

Developing a spatial-based approach for vulnerability assessment of Philippine watersheds and its potential in disaster management

C. L. Tiburan^{1,2}, S. Kobayashi¹, K. Mizuno¹ & I. Saizen¹

¹*Laboratory of Regional Planning,
Graduate School of Global Environmental Studies,
Kyoto University, Japan*

²*College of Forestry and Natural Resources,
University of the Philippines Los Baños, Philippines*

Abstract

The Philippines is considered as one of the most vulnerable countries in the developing world that has experienced various kinds of disaster such as typhoons, flooding, earthquakes, landslides and many other forms of environmental crises. Despite being an archipelago with 7,107 islands, 53% or around 15.8 million ha of its total land area are classified as forestlands. These areas have also been subjected to several catastrophic events and have greatly affected the condition of the environment, the lives of many Filipinos as well as the economy of the country. It is for these reasons that this study aimed to develop a spatial-based approach to assess the vulnerability of watersheds in the Philippines to climate change and to describe its potential in disaster management. The approach had three major components namely, climatic variability component, exposure and sensitivity component and the adaptive capacity component. It consisted of 22 indicators which were also classified under three aspects of vulnerability – hazard, damage and resistance indicators. The model used a scale of 1 to 5 to describe the levels of vulnerability for each indicator and their thresholds were generated using statistical test, existing indices and relevant literature. All indicators were given equal weights and the overall vulnerability classification of a watershed was evaluated by using a ratio between the average scale of all indicators used and the maximum scale. The



results of the assessment were also summarized in a template which includes a vulnerability map, scales given for each indicator, overall points, vulnerability classification and category, list of most resilient and vulnerable indicators and other relevant information.

Keywords: vulnerability assessment, watershed, spatial-based methods, climate change, disaster management.

1 Introduction

In the Philippines, climate change is already evident. Based on the historical records of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) from 1960 to 2003, there has been a significant increase in the frequency of hot days and warm nights in many parts of the country, and a decreasing trend in the number of cool days and nights [1]. It was also observed that there has been a general increase in the amount and intensity of rainfall and the number of rainy days in some parts of the country. However, data on tropical cyclones from 1948 to 2005 did not demonstrate any significant trend in the number of cyclones forming in or entering the Philippine Area of Responsibility (PAR). Nonetheless, based on the list of typhoons that caused the heaviest damage to property in the country, the top five occurred in the past two decades, four in the 1990s and one in the 2000s. In addition, the most destructive typhoon based on the number of deaths was recorded in 1991 (5,080 dead, 292 injured and 1,264 missing) while the strongest tropical cyclone that made landfall in the country has been experienced in 2006 with a peak gustiness of 320 kph.

The country's climate-related problems, however, should not be solely attributed to climate change, but also to its changing environment. In its "State of the World's Forests", the Food and Agriculture Organization (FAO) reported that the forest cover in the Asia and Pacific Region was estimated to be around 734 million ha [2]. This accounted to about 19% of the total global forest cover. Although there was a net increase in the forest area in the entire region of about 633,000 ha annually (2000-2005), the Southeast Asia sub-region recorded the largest decrease in forest cover with approximately 2.76 million ha of forest loss annually. The greatest net loss in forest cover occurred in Indonesia, Myanmar, Cambodia, the Philippines and Malaysia. Based on the recent Philippine Forestry Statistics of the Forest Management Bureau of the Department of Environment and Natural Resources (DENR), the forest cover of the country, as of 2003, is estimated at 7.17 million ha, or approximately 24% of the total land area compared to its cover in 1934 which is around 17.18 million ha or about 57.3% [3, 4].

Due to these evidences of changing climate and environment in the country, the occurrence of disasters has become more imminent than before. Their effects and scope have also increased which, over the past decades, have caused many deaths and displaced thousands, if not millions, of families. Based on the data of the National Disaster Coordinating Council (NDCC) of the Philippines, around 247 areas have been already declared under state of calamity from 2001 to 2007



alone [5]. The types of disaster include typhoons, flooding, landslides and flashflood, El Niño phenomenon and earthquake, among others. These unlikely events have greatly affected the lives of most Filipinos and even the economy of the country. At present, the population of the country, based on the 2007 national census data, is estimated at 88.6 million [6]. This indicates an annual growth rate of 2.04 % from 2000 to 2007. Meanwhile, a study conducted by the University of the Philippines – Population Institute (UPPI) in 2003 estimated that around 24 million people were already living in upland areas [7]. This figure does not only imply additional pressure on the possible exploitation of resources, but it also poses the extent of potential risk for vulnerable areas. The UPPI also projected that this estimate will double in the next three decades if continuous lowland-to-upland migration is observed.

This growing pressure on the environment has lead to the development of this spatial-based approach to assess the vulnerability of watersheds in the Philippines. Moreover, the results of this study can be used to mainstream environmental strategies not only to further strengthen the monitoring system of watersheds over time in the country but the study also seek the potential application of the approach in disaster management of mountain ecosystems.

2 Materials and methods

The study mainly involved the integration of some spatial-based methods and indices in developing an assessment method for vulnerability. Since the assessment was designed mostly for watersheds, majority of the indicators were based on the concept of biophysical vulnerability. Biophysical vulnerability was defined as the interaction of hazards and social vulnerability. This ultimately produces an outcome which is generally measured in terms of physical or economic damage or human mortality and morbidity [8]. The model was also founded on the IPCC definition of vulnerability which described it 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*” [9, 10]. Using these definitions, the indicators in the model were classified under three major components namely, climate variability, exposure and sensitivity, and adaptive capacity.

2.1 The GeoREVIEW approach

The approach was called the Geospatial-based Regional Environmental Vulnerability Index for Ecosystems and Watersheds, or the GeoREVIEW model. This approach involved the inter-connectivity of the 22 indicators that were classified under three major components as shown in Figure 1.

The *climate variability* included indicators that have significant effects on the environment and hydrological conditions of watersheds such as precipitation, temperature and wind. Band et al. [11] observed that projected changes in the



precipitation and temperature could result in significant watershed climate change impacts. These two parameters alone yielded qualitatively different forecasts when compared to a simulation that included an alteration in the canopy physiology and increase of atmospheric CO₂ concentrations. On the other hand, Lentz et al. [12] hypothesized that wind interacting with topographic features can significantly change the distribution of rainfall over a given landscape. As a result, they have found that rainfall pattern differed with the combined effects of meteorological rainfall, incident wind speed, and hill-summit elevation. Mabry et al. [13] also examined the effects of typhoons in a tropical forest in northeastern Taiwan. The study revealed that damage caused by typhoons includes uprooting of trees, snapped boles, and defoliation.

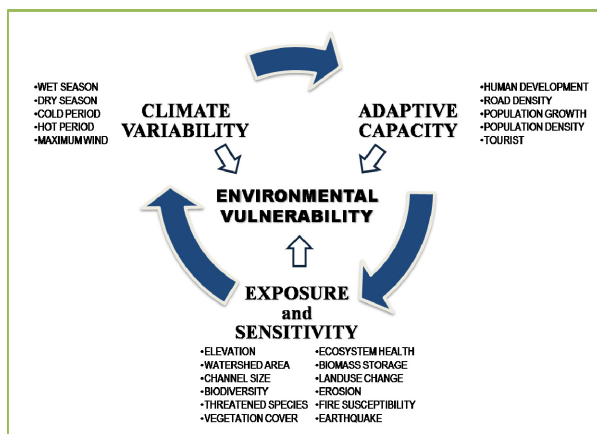


Figure 1: Conceptual framework of the GeoREVIEW approach.

The second major component of the model was the combined *exposure and sensitivity* component which describes the biophysical characteristics of the landscape. This consisted of topography, channel size, vegetation cover, ecosystem health, biomass content, watershed area, biodiversity and the presence of threatened species. Reid [14] explained that land use could alter biological communities in watersheds especially in terms of its influence on production, quality and transport of water and sediment. As such, the biological and physical attributes of watersheds, together with the processes and interactions between them, are of great significance to the study.

Potential hazards and susceptibility concerns of the area to possible damage were also included in this component. These were comprised of erosion estimates, landuse change, fire susceptibility and seismicity records. Kaly et al. [15] indicated that such hazardous events can lead to loss of diversity, extent, quality and function of an ecosystem. Therefore, these parameters were incorporated in the development of the model.

The third component was *adaptive capacity*. Indicators under this component describe the capacity or ability of the system to modify or change its characteristics or behavior so as to adjust or cope better with existing or

anticipated external stresses [16]. These indicators were human development, road density, population growth, population density, and number of tourists. Majority of these are human-related indicators that mainly influence the extent of use and damages that can be made to the resources within the watershed, the carrying capacity of the area, and the additional pressure to the environment in terms of pollution as well as further disturbance in the ecosystem.

The indicators in the model were also classified under three different aspects – hazard, resistance and damage. *Hazard* indicators address the possibility of a hazardous event to occur, its frequency and intensity. *Resistance* indicators, on the other hand, are those referring to the inherent capacity or characteristics of the watershed to withstand the impacts of hazardous events. These also measure the ability level of an ecosystem or watershed to cope with natural and anthropogenic hazards. Lastly, the *damage* indicators illustrate the extent of degradation experienced by a system from past unlikely incidents or demonstrate the loss of ecological integrity from recurring hazards.

A unique ID was also assigned for each indicator to emphasize its component and aspect. For instance, the wet season indicator was given an ID of *CViIH*. The *CV* stands for climate variability which also refers to its component, *iI* indicates it's the first indicator in the GeoREVIEW model and *H* denotes hazard which represents the aspect of vulnerability.

2.2 Vulnerability assessment using GeoREVIEW

2.2.1 Calibration of threshold levels for the indicators

The GeoREVIEW approach involved a scale of 1 to 5 to indicate the degrees of vulnerability. A value of 1 implies a resilient state while a value of 5 specifies the most vulnerable scale. An indicator may also demonstrate either a discrete or a continuous value. Discrete values may be generated if an indicator uses a single scale to describe the entire watershed. This can be attributed to the nature of the indicator or because of data availability. On the other hand, continuous values may be derived from indicators that involve spatial analyses and application of environmental indices. The values of this type of indicators can be expressed initially as a ratio multiplied by its corresponding scale. Their products will then be aggregated into a single value to represent the overall vulnerability level of that indicator.

The setting of threshold levels for each indicator was determined using statistical test, spatial-based methods and indices, while some indicators were reviewed and evaluated based on previous related researches.

The statistical test employed the use of the Kolmogorov-Smirnov (K-S) test. This test is used to find if a sample comes from a hypothesized continuous distribution and is mainly based on the empirical cumulative distribution function (ECDF). There were 12 indicators in the model that were assessed using the K-S test. The raw data were initially plotted into a frequency distribution with nine (9) equally divided classes and the graph was tested under three different distribution curves namely, normal, lognormal and exponential distribution. The goodness of fit to these distribution curves was evaluated using a comparison of the K-S test statistic (D) and the critical value at a specified

level of significance (α). The D value refers to the largest vertical difference between the theoretical and ECDF.

If the initial test revealed the normal distribution as the best fit, the values in the classes were applied in assigning the threshold levels. However, if either lognormal or exponential distribution was found as the best fit, the raw data were transformed first into their non-linear values using natural logarithm or square root function. After which, the resulting values were again refitted against a normal distribution curve. If the test found a non-significant result, these categories were finally used to distribute the range in each scale for a given indicator.

The scaling system under the K-S test was mainly based on the range of the nine (9) classes. Scale 1 was assigned to classes 1 and 2, scale 2 was designated from class 2 to 4, scale 3 from class 4 to 6, scale 4 from class 6 to 8 and finally, scale 5 was assigned for classes 8 and 9. The distribution was regarded as continuous hence the overlap between scales.

On the other hand, the remaining 10 indicators were evaluated using various indices, spatial-based methods, standards and literature reviews. Their threshold levels were assigned based on the nature and characteristics of the index, their limits, previous studies conducted in the Philippines where these methods have been applied and the like. Some of the methods used to develop the approach include the Shannon-Weiner index, normalized difference vegetation index (NDVI), potential biomass density index (PBDI), revised universal soil loss equation (RUSLE), fire susceptibility index (FSI), PHIVOLCS earthquake intensity scale (PEIS), human development index (HDI) and the Strahler's method.

2.2.2 Classification of overall vulnerability and category

The overall vulnerability point (OVP) of a watershed was determined using the equation:

$$OVP = \frac{\frac{1}{n} \sum_{i=1}^n S_i}{S_{\max}} \times 100 \tag{1}$$

where: S_i - scale of indicator i
 S_{\max} - maximum scale
 n - total number of indicators

Table 1: Overall vulnerability classification of the GeoREVIEW approach.

Category	Overall Classification	Overall Vulnerability Point
5	Extremely Vulnerable	>85
4	Highly Vulnerable	70 – 85
3	Vulnerable	55 – 70
2	At Risk	40 – 55
1	Resilient	<40



Table 1 shows the details in assigning overall vulnerability and category. The results of the assessment were also presented in a template that shows relevant information about the evaluation.

3 Results and discussion

3.1 Description and threshold levels of the indicators in GeoREVIEW

The results of the calibration of threshold levels and scales for all 22 indicators are summarized in Table 2. It also describes the nature of each indicator, the ID for each indicator, its effects to climate and the environment, and the unit of measurement.

3.2 The potentials of GeoREVIEW in disaster management

The GeoREVIEW approach was designed primarily to assess vulnerability-related problems of watersheds and other ecosystems in the Philippines to climate change but this does not restrict its application. With its capacity to classify its indicators into different components and aspects of vulnerability, the model can be a potential tool also in disaster management. In this field of discipline, many elements are involved such as disaster preparedness, disaster response and post-disaster support system. These similar elements can also be found in GeoREVIEW and can be interpreted particularly in terms of the three aspects of vulnerability. Hazard can be associated to disaster preparedness, resistance to disaster response and damage to post-disaster support systems.

There were eight (8) indicators in the approach that were classified under the hazard aspect namely, wet season, dry season, cold period, hot period, maximum wind, erosion, fire susceptibility, and earthquake. These same indicators covered most of the hazards being experienced by the country over the past decades. These include typhoons, flashfloods, landslides, forest fire and earthquake. On the other hand, seven (7) indicators were regarded as measures of resistance (elevation, watershed area, channel size, vegetation cover, biomass storage, human development and road density) while the other seven (7) indicators were attributed to damage (biodiversity, threatened species, ecosystem health, landuse change, population growth, population density and number of tourists). The indicators under resistance tackle the contributions of the environment and society in minimizing the impacts and possible effects of disasters. They also capture the ability of the system to cope up from such unlikely events. The damage indicators, on the contrary, highlight the degree of harm sustained by the area over the past years. These indicators are very essential to determine the present state of the area and how these problems can be properly addressed.

With these attributes of GeoREVIEW, the model can also be utilized to identify areas which are most vulnerable to disaster. Since a vulnerability map is generated from the assessment, this can be utilized also in making better decisions, prioritization, management and policy formulation in the area. The evaluation results can also further improve the reliability and design of



Table 2: Detailed summary of threshold levels and scale distribution for all 22 indicators in the GeoREVIEW approach.

ID	Indicator	Unit	Description	Range	Scale
Climate variability component					
CVi1H	Wet Season	mm	Average annual rainfall excess (mm) over the past five (5) years for all months with 20% higher than the 25-year monthly average. It accounts for flooding and effects of storms to ecosystem disturbance.	<182.53	1
				182.53-496.01	2
				496.01-962.99	3
				962.99-1583.49	4
				>1,583.49	5
CVi2H	Dry Season	mm	Average annual rainfall deficit (mm) over the past five (5) years for all months with 20% lower than the 25-year monthly average. It describes vulnerability to drought and other water-related problems.	<176	1
				176-352	2
				352-528	3
				528-704	4
				>704	5
CVi3H	Cold Period	°C	Average annual heat deficit (°C) over the past five (5) years for all months with 2°C lower than the 25-year monthly minimum average. It relates to temperature stress, productivity, and reproduction.	<2.95	1
				2.95-11.80	2
				11.80-26.54	3
				26.54-47.19	4
				>47.19	5
CVi4H	Hot Period	°C	Average annual heat excess (°C) over the past five (5) years for all months with 2°C higher than the 25-year monthly maximum average. It provides a measure of stress to forest growth and biodiversity survival.	<0.51	1
				0.51-2.05	2
				2.05-4.61	3
				4.61-8.19	4
				>8.19	5
CVi5H	Maximum Wind	km/hr	Average annual excess wind over the past 10 years for all months with 20% higher than the 25-year maximum wind speed average for that month. It affects storm surges, fire spread and damage to forest.	<11.83	1
				11.83-22.22	2
				22.22-41.30	3
				41.30-77.55	4
				>77.55	5
Exposure and Sensitivity Component					
ESi6R	Elevation	masl	Topographic relief of the area. It has significant effects on the variety of ecosystems and can be attributed also to pollution, flooding, human disturbance, and exploitation of natural resources.	>2,800	1
				2,100-2,800	2
				1,400-2,100	3
				700-1,400	4
				<700	5
ESi7R	Watershed Area	ha	Extent of the boundary of watershed which also captures the richness of habitats and diversity present in the site.	>50,355	1
				28,325-50,355	2
				12,589-28,325	3
				3,147-12,589	4
				<3,147	5
ESi8R	Channel Size	stream order	Stream order generation based on Strahler's method for all major sub-watersheds in the landscape. It explains the relative channel size and to some extent, water supply and the stream types present.	≥5	1
				4	2
				3	3
				2	4
				1	5
ESi9R	Vegetation Cover	land cover class	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.	forest	1
				agroforestry	2
				brushland	3
				grassland	4
				bare/built-up	5
ESi10R	Biomass Storage	PDBI value	Potential biomass density estimates based on geo-physical characteristics of the area. It takes into account the optimum capacity of the landscape to produce biomass and its potential as carbon sink.	85-100	1
				70-85	2
				55-70	3
				40-55	4
				<40	5

Table 2: Continued.

ID	Indicator	Unit	Description	Range	Scale
ESi11D	Biodiversity	H' index	Number and evenness of floral species using the Shannon-Weiner index. It describes the type of ecosystems present in the watershed.	>1.50	1
				1.25-1.50	2
				1.0-1.25	3
				0.5-1.0	4
				<0.5	5
ESi12D	Threatened Species	number of species / 100km ²	Number of threatened species based on PAWB National Red List of Philippine Wild Fauna. It has effects on biodiversity and ecological interaction.	0	1
				0-5	2
				5-10	3
				10-15	4
				>15	5
ESi13D	Ecosystem Health	NDVI value	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 disease attacks.	>0.4	1
				0.3 - 0.4	2
				0.2 - 0.3	3
				0.1 - 0.2	4
				<0.1	5
ESi14D	Landuse Change	%	Mean annual percentage of forest cover change over at least the past five (5) years. It has effects on landscape integrity, biodiversity and carbon storage.	<0	1
				0	2
				0-4	3
				4-8	4
				>8	5
ESi15H	Erosion	ton/ha/ye ar	Erosion potential estimates of the area using the RUSLE method. It captures hazards to landslide and habitat disturbance.	0-1	1
				1-12	2
				12-35	3
				35-60	4
				>60	5
ESi16H	Fire Susceptibility	FSI value	FSI values are estimated based on the required heat energy to bring a fuel from its current temperature to ignition using satellite images. It relates to habitat disturbance and carbon release to the atmosphere.	<10	1
				10-20	2
				20-30	3
				30-40	4
				>40	5
ESi17H	Earthquake	PEIS intensity scale	Seismicity records of the area over at least the past 10 years based on PEIS system. It triggers landslides and fire, and can result to habitat disturbance and species loss.	I-II	1
				III-IV	2
				V-VI	3
				VII-VIII	4
				IX-X	5
Adaptive Capacity Component					
ACi18R	Human Development	HDI value	The index is generated using GDP, life expectancy, and education. It reflects the achievement and development of people and/or communities within the watershed.	>0.74	1
				0.68-0.74	2
				0.62-0.68	3
				0.56-0.62	4
				<0.56	5
ACi19R	Road Density	m/ha	Road density calculation only includes primary and secondary roads. It affects the contiguosness of species habitats and provides access to resource exploitation and infrastructure development.	<1.6	1
				1.6-2.2	2
				2.2-3.0	3
				3.0-4.1	4
				>4.1	5
ACi20D	Population Growth	%	Annual population growth rate based on two consecutive census data. It is associated to possible exploitation of natural resources, disposal of wastes and poverty incidences.	<0.97	1
				0.97-1.68	2
				1.68-2.92	3
				2.92-5.05	4
				>5.05	5
ACi21D	Population Density	person/ km ²	Population density of communities within the boundary of the watershed. It may increase pressure to the environment such as habitat damage and resource use.	<220	1
				220-440	2
				440-660	3
				660-880	4
				>880	5



The GeoREVIEW, however, does not limit its capability in vulnerability studies alone but the model can be applied as well to other fields of interest. In this paper, the model is also associated to disaster management because the indicators in GeoREVIEW can also be interpreted based on hazard, resistance and damage. These different aspects of vulnerability are often observed also in various kinds of disaster and are imperative in developing better perspective and understanding about the nature of such events. In addition, the assessment in the model is coupled with the use of spatial-based technologies such as geographic information system (GIS) and remote sensing. The integration of these tools further increases the reliability of results, faster retrieval of information, provision of more alternatives or options, and a more efficient and effective resource allocation. These important features have also become essential elements of the model to further advance the assessment process in disaster management.

The model, however, can still be improved with the incorporation of additional databases in the development of its scales to better capture the diverse conditions in the Philippines. The results from future application of the model are also very essential in the evaluation of the behavior and performance of the indicators. These results will also dictate later if an adjustment of the current threshold levels for the different indicators is indispensable. Moreover, the information generated from this evaluation will be vital also in determining whether a weighing system among components or indicators in the model will be necessary or not.

Acknowledgement

The authors would like to acknowledge the Hitachi Scholarship Foundation for providing a scholarship grant to C.L. Tiburan Jr.

References

- [1] Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA), www.pagasa.dost.gov.ph/
- [2] State of the World's Forests 2007; Food and Agriculture Organization (FAO), Rome, www.fao.org/docrep/009/a0773e/a0773e00.htm
- [3] Forestry Statistics; Forestry Management Bureau, Department of Environment and Natural Resources (DENR) <http://forestry.denr.gov.ph/>
- [4] Chokkalingam, U., Carandang, A.P., Pulhin, J.M., Lasco, R.D., Peras, R.J.J. & Toma, T., *One century of forest rehabilitation in the Philippines: approaches, outcomes and lessons*, Center for International Forestry Research (CIFOR): Bogor, Barat, Indonesia, pp.6-13, 2006.
- [5] National Disaster Coordinating Council (NDCC), <http://ndcc.gov.ph/home/>
- [6] National Statistics Office (NSO), <http://www.census.gov.ph/>
- [7] Department of Environment and Natural Resources (DENR) <http://www.denr.gov.ph/>



- [8] Country Level Risk Measures of Climate-related Natural Disasters and Implications for Adaptation to Climate Change; Tyndall Centre for Climate Change Research, Norwich, United Kingdom, Tyndall Centre Working Paper 26. www.tyndall.ac.uk/publications/working_papers/wp26.pdf
- [9] McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. & White K.S. (eds).. *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Geneva, IPCC, 2001.
- [10] Parry, M., Canziani, O., Palutikof, J., Van Der Linden, P. & Hanson, C. (eds). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Geneva, IPCC, 2007.
- [11] Band, L.E., Mackay, D.S., Creed, I.F., Semkin, R., & Jeffries, D., Ecosystem processes at the watershed scale: sensitivity to potential climate change. *Limnology and Oceanography*, **41(5)**, pp. 928-938, 1996.
- [12] Lentz, R.D., Dowdy, R.H. & Rust, R.H., Measuring wind and low-relief topographic effects on rainfall distribution. *Applied Engineering in Agriculture* **11(2)** pp. 241-248, 1995.
- [13] Mabry, C.M., Hamburg, S.P., Lin, T.C., Horng, F.W., King, H.B., & Hsia, Y.J., Typhoon disturbance and stand-level damage patterns at a subtropical forest in Taiwan. *BIOTROPICA* **30(2)** pp. 238-250, 1998.
- [14] Reid, L.M., *Research and Cumulative Watershed Effects*. General Technical Report PSW-GTR-141, Pacific Southwest Research Station, Albany, California, USA, pp. 1-118, 1993.
- [15] Kaly, U., Pratt, C. & Mitchell, J., *The Demonstration Environmental Vulnerability Index (EVI) 2004*, SOPAC Technical Report 384, pp. 1-320, 2004.
- [16] Vulnerability, Risk and Adaptation: A Conceptual Framework; Tyndall Centre for Climate Change Research, Norwich, United Kingdom, Tyndall Centre Working Paper 38. www.tyndall.ac.uk/publications/working_papers/wp38.pdf