Assessing the impact of climate change on the traditional hydrological system of the Cordillera Rice Terraces

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Abstract: This paper assesses the impact of climate change on the traditional hydrological system of the Cordillera Rice Terraces. The terracing method is a part of the whole complex and robust socio-ecological system (SES) built within the Tropical Montane Cloud Forest (TMCF). We devised assessment schemes that determine the vulnerabilities climate change brings about to this system. We listed SES specific variables based on the Turner Framework Vulnerability Analysis and utilized the Smith and Pilifosova vulnerability model in order to achieve a standardized value for comparison across different SES regions. After identifying factors of constant exposure, sensitivity, and resilience, we designated a value of 0-1 based on the factor’s degree of impact towards climate change as well as attributed a weight for each. We could then assess the vulnerability of an SES to a given stimulus over a given time. The most vulnerable SES would have the maximum value of 1 for the exposure and sensitivity factors, while the resilience factor would have the minimum value of 0. Given the context of the Cordillera Rice Terraces, we can conclude that the system’s vulnerability to climate change, is higher than average.

1. Introduction
The Cordillera Region lies at the landlocked mountainous area of north-central Luzon Island, the biggest island among the three major islands of the Philippines. The region is composed of six provinces: Abra, Benguet, Kalinga, Apayao, Ifugao and the Mountain Province. The rice terraces, which span approximately 50,000 square kilometers, predominantly exist all throughout the mountain ranges and provinces. The Cordillera constitutes mainly of a Tropical Montane Cloud Forest (TMCF) characterized by high precipitation. Its rolling hills and mountains are constantly covered in mist and fog. Cordillera's TMCF has an area of 15,000 square kilometers owing to the region’s location and elevation which reaches an average of 1600 meters [1]. Assessing the region’s vulnerability from impact of climate change remains problematic as the terraces were built to withstand changes in environmental conditions. Watersheds are managed effectively as repository of water from the constant rain while the terrace system is utilized to grow rice and other crops and to filter water for drinking. The terraces, managed by the indigenous tribes that built them, therefore, act as cushion against drought, typhoons and prolonged rain. Terracing remains dependent on other systems that are intricately woven together and as a socio-ecological system, culture, environmental law, criminal law, customs and traditions are intertwined [1]. But just like any other thousand-year old civilization and socio-ecological systems, the Cordillera Rice Terraces faces problems resulting from climate change that challenge its resilience and robustness. However, the complexity and the intricacies of this SES as well as the lack of gauges and assessment schemes that can measure its vulnerability amid changing conditions make it impossible to determine its sustainability. Thus, this paper will present vulnerability analysis specific only to the Cordillera SES, taking into consideration the complexity of its terracing system and its prevailing conditions.
2. Methodology

2.1. Framework and Model
This paper utilizes the Turner Framework which is a method for vulnerability analysis, taken into consideration the perturbations on a given biosphere such as that of the TMCF, especially given factors of climate affiliated environmental changes [2]. As vulnerability is defined as the extent in which a system will experience consequences beyond the impacts in the scope it is normally associated with, it should also operate at multiple spatial, functional, and temporal scales. Vulnerability is also defined by The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report as a function of a system’s exposure, sensitivity and resilience, which can be defined respectively as the external source of disturbance to the system, the internal factors which make it more or less susceptible to such, and the system’s ability to cope with the consequences that arise such that vulnerability bears a positive functional relationship with exposure, sensitivity and vulnerability, and a negative functional relationship with resilience [3]. Through this qualitative categorization, we can be able to identify the interconnectedness and complex interactions within the biotic sphere.

However, the framework on its own does not yield an appropriate form of comparative analysis between different SES or even more general TMCF geographical areas. Thus, we utilized the quantitative vulnerability model introduced by Smit and Pilifosova [4]. This takes into account a functional relationship between the exposure, and adaptive factors of a system expressed by (1):

$$ V = f(E, A) $$

Where $V$ represents the system’s vulnerability, $E$ represents the system’s exposure, and $A$ represents the system’s adaptive capacity or resilience.

2.2. Use of Indicators
In order to quantitatively assess the vulnerability of Cordillera, individual values for exposure, sensitivity and resilience are needed. To derive these values, we utilized the IPCC’s definitions of exposure, sensitivity and vulnerability and used the following indicators presented in Table 1:

| Table 1. Indicators used with their corresponding functional relationships. |
|------------------|------------------|-----------|------------------|
| Component        | Indicator         | Value a   | Functional Relationship |
| Exposure         | Introduction of alien species | 0.64667 | Positive (+) |
| Exposure         | Inorganic pesticides and fertilizers | 0.15556 | Positive (+) |
| Sensitivity      | Rates of erosion  | 0.48314 | Positive (+) |
| Resilience       | Diversity of edible plants | 0.88333 | Negative (–) |
| Resilience       | Multifunctionality of forest  | 0.24074 | Negative (–) |
| Resilience       | Food Self-sufficiency | 0.19259 | Negative (–) |

*Values from [6]*

Where introduction of alien species refers to the the number of invasive species reported to be exotic; inorganic pesticides and fertilizers refers to the proportion of households reporting the use of inorganic pesticides and fertilizers; rates of erosion refers to proportion of damaged terraces by number of households; diversity of plants refers to the total number of plant species grown per household; multifunctionality of forest refers to the total number of uses of forest goods per household; food self-sufficiency refers to the autonomy from rice fields.
A limitation on the total number of indicators used is due to the lack of credible and quantified indicators within the Cordillera region. However, the indicators presented above are sufficient representations of the exposure, sensitivity and resilience factors and are used to quantify the vulnerability of the region.

2.3. Normalization of indicators

That the indicators vary in measurement scales and units presents the need to standardize the values in order for the factors to be comparable and for the Smit and Pilissofova’s vulnerability model to be applied. The standardizing technique employed by (Zurovec 2017) [6] was utilized for both positive functional relationships as expressed in (2) and negative functional relationships as expressed in (3)

\[
X_p = \frac{X - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}} \quad (2)
\]

\[
X_n = \frac{X_{\text{max}} - X}{X_{\text{max}} - X_{\text{min}}} \quad (3)
\]

Where \(X_p\) refers to standardized value of indicators with positive functional relationships with vulnerability, \(X_n\) refers to the standardized value of indicators with negative functional relationships with vulnerability, \(X\) refers to the true value of the indicator, \(X_{\text{max}}\) refers to the maximum theoretical value of the indicator, \(X_{\text{min}}\) refers to the minimum theoretical value of the indicator.

Hence, equation (2) for positive functional relationships was used to obtain the standardized values of the exposure and sensitivity indicators: introduction of alien species, inorganic pesticides and fertilizers, and rates of erosion. On the other hand, equation (3) for negative functional relationships was used to obtain the standardized values of the resilience indicators: diversity of edible plants, multifunctionality of forest, and food self-sufficiency.

2.4. Weighting of Indicators

Given that the extent of influence of each indicator on vulnerability varied, a weighting system was introduced to account for these variances such that more credible and more relevant indicators received higher weightings as shown in Table 2.

| Component | Indicator                      | Value     | Weighting | Final Value | Weighted Value |
|-----------|--------------------------------|-----------|-----------|-------------|----------------|
| Exposure  | Introduction of alien species | 0.64667   | 0.75      | 0.4850025   |                |
| Exposure  | Inorganic pesticides and fertilizers | 0.5   | 0.25      | 0.125       |                |
| Sensitivity | Rates of erosion               | 0.48314   | 0.25      | 0.120785    |                |
| Resilience | Diversity of edible plants    | 0.88333   | 0.10      | 0.088333    |                |
| Resilience | Multifunctionality of forest  | 0.4254    | 0.40      | 0.17016     |                |
| Resilience | Food Self-sufficiency         | 0.2222    | 0.50      | 0.1111      |                |
2.5. Calculating Index
Using the weighted values in table 2, a sub-index was obtained for exposure and sensitivity since both have positive functional relationships with vulnerability. The sub-index value for exposure and sensitivity was calculated through the Xp

2.5.1. Calculating the sub-index for exposure and sensitivity:

\[
\frac{(0.4850025 + 0.125 + 0.120785) - 0}{1 - 0} = 0.7307875 \approx 0.73079 \quad (4)
\]

Similarly, a sub-index for resilience was obtained for resilience using the weighted values in table 2. The sub-index for resilience was calculated through Xn due to the negative functional relationship.

2.5.2. Calculating sub-index for resilience:

\[
\frac{1 - (0.088333 + 0.17016 + 0.1111)}{1 - 0} = 0.630407 \approx 0.63041 \quad (5)
\]

Since the standardizing method employed accounted for both the positive and negative functional relationships of the indicators, the final vulnerability index can then be found by calculating the arithmetic mean of the exposure and sensitivity sub-index and the resilience sub-index, which is the same method used by Zurocev [6], Ravindranath [7], and O’Brien et al [8].

2.5.3. Calculating vulnerability index:

\[
\frac{0.7307875 + 0.630407}{2} = 0.68059735 \approx 0.68060 \quad (6)
\]

Hence, a final vulnerability index value of 0.68060 is obtained for the Cordillera Rice Terraces.

3. Results and Discussion
Through the standardization of the exposure, sensitivity and resilience factors as well as the utilization of the Smit and Polosova vulnerability method, the impact of climate change on the traditional hydrological system of the Cordillera Rice Terraces was quantified through the vulnerability index. However, since the indicators used had varying importance and relevance to climate change vulnerability, each was weighted differently for the index calculation. Weighting values of 0.75, 0.25, 0.25, 0.10, 0.40, 0.50 were applied to the following indicators: Introduction of alien species, Inorganic pesticides and fertilizers, Rates of erosion, Diversity of edible plants, Multifunctionality of forest, and Food Self-sufficiency respectively. For the exposure and sensitivity indicators, Introduction of alien species indicator was given more weighting since it had more pronounced implications on the exposure of the socio-ecological system while food self-sufficiency and multifunctionality of forest were given the highest weighting for the resilience factors as both indicators are relatively more relevant and encompass larger domains than the remaining indicator. This weighting technique also considered the relevance, sample size, and credibility of each indicator which allowed realistic derivations of sub-index values. Using the standardizing methods from equations (2) and (3), a sub-index value of 0.73079 was calculated for exposure and sensitivity as shown in equation (4) while a sub-index value of 0.63041 was calculated for resilience as shown in equation (5). Through the normalization techniques, however, a final vulnerability index of 0.68060 was obtained for the Cordillera Rice Terraces as shown in equation (6) and Table 3. This indicates a higher than average rate of vulnerability as compared to potential various other socio-ecological systems, not altered by geographical location.
| Index                | Value    | Functional Relationship         |
|---------------------|----------|---------------------------------|
| Exposure & Sensitivity | 0.73079  | Positive Causal Relationship (+) |
| Resilience          | 0.63041  | Negative Causal Relationship (-) |
| Vulnerability       | 0.68060  | N/A                             |

4. Conclusion

The traditional hydrological system, unique especially in its ecological composition, contain a variety of factors that impact its stability to external forces. This can now be transitioned from a qualitative to a quantitative mode of measurement. By establishing the frailty and interconnectedness of the exposure, sensitivity, and resilience, related to the existence of the rice terraces, therefore comparison can be made between various socio-ecological systems and we learned that the increasing loss in trend of rituals that the indigenous people offer to their community impacts not only the obtention of knowledge to be documented, but also the status of the ecosystem itself. The Ifugao, though a strong model of sustainability, is susceptible to the pressures brought by man. As a result, this research shows that the six indicators as stated previously were successfully able to assess the state of the Cordillera Rice Terraces to that of a higher than average vulnerability to climate change. Though unlike previous conceptions, some variables are more critical than others, based off the system’s adaptation of occurrences, one should not discount for the fact that the slight disruption of such a complex status of the system will result in unwanted changes as a whole.

The main condition of the results of the paper is whether it’s applicable for other socio-ecological regions in different geographical contexts. Since specific mathematical computations regarding the factors’ prevalence in the Cordillera Rice Terraces were accounted for, it is not known whether these can be translated to other given areas or whether the factors can be even qualitatively analyzed as well. One way of ensuring a concrete representation of how the results can be perceived is through growth analysis over a period of time and whether the overall vulnerability, since susceptible to change, will worsen over time. Knowing this general structure will eradicate the need for specific measurements and allow for flexibility for the type and amount of factors that will be placed into our formulated equation above. However, a localized system for vulnerability, as done in this research, will result in chosen variables that are relevant, specific, and accurate.

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