushland has increased by 5.08 % (187 ha) with a mean annual rate of 0.73 % (27 ha). The generated land cover maps also indicate that about 0.15 % (5 ha) has been developed into grassland, and about 0.98 % (36 ha) of the total watershed area has been converted into built–up area. A relatively large reduction of about 3.56 % (131 ha) of agricultural/cropland of the watershed has also been detected with an annual mean of 0.51 % (19 ha). The resulting change in the area's forest cover falls under the scale of 4. In the absence of developed climate change adaptations strategies, watersheds that are stressed by intensive land use change will become highly vulnerable (IPCC 2001). Water resources degradation on the other hand according to Lasco *et al.* (2011), is largely attributed to the deterioration of the watershed in general and of the land in particular. The results therefore imply that Irawan watershed is highly vulnerable to biodiversity loss, and water quality and shortage which could be aggravated by the absence of measures to effectively stop the loss of its forest cover.

Threatened Species. Based on the fauna survey report of PCSDS (2006), there are about eleven (11) threatened species found in the Irawan watershed (Table 13). Seven (7) of the eleven species are mammals such as *Amblonyx cinereus, Eonycteris spelaean, Manis javanica, Mydaus marchei, Sundasciurus juvencus, Sus barbatus ahoenabarbus* and *Tupaia palawanensis*; while the remaining four (4) species are birds such as *Anthraceros marchei, Cyornis lemprieri, Parus amabilis* and *Terpsiphone cyanescens*. This result gives the watershed on fauna threatened species a scale of 4 which is highly vulnerable. Some species that are already threatened are particularly vulnerable to the impacts of climate change (Djoghlaf 2007). Accordingly, there is evidence that climate change is already affecting biodiversity and will continue to do so. This implies that utmost protection must be taken into consideration such that

Table 13. List of threatened fauna species in the Irawan Watershed.

No.	Species	Common Name	Scale
Mammals			
1	*Amblonyx cinereus*	Oriental small clawed otter	
2	*Eonycteris spelaea*	Common nectar bat	
3	*Manis javanica*	Malayan pangolin	
4	*Mydaus marchei*	Palawan stink badger	4
5	*Sundasciurus juvencus*	Northern Palawan tree shrew	
6	*Sus barbatus ahoenabarbus*	Bearded pig	
7	*Tupaia palawanensis*	Palawan tree shrew	
Birds			
8	*Anthraceros marchei*	Palawan hornbill	
9	*Cyornis lemprieri*	Palawan blue flycatcher	
10	*Parus amabilis*	Palawan tit	
11	*Terpsiphone cyanescens*	Blue paradise flycatcher	

Data source: PCSDS, 2006

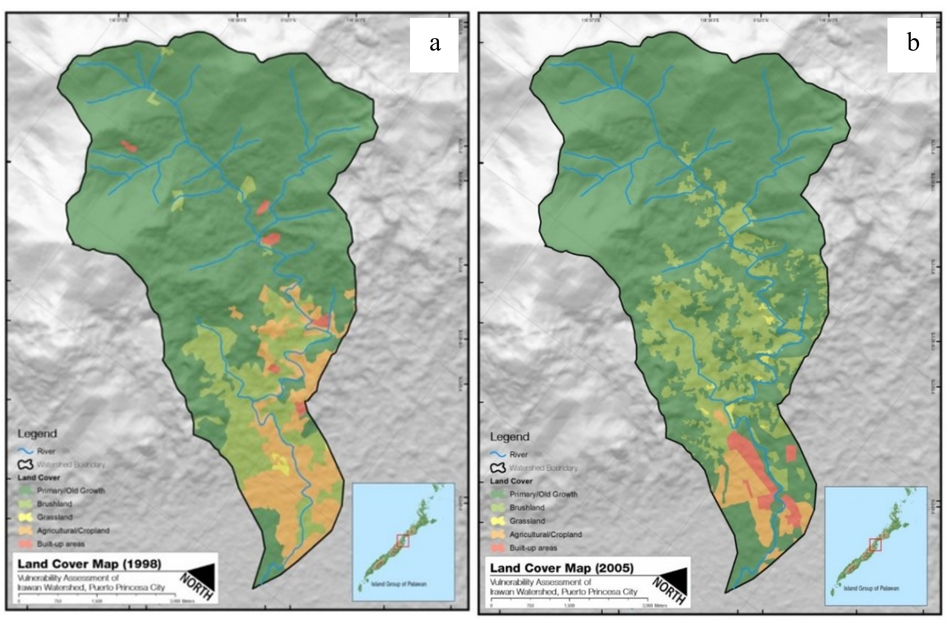

Figure 3. The 1998 (a) and 2005 (b) land cover maps of Irawan watershed.

their population would be kept intact and enhanced. The resilience of ecosystems can be enhanced and the risk of damage to human and natural ecosystems reduced through the adoption of biodiversity–based adaptive and mitigative strategies.

Biodiversity. The watershed has an H'=1.87 at upper slopes while lower slopes has H'=1.86 value based on the flora survey report of PCSDS (2005) classifying the area under a composite scale of 2 under this indicator (Table 14). The result indicates that there is a high diversity of flora in the Irawan watershed. This is even higher than the floral species diversity of the Makiling Forest Reserve (MFR) (H'=1.61) (Pancho, 1983; Abraham *et al.* 2010 as cited by Tiburan 2010). However, changes in climate and carbon dioxide concentration will affect the structure and function of ecosystems, species' ecological interactions, and species' geographical ranges, with consequences for biodiversity (Malcolm *et al.* 2006; Djoghlaf 2007) and ecosystem services. Aside from climate change, many ecosystems including tropical forests, are likely to be affected other climate change associated disturbances (e.g., flooding, drought, wildfire, insects), and other global change drivers (e.g., land use change, pollution, overexploitation of resources) (Locatelli *et al.* 2008). There is therefore a need to develop strategies that will strengthen the resilience of the watershed in order to maintain if not to increase its resilience from climate change related risks.

Table 14. Floral diversity index of Irawan watershed.

Location	Shannon–Wiener's Diversity Index (H')	Scale
Mt. Beaufort	1.87	2
Irawan Downslope	1.86	2

Data source: PCSDS, 2005.

Ecosystem Greenness. Most of the area have high NDVI values ranging from 0.5747 to 0.8677 comprising 98.24 % (3,614 ha) of the watershed as shown in Table 15 and Figure 4. Only a meager of 1.76 % (65 ha) have NDVI value below 0.5747. High values of NDVI ranging from 0.6 to 0.8 indicate tropical rainforests (Weier & Herring 2000). The ecosystem greenness of plants and vegetation quality of the area is high, which therefore indicates that a large part of the area is still covered by a good stand of tropical rainforest. The composite scale for ecosystem greenness is 1.45 classified under low vulnerability. This implies that the watershed has high vegetation productivity, high capacity of carbon dioxide sequestration, and environmental fluxes, thus making its vegetation more resilient than vulnerable to impact of climate change.

Table 15. Ecosystem greenness of Irawan watershed.

NDVI	Area (ha)	Percentage	Scale
0.0053 – 0.3702	8	0.23	5
0.3702 – 0.5747	56	1.53	4
0.5747 – 0.6908	297	8.06	3
0.6908 – 0.7627	849	23.09	2
0.7627 – 0.8677	2,469	67.09	1
Total	**3,679**	**100.00**	

Erosion Potential. The soil erosion potential of the watershed was based on the normalized values of estimated soil erosion (Figure 5). Majority (3,239 ha or 88 %) of the watershed have very high soil loss intensity (15.16) which is far greater than the soil loss tolerance level, hence classified under vulnerability scale of 5 (Table 16).

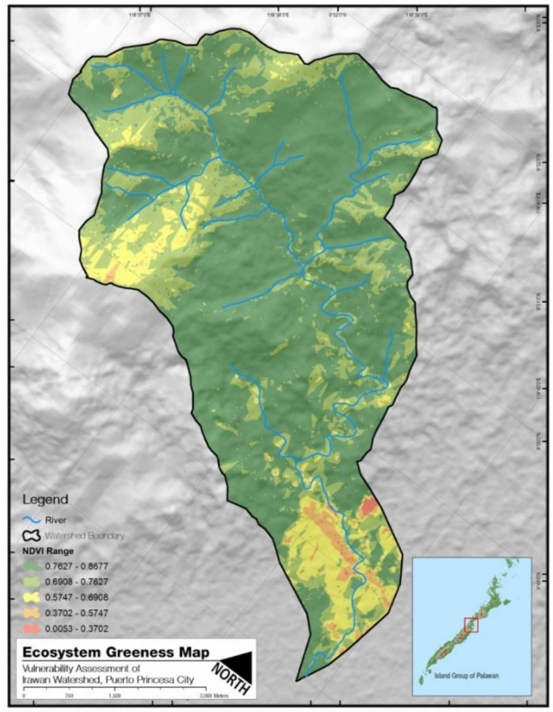

Figure 4. Ecosystem greenness of the Irawan watershed.

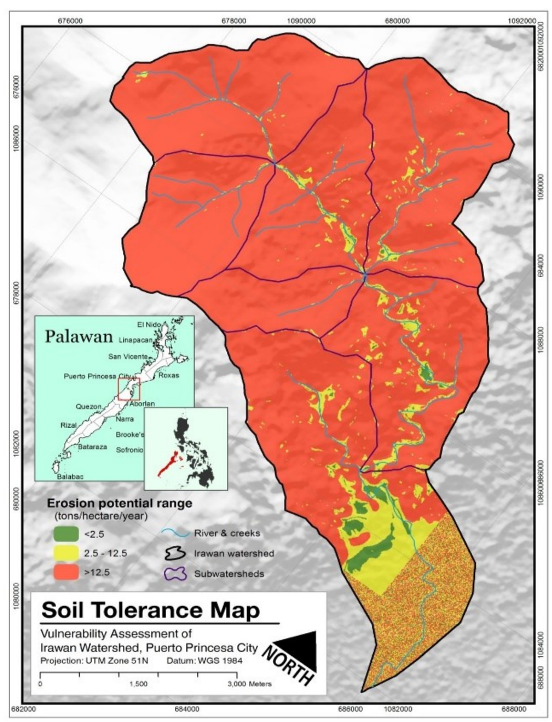

Figure 5. Soil loss tolerance map of the Irawan watershed.

Table 16. Erosion potential for the Irawan watershed.

Soil Loss Intensity	Area (ha)	Percentage	Scale
–0.80	84	2	1
–0.74	139	4	2
–0.30	73	2	3
–0.03	144	4	4
15.16	3,239	88	5
Total	**3,679**	**100**	

Around 144 ha (4 %) have soil loss intensity of –0.03 which falls under a vulnerability scale of 2.73 ha (2 %) was estimated at an intensity of –0.30 with a vulnerability scale of 3, 139 ha (4 %) of the area have an intensity –0.74 with a vulnerability scale of 2, and 83 ha have –0.80 soil loss intensity which is the lowest with an equivalent vulnerability scale of 1. The entire watershed has a composite vulnerability scale for erosion potential of 4.72 indicating that it has a very high level of vulnerability to climate change related risks on damage such as soil erosion. The results indicate that the watershed has a very high soil loss exceeding beyond the tolerance limits, hence, it is unacceptable and a cause for alarm. This implies that erosion is a potential hazard in the area which could be aggravated by alteration of its ecosystem and the impending threats of climate change. According to the Save Palawan Campaign (2009), the high rate of erosion potential for the watershed was due mainly to narrow mainland, small islands and steep topography of Palawan where it is located; highly erodible soils with small watersheds; short rivers and impermeable soil.

Adaptive Capacity Component

Human Development Index. The human development of the watershed was based on the Philippine Human Development Report for 2008 and 2009 (2011) for Palawan in the absence of a more specific data for barangay Irawan or that of Puerto Princesa City. The report indicated that the Province of Palawan has an HDI value of 0.642, ranked 42nd among the 60 Provinces in the country (Table 17). The province had a little bit lower HDI than the country (0.644) in general based on the report. Thus, the vulnerability scale of the watershed for human development falls under a scale of 3 classified as moderately vulnerable. The human development index reflects the achievement and development of people and/or communities within or adjacent the watershed. The basic assumption is that high HDI of affected communities are more resilient and have higher capacity to adapt to climate change. The major impacts of climate change consequently affect people's lives and that the poorest of the poor are expected to bear the brunt (Locatelli *et al.* 2008; Pulhin 2005 as cited by Lasco *et al*. 2009).

Table 17. Human Development Index value for Palawan.

Region/Province	HDI Value	Rank	Scale
MIMAROPA			
Marinduque	0.692	1st	
Oriental Mindoro	0.678	2nd	
Romblon	0.661	3rd	
Palawan	**0.642**	**4th**	**3**
Occidental Mindoro	0.639	5th	
Country wide			
Metro Manila	0.792	highest	
Tawi–Tawi	0.500	lowest	

Data source: Philippine Human Development Report for 2008/2009 (2011).

Population Growth. For the population growth rate, Barangay Irawan has an annual growth rate of 6 % based on the 2000 and 2010 NSO census report, and as reflected in the Puerto Princesa City Socio Economic and Physical Profile for 2007 and Comprehensive Development Plan for 2011–2013 (Table 18).

Table 18. Population growth of Barangay Irawan based on the NSO 2000 census.

Census Period	Annual Growth Rate (%)	Scale
Barangay Irawan	**6.00**	**5**
Puerto Princesa City	4.55	

Data source: Socio Economic and Physical Profile of Puerto Princesa City: 2007; Puerto Princesa City Comprehensive Development Plan for 2011–2013; NSO Report 2000 and 2010.

This is higher than the growth rate for the whole Puerto Princesa City which was reported 4.55 %. However, these rates are much higher than the 2.36 % national average in 2000. The high rate of annual population growth of the Irawan watershed falls at a scale of 5 in the model indicating a very high vulnerability to climate change. Urban dwelling was high due to inevitable course of development and rapid urbanization (Socio Economic and Physical Profile of Puerto Princesa City 2007). The high population growth rate implies that it would consequently impact the natural resources and the environmental quality of the watershed affecting the biodiversity of its ecosystem and water resources which are vital and critical. The population growth and associated pressures for development and maintenance of infrastructure and services may exacerbate the impacts of climate change (CSIRO & BOM 2007 as cited by Timothy *et al.* 2011), thus making the ecosystem less adaptive.

Population Density. The 3,679–ha area of Irawan watershed and the 4,652 population count for barangay Irawan of the same period indicates a density of 126 individuals km^{-2} (Table 19). The population density in the watershed falls under a vulnerability scale of 1 indicating that it has a very low vulnerability. The results on population density imply that the Irawan watershed ecosystem is resilient to pressure from its population and climate change. Although there is a high rate of population increase in the watershed for the past decade, its area size and population ratio is minimal, thus making it more resilient than vulnerable to anthropogenic pressure as influenced by climate change. The watershed's resilience was further complemented by the efficacy of management strategies and programs implemented by the local government of Puerto Princesa City and the Water District Office despite some issues on their implementation (PPCWD 2008; and PAMB–PFFWR 2002). The more prominent programs implemented were the relocation of occupants from within the protected area boundary of the watershed to nearby Barangays, strengthened monitoring and patrolling, and the tree planting activities conducted yearly. However, climate change and population increase are among the

Table 19. Population density of the Irawan watershed in 2007.

Administrative Jurisdiction	Population	Population Density (person km^{-2})	Scale
Barangay Irawan	4,652	126	1
Puerto Princesa City	222,673	80	

Data source: PPC Socio Economic and Physical Profile (2007) and NSO report (2010).

crucial driving forces in the increase of vulnerability of natural resources and the environment (Varis 2003). Enough measures therefore are needed to maintain the level of resilience of the Irawan watershed to human pressures and natural hazards.

Number of Tourists. The Irawan Forest Canopy Zipline and Tours is a tourist attraction situated at the southeastern area of the watershed. Its operation started on June of 2011 and recorded quite a huge number of visitors and is seemingly increasing as it gains its popularity. Based on the available data that has been obtained from the Irawan watershed ranger park station which includes record of visitors from January to July of 2012, a total of 6,116 individuals have visited the area with an estimated average monthly of 874, and a daily of 29 visitors (Table 20).

Table 20. Number of tourist visitors in the watershed for 2012.

Frequency	Number of Visitors	Scale
Number of monthly visitors		
January	414	
February	936	
March	795	
April	1,716	
May	1,163	
June	522	
July	570	
Total	*6,116*	
Monthly average	874	
Estimated daily average	29	
Estimated annual number of person	10,630	
Estimated number of tourists in a year (person km^{-2})	**289**	**1**

With this data, the estimated annual number of tourists visiting the area is totaling to 10,630 individuals based on the obtained tourist data which if transformed, gives a number of 289 individuals $km^{-2} yr^{-1}$. The estimated value for the number of tourist has a scale of 1 which is classified under a very low vulnerability. Results imply that the watershed is more resilient than vulnerable to pollution, wildlife disturbance, and the capacity to accept tourist has not yet been maximized. However, the estimate of carrying was limited only to the physical carrying capacity of the area which is assumed to reflect the watershed's general condition. The threshold limits to the impacts of tourism or the carrying capacity (Bhattacharya & Sankarthe 2007) as well as climate change risks are essential aspects in the sustainable management of the Irawan watershed ecosystem.

Road Density. Through a geospatial analysis of shape files such as watershed area, land cover, and roads and river shapes obtained from the Puerto Princesa City Planning and Development Office**,** the road density of the study area was estimated by considering the primary, secondary and other roads that possibly affect the contiguousness of species habitats that may provide access to resource exploitation and infrastructure development. The national road across the lower part of the watershed has a length of 2,928 m (Table 21).

Table 21. Road density within the Irawan watershed.

Road	Length (m)	Scale
National road	2,928	
Barangay road	3,050	
Other road (former access road for logging and mining)	10,537	
Total	16,536	
Estimated road density (m ha^{-1})	**4.49**	**5**

The barangay road connecting the highway to the interior part of the watershed has a length of 3,039.92 m. While a former access road for logging and mining that is laid parallel to the Irawan river has a length of 10,537 m. The dislodged logging/mining road is now currently utilized by the PPCWD management for development, protection and monitoring purposes; tourists; and local residents for the extraction of minor forest products. These roads have a total length of 16,536 m with an estimated density of 4.49 m ha^{-1}. The vulnerability scale for road density based on the model is equivalent to 5 which is very highly vulnerable. According to Magness *et al.* (2011), low road density and a high percentage of protected lands have higher adaptive capacity. The results therefore imply that the area has low adaptive capacity due to its very high level of vulnerability to resource damage. It has an open access to exploitation of its natural resources which definitely cause damage to the watershed's ecosystem. Rapid climate change, in conjunction with other anthropogenic drivers, has the potential to cause mass species extinction.

Vegetation Cover. The Irawan watershed in 2005 is dominated by primary forest (Figure 6) with an area of 2,859 ha (77.72 %) (Table 22). Brushland has a total of 621 ha comprising 16.89 % of the watershed area. Among the minor cover, 14 ha (0.37 %) are grassland areas, 62 ha (1.69 %) are built–up areas, and 123 ha (3.33 7%) are agricultural areas which are mostly fruit orchards. Based on the model's vulnerability scale classification, forest cover has a scale of 1, while for brushland, a scale of 2 was assigned. For the other land cover types, a scale of 3, 4, and 5 were assigned for agricultural/crop land, grassland and built–up areas, respectively. Thus, the composite scale for vegetation cover in the watershed is 1.31 classified under low vulnerability.

Table 22. Vegetation cover of the Irawan watershed based on the 2005 land cover map.

Land Cover Type	Area (HA)	Cover in %	Scale
Primary/old growth	2,859	77.72	1
Agricultural/crop land	123	3.33	3
Brushland	621	16.89	2
Built–up areas	62	1.69	5
Grassland	14	0.37	4
Total	**3,679**	**100.00**	

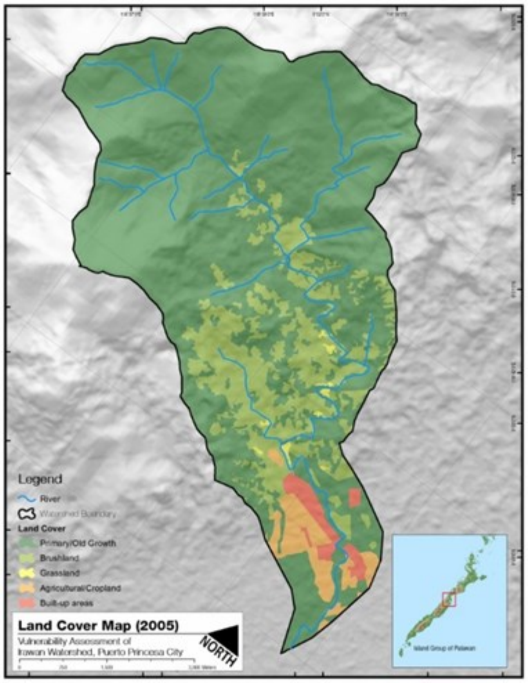

Figure 6. The 2005 land cover map of the Irawan watershed.

The deterioration of the watershed in general and of the land in particular brought about by improper management of land use and land use practices are commonly believed as the root causes (Lasco *et al.* 2011; IPCC 2001) of water resources degradation (erratic streamflow and diminishing ground water resources), soil erosion, and diminishing land productivity as aggravated by climate change and variability specifically that of rainfall and temperature (Cruz 1999; Lasco *et al.* 2011). The results however imply that the watershed is more resilient to climate change than vulnerable as it has still enough forest cover. This also indicates that the remaining forest provide a host of various habitats, biological diversities and environmental services.

Soil Quality. Soil quality is the last indicator of the adaptive capacity component (Figure 7). Organic matter was used as a proxy measure based on the GeoREVIEW model. Majority (54.71% or 2,013 ha) of the soil in the area have 3 to 4% organic matter content which falls at a scale of 1, while 33.44% (1,230 ha) are greater than 4% (4 to 7%) which have an equivalent scale of 2 (Table 23). Only around 11.85% (436 ha) of the area have 2.8 to 3% organic matter which falls at a scale of 3. Based on these results, the watershed has a composite scale of 1.78 indicating that it has a low vulnerability to climate change due to its high organic matter content. According to Dimas and Gnacadja (2008), a rise in global temperature and rainfall accelerates carbon losses from the soil, driving up the concentration of carbon dioxide in the atmosphere and making organic matter content low. Climate change will thus put further pressure on soil quality and will increase the risk of desertification. Therefore, preserving and increasing soil organic matter levels to a greater extent possible can be a significant tool in mitigating climate change.

Table 23. Organic matter distribution of the Irawan watershed.

Organic Matter (%)	Area (ha)	Percent	Scale
>4	1,230	33.44	1
3–4	2,013	54.71	2
2–3	436	11.85	3
Total	**3,679**	**100.00**	

Table 24 shows the summary of generated values for all indicators and their equivalent scales. These derived values based on the description provided in the GeoREVIEW model were then used in generating vulnerability map of the Irawan watershed. Regional and overall analysis was drawn from the map regarding the level of vulnerability of the watershed to climate change.

Weight of Indicators

Figure 8 shows the distribution of weight of indicators under the three components of vulnerability that was applied in assessing the vulnerability of the Irawan watershed due to climate change. Results reveal that vegetation cover had the highest weight (11.47 %) being ranked as number 1, while maximum wind had the lowest weight (2.12 %), thus ranked as the least (rank 20). There are only six (6) of the 20 indicators that have weights above 5 % (5.29 – 11.47 %) which includes; vegetation cover, soil quality, biodiversity, ecosystem greenness, threatened species, and erosion potential. The remaining season, land use change, number of tourists, human development, population density, population growth, minimum temperature, channel size, maximum temperature, road density, elevation and maximum wind.

The output of this study regarding the distribution of weights among the 21 indicators of vulnerability is shown in Figure 9. This output reflects the general condition of Irawan watershed ecosystem in particular and in the Palawan ecosystem in general. Hence, the developed weight distribution of indicators is therefore recommended for its inclusion in assessing vulnerability of ecosystems and watersheds if the option is to use the GeoREVIEW model. These generated weights can be considered as an input towards the improvement of the model in assessing regional environmental vulnerability of ecosystems and watersheds in the Philippines.

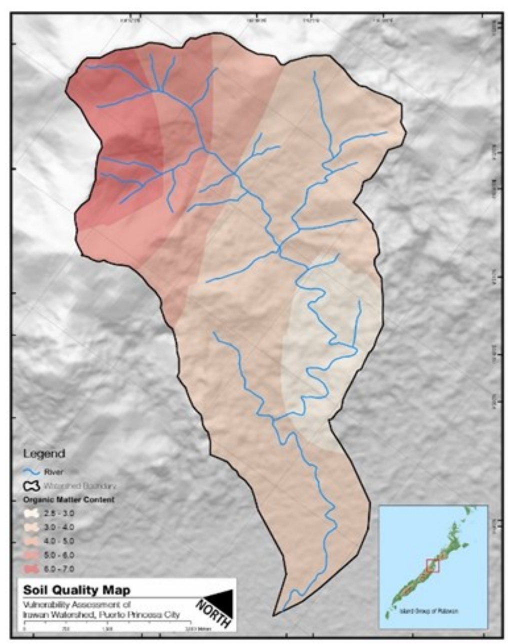

Figure 7. Soil quality map of the Irawan watershed.

Table 24. Summary of gathered/generated values for all indicators and their equivalent scales.

Indicator	Description	Values	Unit	Scale
Exposure Component				
Wet Season	Average annual rainfall excess	483.65	mm	3
Dry Season	Average annual rainfall deficit	233.89	mm	1
Minimum Temperature	Average annual heat deficit	0.00	^{0}C	1
Maximum Temperature	Average annual heat excess	0.07	^{0}C	1
Maximum Wind	Average annual excess wind	42.43	km hr $^{-1}$yr^{-1}	4
Elevation	<773 m	3,653	ha	
	773 – 1,080 m	115	ha	4.97
Watershed Area	Total area of watershed	3,679	ha	2
Sensitivity Component				
Channel Size	Stream order per sub–watershed:			
	Impapay	1.00	order	
	Manlat	3.00	order	
	Manangeb	1.00	order	
	Tagkanarem	3.00	order	3.3
	Pugad Lawin	3.00	order	
	Kalantiaw–Lalandeg	3.00	order	
	Tagpangi	4.00	order	
Land use Change	Mean annual forest cover change	-0.38	%	4
Threatened Species	Number of threatened fauna	11.00	species	4
Biodiversity	Shannon–Wiener's diversity index of flora	1.865	H' value	2
Ecosystem Greenness	NDVI range of values:			
	0.0053 – 0.3702	8	ha	
	0.3702 – 0.5747	56	ha	
	0.5747 – 0.6908	297	ha	1.45
	0.6908 – 0.7627	848	ha	
	0.7627 – 0.8677	2,469	ha	
Erosion Potential	Potential erosion rate in ton ha^{-1} yr^{-1}			
	–0.80	84	ha	
	–0.74	139	ha	
	–0.30	73	ha	4.72
	–0.03	144	ha	
	15.16	3,239	ha	
Adaptive Capacity Component				
Human Development	HDI for Palawan	0.64	HDI value	3
Population Growth	Average annual growth rate for 1995 –2000 and 2000–2007 census data	6.00	%	5
Population Density	2007 population data over the total area of the watershed	126	individuals km^{-2}	1
Number of Tourists	Estimated annual number of tourists	289	individuals km^{-2}	1
Road Density	Length of primary and secondary roads over the watershed area	4.49	m ha^{-1}	5
Vegetation Cover	Based on 2005 land cover	Forest	cover	
		Agroforestry	cover	
		Brushland	cover	3.31
		Built–up	cover	
		Grassland	cover	
Soil Quality	Percent soil organic matter:			
	>4	1,230	ha	
	3–4	2,013	ha	1.78
	2–3	436	ha	

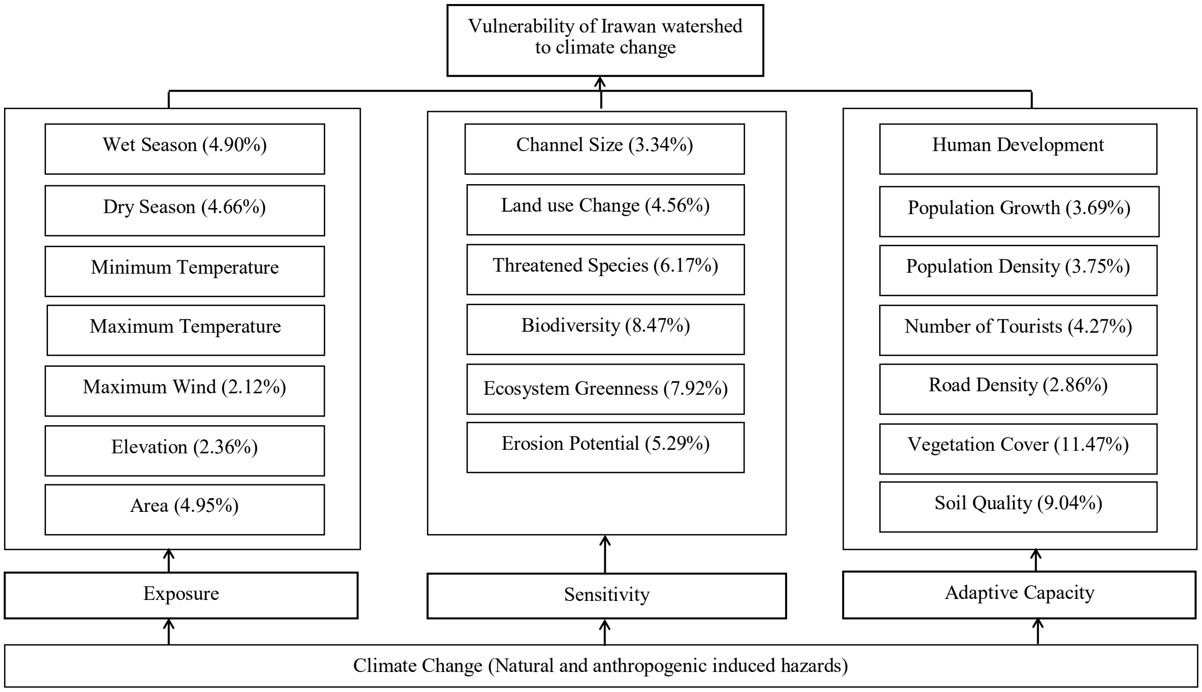

Figure 8. Distribution of weight for the indicators of vulnerability for the Irawan watershed.

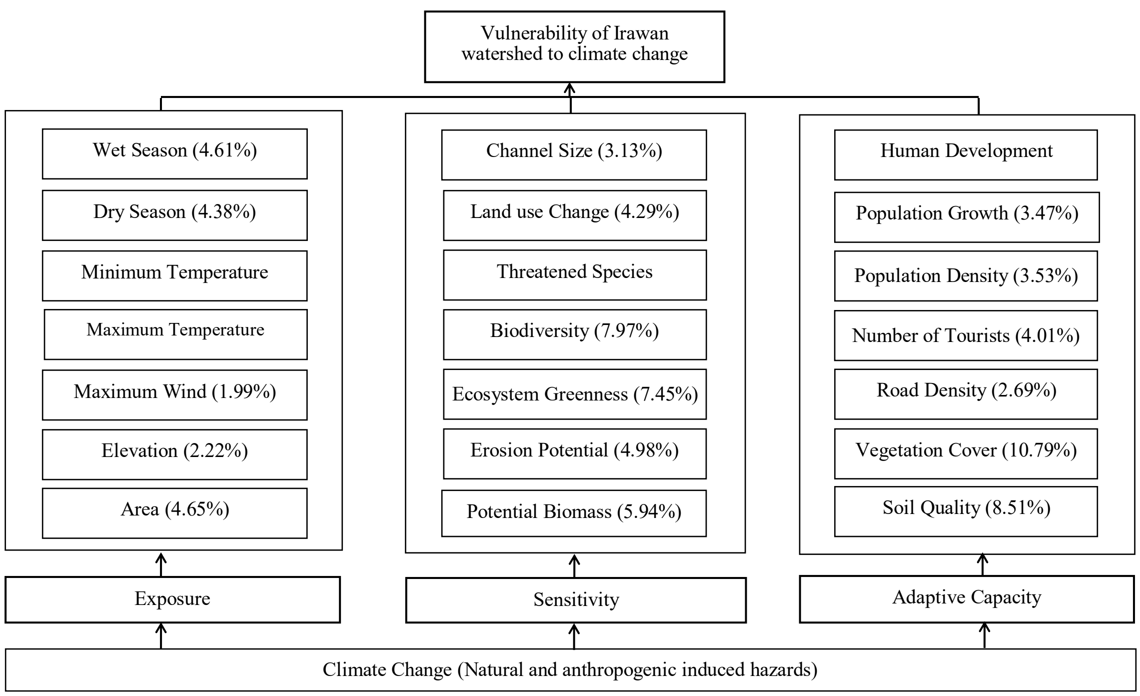

Figure 9. Recommended distribution of weight for the indicators of vulnerability in the GeoREVIEW model.

Overall Vulnerability Assessment of Irawan watershed

A vulnerability map (Figure 10) was generated after overlaying the values for all indicators with their corresponding scales (Table 1) and weight (Figure 2). The figure shows the entire vulnerability of the Irawan watershed to climate change with scales ranging from low (1.90 to 2.00) to moderately vulnerable (2.01 to 2.99). Most (99.51%) of the scale are distributed at mid –range (scale of 2–3) from the 5–point vulnerability scale, hence, the Irawan watershed was classified "moderately vulnerable" to climate change.

Figure 11 shows further detail on the results of the overlay made. The figure particularly displays regions of different vulnerability level under the moderately vulnerable category where the watershed is generally classified. The scale range of 2.01–2.30 had the highest percentage (65.63 %) with an area of about 2,415 ha while the scale of < 2.00 had the lowest percentage (0.49 %) with an area of 18 ha. The regions belonging to a greater range of scale are therefore needed to be prioritized while those regions with the lowest scale ranges are of lesser priorities. However, all areas of varying degree of vulnerability to climate change and anthropogenic hazards in the watershed must be appropriately planned and acted upon to reduce vulnerability of its ecosystem to climate change and to meet sustainable watershed management goals.

Those regions that fall within 2.62–2.99 vulnerability scale have experienced environmental problems associated to climate change and climate variability and extremes in the past based on the historical account of participants in a discussion conducted. Flooding and strong winds due to typhoon were experienced, for instance the typhoon "Norming" in 1998 that struck Puerto Princesa City leaving it under state of calamity. Another example is the typhoon "Lando" last year (2012) leaving the Irawan bridge to total damage due to flooding of headwaters that caused high water turbulence and overflow along the Irawan river. These typhoons experienced in the area have brought flashfloods, destroyed crops, properties, infrastructure, and diseases.

The results imply that adequate interventions must be developed to avoid further aggravation of the present condition of the watershed due to climate change. A planned proactive adaptation measures is further recommended to moderate damages, take advantage of opportunities or cope with the consequences that the current and future climate change would bring. Those areas located in the southern part of the watershed with scale of ≥ 2.62 and classified as moderately vulnerable can be considered as areas for immediate action.

A general vulnerability assessment template is shown in Figure 12. An overall vulnerability point (OVP) of 48.96 was obtained using equation 2. Under this score, the watershed is classified as moderately vulnerable in general. The assessment as shown in the template, five most resilient indicators in the watershed were identified such as the dry season, minimum temperature, maximum temperature, population density, and number of tourists. The most vulnerable indicators on the other hand include the elevation, population growth, and road density. With regards to the three components of vulnerability, sensitivity had the highest average scale (3.18) while the exposure component was found to be the most resilient (2.42). The high average scale for sensitivity component is attributed to high values generated for its indicators of the physical and biological attributes of the watershed.

This implies that physical hazards are more prevalent in the area and the damage to its biological components. This therefore suggests that they must be given attention and be considered critical in planning for the sustainable management of the Irawan watershed and the systems adaptive capacity due to climate change. The overall assessment also provides the aspects of vulnerability where the indicators of damage had the highest average vulnerability scale (2.94) while hazard indicators had the lowest (2.40). The damage indicators of high vulnerability

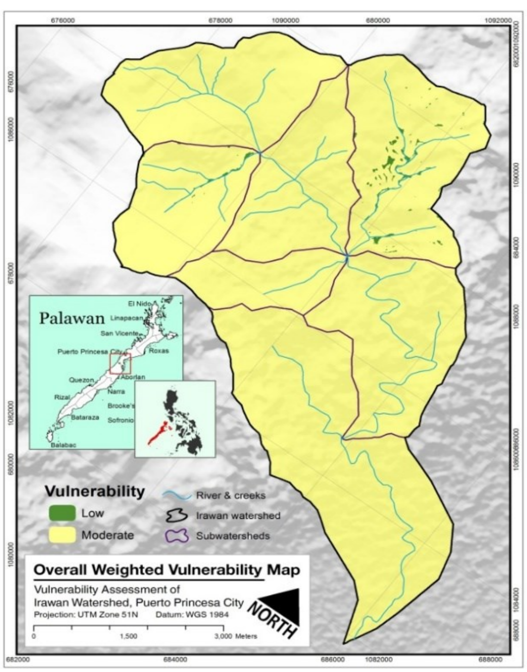

Figure 10. Overall vulnerability map of the Irawan watershed.

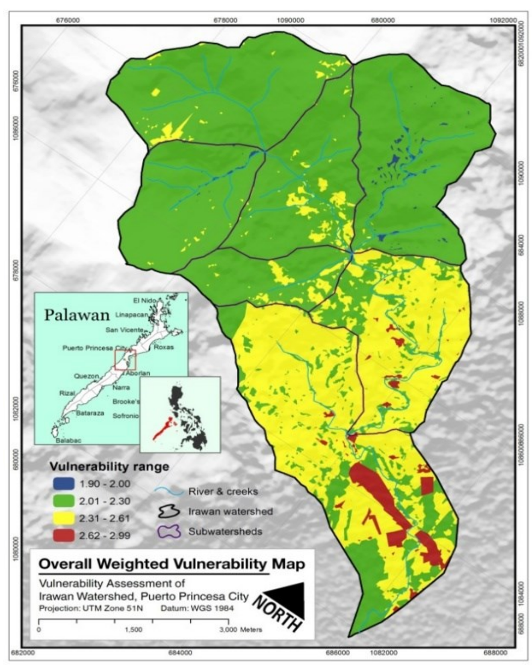

Figure 11. Vulnerability scale distribution map of the Irawan watershed.

imply adequacy of measures to address them that shall strengthen the system's capacity to adjust from impending risks.

From the assessment, information on some policy–relevant issues associated with climate change can also be drawn. Erosion and landslide had the highest overall vulnerability point (58.43) followed by biodiversity loss (56.38), flooding (52.40), and drought (39.20). Most of the policy relevant issues were categorized under moderately vulnerable level. For drought, its category falls under low vulnerability because most of the indicators related to drought are more resilient to climate change. It will be necessary to address the issues and concerns associated with erosion, landslide, and biodiversity in order to prevent the case to be elevated in a more worsened degree of damage into all sectors of the watershed

CONCLUSIONS AND RECOMMENDATIONS

The GeoREVIEW approach of assessing the vulnerability of watersheds and ecosystems in the Philippines is a potential tool for sustainable watershed management planning and in the development of planned proactive actions for climate change mitigation and adaptation. It is flexible enough to accommodate some changes that suit the purpose of its use or even works even when data are limited in assessing general vulnerability.

Due to its flexibility, the GeoREVIEW model allows assignment of weights for indicators of vulnerability. Incorporating the relative importance of the vulnerability indicators can help bring out the true picture on the degree of vulnerability of an ecosystem or watershed being assessed. Based on the pairwise comparisons, biological components of ecosystem are more important indicators of vulnerability to climate change and anthropogenic hazards for protected watershed areas such as the Irawan watershed. Furthermore, the adjusted threshold levels for vegetation index and number of tourists provided better results as they clearly presented more precise ecosystem greenness and tourist carrying capacity of the Irawan watershed.

The Irawan watershed ecosystem is presumed to reflect the condition of protected watershed ecosystems in Palawan in general. The weight of indicators generated in this study can be applied in assessing vulnerability of other protected watershed areas in Palawan. The generated weights can also be considered as an important input towards the improvement of the model for the regional environmental vulnerability index of ecosystems and watersheds in the Philippines.

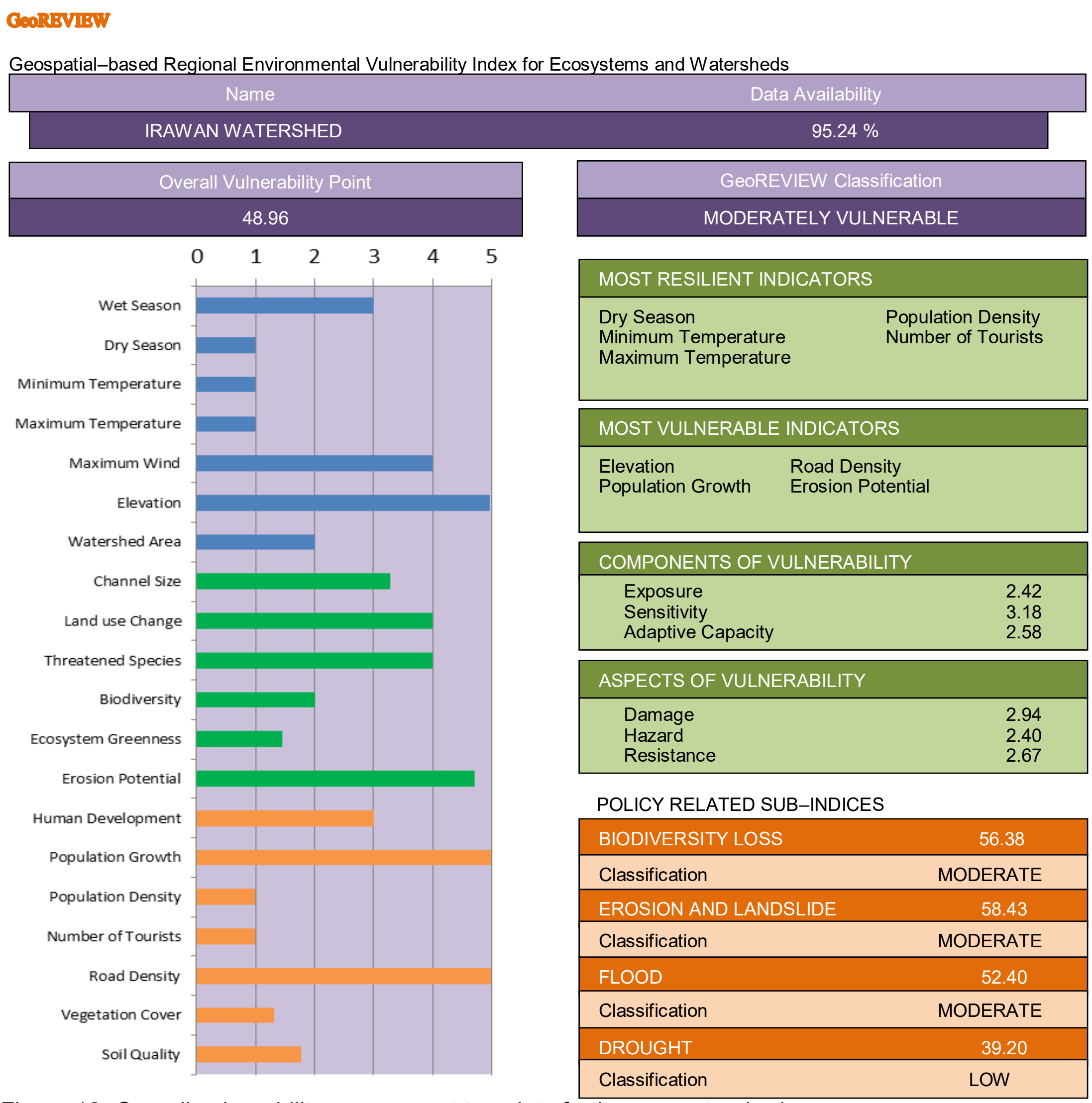

Figure 12. Overall vulnerability assessment template for Irawan watershed.

The general classification of the vulnerability to climate change of the watershed is moderately vulnerable. Those areas located in the southern part of the watershed with scale ranging from 2.62 to 2.99 are areas of immediate concern. Field validation to ensure the accuracy of data and the use of updated information are essential in the accuracy of results of vulnerability assessment studies.

The results of this study may be used as indicative guideline for identifying interventions to avoid further aggravation of the present condition of the watershed due to climate change. Planned proactive adaptation measures must be immediately developed by agencies and stakeholders concerned to reduce vulnerability of the local communities and strengthen the resilience of all sectors of the Irawan watershed to current and future climate risks.

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