EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 13(1) 2020 1-13
DOI 10.14456/ea.2020.1
ISSN 1906-1714; ONLINE ISSN: 2586-8861

# Climate Resilience: Concepts, Theory and Methods of Measuring

Adi Subiyanto[1]*, Rizaldi Boer[2], Edvin Aldrian[3], Perdinan[4], Rilus Kinseng[5]

[1]*Program of Applied Climatology, Graduate School of Bogor Agricultural University, Indonesia*
[2]*Center for Climate Risk and Opportunity Management in Southeast Asia and Pacific, Bogor Agricultural University, Indonesia*
[3]*Intergovernmental Panel on Climate Change, Working Group I Vice Chair, Indonesia*
[4]*Department of Geophysics and Meteorology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Indonesia*
[5]*Department of Communication Science and Community Development, Faculty of Human Ecology, Bogor Agricultural University, Indonesia*

*Corresponding Author: adisbyt@gmail.com
Received: November 6, 2018; 1st Revised: January 14, 2019; Accepted: June 8, 2019

## Abstract

Resilience is an intangible concept. One way to describe it is done by indicators that can represent the same unit (index). The purpose of the study is to develop a method of measuring the climate resilience index (RI) based on the concepts and theory of vulnerability, risk, and resilience. The design of study and methods are: 1) framework for analysis of the concepts of vulnerability, risk, and resilience; and 2) develop RI based on a risk management approach and set up resilience forming factors. The method of measuring RI includes the choice of indicators, weighting and scaling indicators, categories of resilience, and applying methods to measure RI at the provincial level in Indonesia. The results showed that RI=(ACI*TCI)/(EI*SI); where RI: climate resilience index, ACI: adaptive capacity index, TCI: transformative capacity index, EI: exposure index, and SI: sensitivity index. In the case of Indonesia, the average of RI is 0.70. The highest was Jakarta SCR (1.61) and the lowest was East Nusa Tenggara (0.29). In other words, East Nusa Tenggara has to be the first priority of development in the face of climate change threat.

***Keywords:*** Vulnerability; Risk; Resilience; Climate resilience index

## 1. Introduction

Research on resilience related to climate change threats is relatively new when compared to the vulnerability and risk. In fact, there is no consensus on how to measure resilience so it remains a challenge for researchers (Béné *et al*, 2013). The same extreme weather events can have an impact on different socioeconomic conditions, not only depending on location and time of incidence but also determined by community resources and agility associated with their experience and participation in dealing with the disturbance. The change in the research focus from vulnerability and risk to resilience is based more on the meaning of resilience that refers to a positive concept (reinforce), so it can be more integrated with sustainable development goals (Malone, 2009).

The Intergovernmental Panel on Climate Change (IPCC) continues to develop its methodology in addressing the challenges of climate change. Significant changes are the change of the concept of vulnerability in the fourth assessment report or AR4 (IPCC, 2007) to risk assessment in the fifth assessment report or AR5 (IPCC, 2014).

The change of conceptual brings consequences when it comes to measure the vulnerability and risk indices. In AR4, vulnerability factors include exposure, sensitivity, and adaptive capacity; meanwhile AR5 has separated exposure from vulnerability. AR5 emphasizes on the concept of risk in order to be more easily integrated with disaster studies.

Based on this fact, it is necessary to know about how the linkage (connectivity) between the concepts of vulnerability (in AR4) with the concept of risk (in AR5) is; and whether climate resilience measures can be developed based on the concept of vulnerability and risk. The objectives of the study are (1) to analyze vulnerability, risk or impact, and resilience by means of connectivity to changes concept in the AR4 to AR5 and compare to the resilience concept, and (2) to develop a method of measuring the climate resilience index based on the results of connectivity and comparability between concepts of vulnerability, risk, and resilience. The results of this analysis are expected to be used in measuring climate resilience index, both at national and sub-national scales (province).

## 2. Framework for analysis

Basically, this study was conducted to develop a method for measuring climate resilience index based on existing theories and concepts (Figure 1). The definition of theory is a set of concepts, assumptions, and generalizations that can be used to express and explain behavior in various organizations (Hoy and Miskel, 2010). Meanwhile, the concept is a number of characteristics associated with an object where the concept is created by classifying and grouping certain objects that have the same characteristics (Umar, 2004).

Theory can also be interpreted as a set of interrelated concepts and definitions that reflect a systematic view of phenomena and explain the relationship between variables (Siswoyo in Mardalis, 2003). The theory can limit the number of facts that are needed to be learned and can be used to predict further facts to be sought. The main concepts that being used in this study are the concept of vulnerability (AR4), the concept of risk/impact (AR5) and the concept of resilience. The concept of adaptive capacity is also used to clarify the discussion of the main concept. The reason, adaptation is often equated with the meaning of resilience. The result of the connectivity and the comparison between the concepts, is expected to be used to develop a method for measuring climate resilience index (RI).

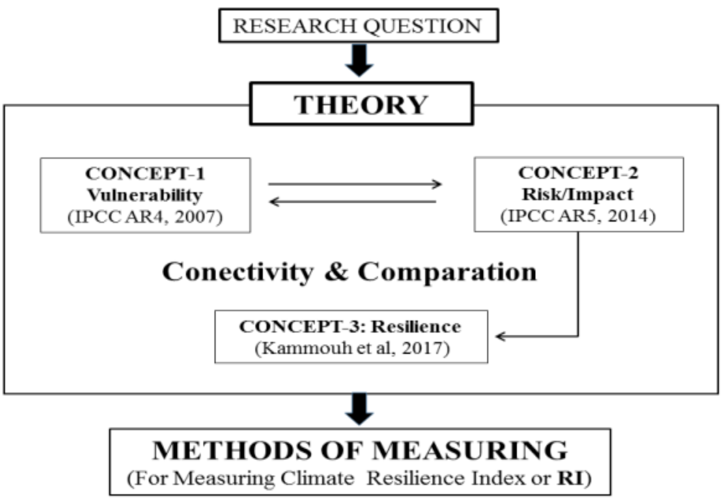


**Figure 1.** Thinking Framework

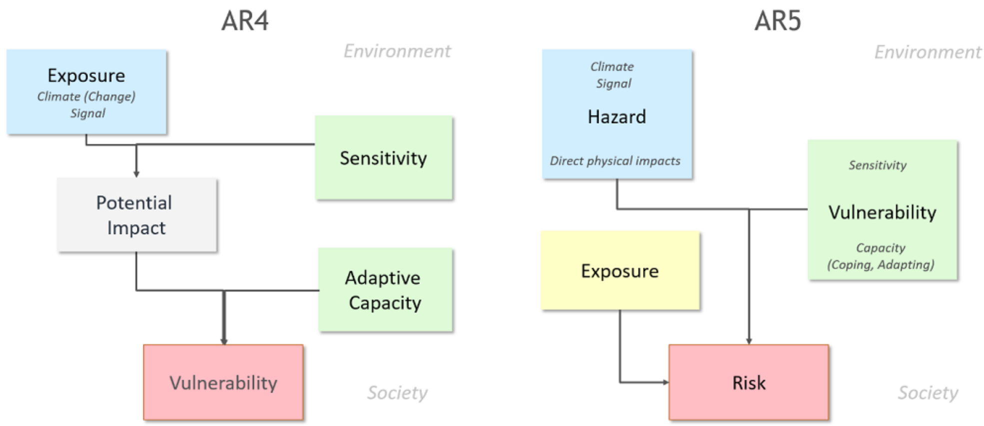


**Figure 2.** Vulnerability Concept

*2.1 Vulnerability and risk concept*

Vulnerability indicates the ease of an affected system or the inability to deal with the adverse effects of climate change, including climate variability and extreme weather. Referring to IPCC AR4 (2007), the concept of vulnerability is influenced by exposure, sensitivity, and adaptive capacity (Figure 2).

Vulnerability (V) can be described mathematically (Metzger *et al*, 2006; IPCC, 2007) as a function of E= exposure, S= sensitivity, and AC= adaptive capacity:

$$V = f(E, S, AC) \qquad (1)$$

The function can be formulated in the form of mathematical equations (UNU-EHS, 2006) to be:

$$V = (E*S)/AC \qquad (2)$$

Furthermore; Polsky *et al* (2007) has developed a vulnerability index measurement (VI) based on an exposure index (EI), sensitivity index (SI), and adaptive capacity index (ACI) with the equation:

$$VI = (EI*SI)/ACI \qquad (3)$$

From equation (2), a system becomes more vulnerable when its level of exposure and its sensitivity to disturbance (climate change/extreme weather) increases, while its capacity and opportunities for adaptation are reduced/low. Similarly with equation 2, the vulnerability index (equation 3) is determined by the values of EI, SI, and ACI.

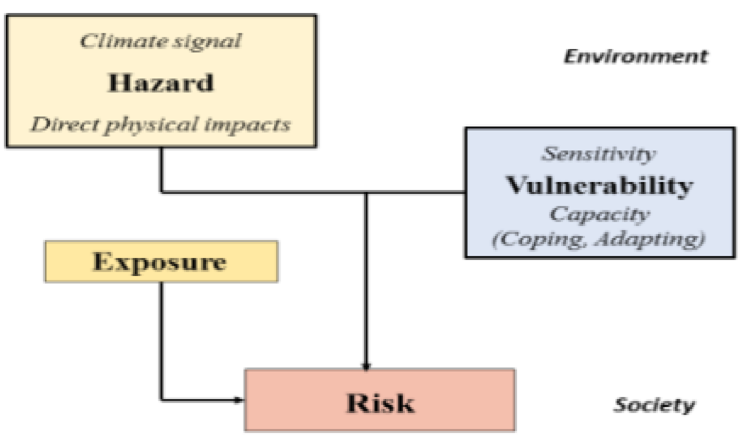


**Figure 3.** Climate Risk Concept

The IPCC has made changes from the vulnerability approach (IPCC AR4, 2007) to risk approach (IPCC AR5, 2014); wherein AR5 the exposure aspect is separated from vulnerability (Figure 3). The separation of exposure from vulnerability is based more on the notion that although a system is not exposed to disturbance, it still has a degree of vulnerability, as well as an effort to integrate climate change adaptation and disaster risk reduction. As a consequence of the change of AR4 to AR5 then the mathematical equation of vulnerability (equation 2) is no longer relevant and is formulated as:

$$V = S/AC \qquad (4)$$

Similarly, the measurement of vulnerability index (VI); is only the result of the comparison between the sensitivity index (SI) and adaptive capacity index (ACI):

$$VI = SI/ACI \qquad (5)$$

Meanwhile, climate risk/impact (IPCC, 2014) can be formulated as a result of multiplication between exposure (E), hazard (H), and vulnerability (V):

$$R_{isk} = E*H*V \qquad (6)$$

*2.2 Resilience concept*

The concept of resilience was first introduced by physical scientists to show the characteristics of spring to describe the stability of the material and its resilience to external shocks (Davoudi, 2012). In subsequent developments, in the 1960s, the concept of resilience was used in the ecological field (Holing, 1973). The concept of resilience was also developed in the social field, first introduced by Adger (2000); social resilience is seen as the community's ability to withstand external disturbances to infrastructure conditions. The interaction between the natural (ecological) system and the human (social) system is known as the Socio-Ecological System (SES) (Anderies *et al*, 2004).

Climate signal and direct physical impacts (hazard) that occur within both social and ecological systems require adaptation, so the impact can be minimized. Adaptability in socio-ecological systems is often known as resilience (Folke, 2006; Lloyd *et al*, 2013). The meaning of adaptation and resilience is often equated, while adaptations are related to actors, policies, and activities; while resilience is associated with thinking systems (Nelson *et al*, 2007). In the context of climate change, resilience often associates with "adaptation"; while in disaster, risk replaces "vulnerability reduction".

## 3. Development of climate resilience index

In the issues related to climate change, The IPCC plays a role in conducting assessments and makes scientific decisions, providing relevant technical information and understanding of potential risks/impacts and response options. The IPCC makes an assessment report based on scientific literature published by the experts. As a consequence, the assessment report (AR) issued by the IPCC still provides space for comment or rejection from experts who pursue the field of climate. The report of the review is only for a relevant policy (the material of consideration), not guidance or a provision (prescriptive).

*3.1 Resilience: risk management approach*

There is a link between risk assessment and resilience. In the context of risk, resilience can be viewed as a complement and an alternative to conventional risk management (Linkov *et al*, 2016). In this study, the second view where resilience is used as an alternative to risk assessment. The comparison between risk and resilience (Kammouh *et al*, 2017) that aligns with the "vulnerability" in risk assessment with "intrinsic resilience" in resilience study's results in a separate consequence (methods) when applied to the discussion of resilience related to climate change.

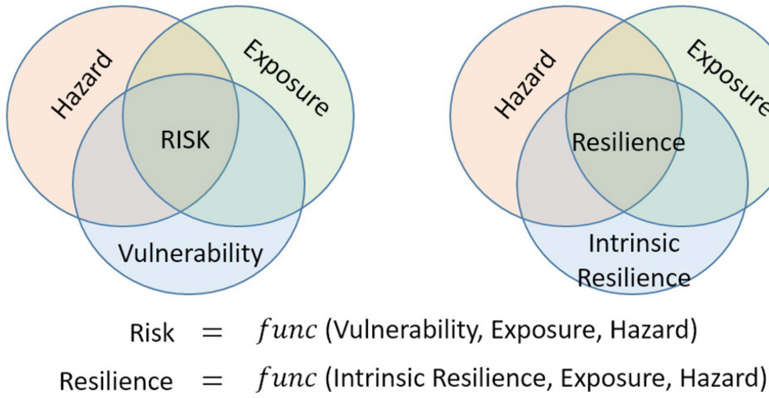


**Figure 4.** The Concept of risk and resilience

The risk is a function of vulnerability, exposure, and hazard; while resilience is a function of intrinsic resilience, exposure and hazard (Figure 4). Resilience is visualized as the ability to recover after hazard events; so independent of whatever type of extreme events (Bogardi and Fekete, 2018). The incidence caused by climate change (including extreme weather) is largely determined by the ability of the community that is related to experience and its participation in the face of disturbance. By assuming a hazard of one value, then the resilience measurement is determined by exposure and intrinsic resilience. In the following discussion, it is shown that the concept of resilience emphasizes on the system's ability to adapt and transform.

*3.2 Factors to build resilience*

The concept of resilience in Fig. 4, when used to assess resilience related to climate can be matched by the risk assessment of IPCC AR5 (2014). The number of resilience forming factors is similar to the risk; the difference in the dimensions of "vulnerability" and "intrinsic resilience". Resilience includes hazard, intrinsic resilience, and exposure. Intrinsic resilience itself is an existing condition and is owned by a socio-ecological system in the face of various hazards.

Sensitivity factors of vulnerability (Figure 5a) should be replaced by other indicators that have the opposite meaning. In this study, "survival" terminology is used as part of intrinsic resilience (Figure 5b). Survival is an internal condition that is owned or attached to the system and shows the degree of toughness to the disturbance, influenced by the experience and the capacity of the community in the face of climate disturbance (climate change and extreme weather). In addition to be influenced by coping/adapting capacity and to be more resilient in the face of future climate disturbances, it needs to be sustained by the ability to make changes (transformative capacity).

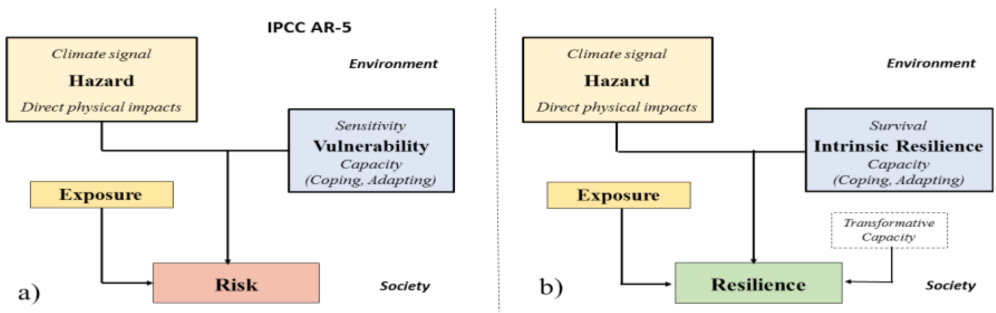


**Figure 5.** Comparison of Risk (a) and Resilience (b)

Base on Fig. 5b, the measurement of the resilience index can be determined by the level of exposure and intrinsic resilience. The addition of the transformative capacity factor is important when it wants to know the effectiveness and role of government (including community participation) in making changes to better conditions. Governance and politics are the fundamental importance to understanding and analyzing the transformation (Patterson *et al*, 2017). The transformative capacity is at once an advantage of the concept of resilience compared to vulnerability and risk. It can be said that resilience is more assured in the face of various uncertainties in the future.

## 4. Methods for measuring climate resilience index

From the description of the concept of vulnerability, risk, and resilience; the measurement of climate resilience index can be done in two ways (methods). The first method is by altering the dimension of sensitivity with the internal resistance (survival) that has been embedded in the system (Figure 6). Assuming the hazard is worth "1" (one), the measurement of climate resilience index (RI) can be obtained from the calculation of exposure index (EI), intrinsic resilience index ($R_iI$), adaptive capacity index (ACI) and transformative capacity index (TCI). The intrinsic resilience ($R_i$) is composed of survival ($S_v$) and adaptative capacity (AC) factor. The addition of transformative capacity (TC) factor is used to enhance future resilience by including the role of government and civil society.

$$R_iI = S_vI*ACI \qquad (7)$$

When adding the transformative capacity, then the equation becomes:

$$R_iI = S_vI*(ACI+TCI) \qquad (8)$$

Sv, AC, and TC are positively correlated to climate resilience, while exposure (E) is negatively correlated; so the final result of the measurement is calculated by the equation:

$$RI_1 = (R_iI*TCI)/EI \qquad (9)$$

As another alternative or second method (Figure 7), by using sensitivity (S) that is part of the vulnerability, it can be done by developing equation 5 (or VI= SI/ACI) by reversing (vulnerability and resilience are inversely proportional) and add exposure dimension (E):

$$RI_2 = (ACI*TCI)/(EI*SI) \qquad (10)$$

### *4.1 Selecting climate resilience indicators*

Connectivity factors are forming vulnerabilities, risks, and resilience (Figure 8), clarified in the determination of climate resilience indicators. Indicators to illustrate hazard are obtained from the hazard (in AR5) or exposure (in AR4). Indicators for invulnerability are derived from a vulnerability in AR5 (or sensitivity and adaptive capacity in AR4); while the indicator for non-exposure is obtained from the exposure criteria in AR5.

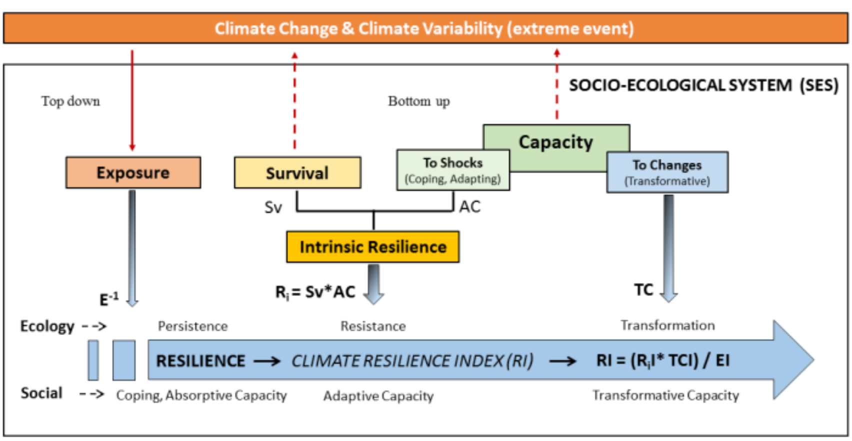


**Figure 6.** First framework ($RI_1$)

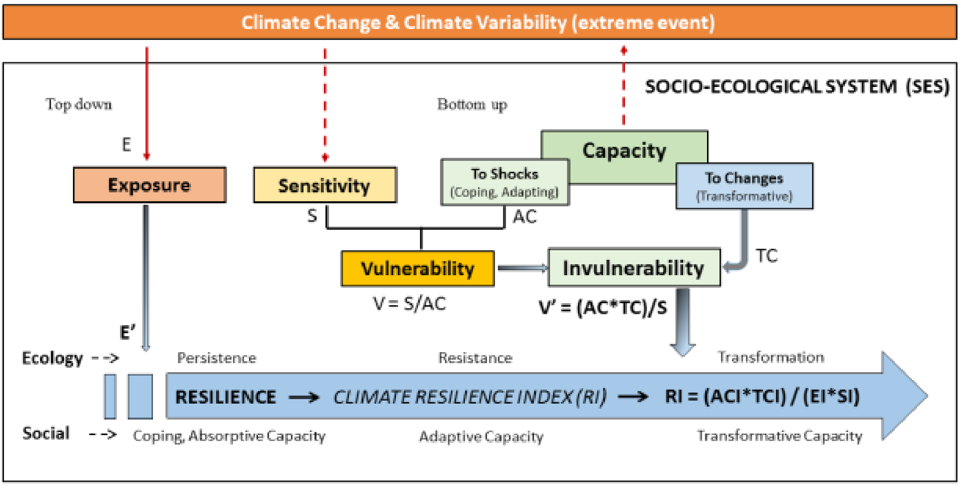


**Figure 7.** Second framework ($RI_2$)

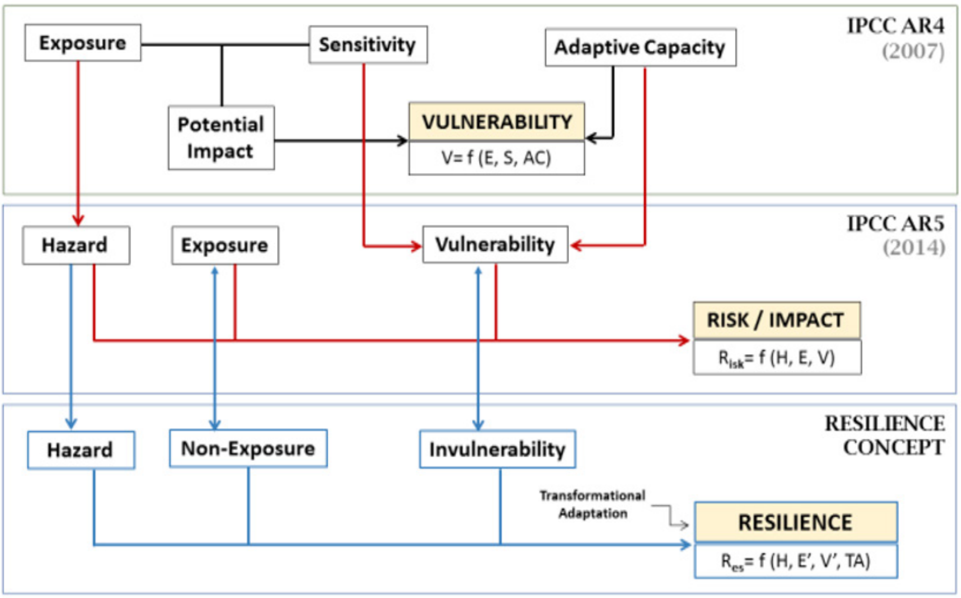


**Figure 8.** Connectivity factors

Selection of climate resilience indicators based on the criteria of each factor, are as follows:

a. **Hazard:** The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term *hazard* usually refers to climate-related physical events or trends or their physical impacts (the same definition of exposure in IPCC AR4, 2007).

b. **Exposure:** The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected. (New factor in AR5 and not the same as the exposure definition in AR4).

c. **Sensitivity:** An internal condition of the system indicating its degree of susceptibility to interference (IPCC AR4, 2007).

d. **Adaptation:** The process of adjustment to the actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC AR5, 2014).

***Incremental adaptation:*** Adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale (IPCC AR5, 2014).

***Transformational adaptation:*** Adaptation that changes the fundamental attributes of a system in response to climate and its effects (IPCC AR5, 2014).

Although transformational adaptation has appeared on AR5, it is still rarely used in climate risk assessment. Meanwhile, transformational is an important factor and can be applied to the concept of resilience (Hölscher *et al,* 2018). The three spheres of transformation (Figure 9) include: *First,* Practical: behavioral changes and technological innovations; *Second,* Political: systems and structures that create the conditions for transformations in the practical sphere; and *Third*, Personal: individual and collective beliefs, values, worldviews, and paradigms that shape the ways that influence what types of solutions are considered "possible" (O´Brien and Sygna, 2013). Furthermore, based on the criteria each of these factors is used as a basis in setting key indicators (see attachment 1).

*4.2 Weighting and scaling indicators*

One of the approaches in determining the index is through the method of weighting and scaling indicators to produce a particular score. To produce a single index, the indicators are standardized into the same unit (Bossel, 1999). Single index on each factor can be obtained from the equation:

$$\text{Index} = \text{weight} \times \text{scale} \quad (11)$$

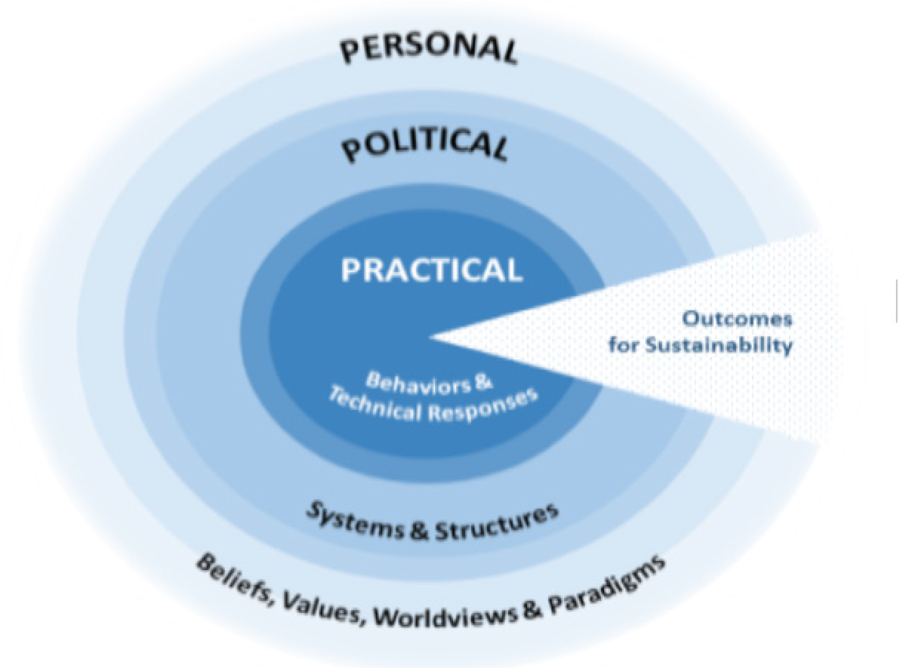


**Figure 9.** The three spheres of transformation

Weight determination was performed by the Analytical Hierarchy Process (AHP) (Saaty, 2005). The AHP analysis is used to derive the determinant and most influential factors that will later be scored to obtain a climate resilience index, which is a function of exposure, sensitivity, adaptive capacity and transformation capacity. The AHP analysis technique is performed on these four factors separately. The complete AHP stages are as follows:

1. Preparation of hierarchical model on each indicator (exposure, sensitivity, adaptive capacity, and transformative capacity).
2. Making the comparator field pairwise between variables (matrix in pairs).
3. Synthesis comparison to get priority (normalization test).
4. Consistency test is by using the value of consistency ratio (CR) if CR ≤ 0.1 then it is stated as consistent.

Referring to the scaling done by Doukakis (2005), 5 levels are used; namely: very low (scale 1), low (scale 2), medium (scale 3), high (scale 4), and very high (scale 5). In order to generate an index, each indicator of the resilience factor (exposure, sensitivity, adaptive capacity, and transformative capacity) is scaled between 1 and 5 (see attachment 2).

*4.3 Types of resilience*

The formula that is recommended to be implemented is the second method [$RI_2$=(ACI*TCI)/ (EI*SI)], on the premise that between vulnerability and resilience there are opposite meanings. RI is basically an inversion development (reversal of position) from the mathematical equation about vulnerability index (VI=(EI*SI)/ACI). In accordance with the equation $RI_2$ = (ACI*TCI)/(EI*SI), the lowest climate resilient indices up to the highest is:

The lowest climate resilience index (RI minimum) is obtained from ACI=1, TCI=1, EI=5, and SI=5 so that:

$$RI_{min} = (ACI_{min} x TCI_{min})/(EI_{max} x SI_{max}) = (1x1)/(5x5) = 1/25 = 0.04$$

The highest climate resilience index (RI maximum) is obtained from ACI= 5, TCI = 5, EI=1, and SI= 1 so that:

$$RI_{max} = (ACI_{max} x TCI_{max})/(EI_{min} x I_{min}) = (5x5)/(1x1) = 25$$

Based on the interval of $RI_2$, it is then divided into 5 levels (qualitative) so that it is relevant to the determination of the robustness scale which illustrates its correlation with the level of resilience. The advantage of using the same division like this, if each index compiler indicator is low or medium, then the calculation of the index will produce the same qualitative class (low or medium) so that there is consistency between the calculation of index value (quantitative assessment) and qualitative assessment. For this reason, based on qualitative and quantitative considerations, the value ranges of $RI_2$ are set to 5 levels (Table 1), namely: very low, low, moderate, high, and very high.

*4.4 RI at provincial level in Indonesia*

Table 2 is an example of the implementation of RI measurements at the provincial level in Indonesia. Based on the table, RI averages 0.70 in the moderate category. There are 6 provinces that have RI with a lower category (0.1-0.4), namely: East Nusa Tenggara (0.29), West Nusa Tenggara (0.30), West Sulawesi (0.32), Central Sulawesi (0.34), West Papua (0.36), and Lampung (0.37).

## 5. Summary and Conclusions

As a consequence of the change of AR4 to AR5, the function of vulnerability only includes sensitivity and adaptive capacity [V=*f*(S, AC)]. Another consequence is that the measurement of vulnerability index (VI) is only the result of a comparison between the sensitivity index (SI) and adaptive capacity index (ACI) or VI=SI/ACI. There is a linkage between vulnerability, risk, and resilience so that the concept of vulnerability and risk can be used as an entry point in developing climate resilience.

Comparison of the concept of risk and resilience proposed by Kammouh *et al*, (2017) is more appropriate for disaster studies. Meanwhile, vulnerability (in risk) can be aligned with intrinsic resilience (in resilience) but it must be interpreted as survival (non-sensitivity) and adaptive capacity. Explicitly, vulnerability (plus transformative capacity) can be used in measuring resilience by inverting the position (inversion) of the mathematical equation for vulnerability index (VI= (EI*SI)/ACI) with the result that $RI_1$= ($R_1$I*TCI)/EI or $RI_2$= (ACI*TCI)/(EI*SI).

From the two RI measurement methods, the second method ($RI_2$) is recommended to carry out in measuring climate resilience index. In the case at the provincial level in Indonesia, the results showed that the average RI is 0.70; the highest was Jakarta SCR (1.61) and the lowest was East Nusa Tenggara (0.29). In other words, East Nusa Tenggara has to be the first priority of development in facing the climate change threat.

**Table 1.** Resilience category

| | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| **Qualitative** | **1** | **2** | **3** | **4** | **5** |
| Range (%) | 0– 12.5 | 12.5– 37. | 37.5– 62.5 | 62.5– 87. | 87.5- 100 |
| **Index value** | | | | | |
| $RI_2$ | 0.04– 0.1 | .1– 0.4 | 0.4–2.2 | 2.2–1.2 | 11.2– 25 |

**Table 2.** RI at provincial level in Indonesia

| No. | Province | Index of each factor | | | | **RI** | **$R_k$** |
|---|---|---|---|---|---|---|---|
| | | EI | SI | ACI | TCI | | |
| 1. | Aceh | 2.65 | 2.85 | 2.34 | 2.24 | 0.70 | 12 |
| 2. | North Sumatra | 2.61 | 3.18 | 3.48 | 2.01 | 0.84 | 8 |
| 3. | West Sumatra | 3.22 | 2.42 | 3.42 | 1.65 | 0.72 | 11 |
| 4. | Riau | 2.35 | 2.90 | 2.80 | 2.20 | 0.90 | 7 |
| 5. | Jambi | 2.83 | 2.64 | 2.63 | 1.48 | 0.52 | 18 |
| 6. | South Sumatra | 2.33 | 3.17 | 2.41 | 1.74 | 0.57 | 17 |
| 7. | Bengkulu | 2.18 | 2.62 | 2.38 | 1.77 | 0.74 | 10 |
| 8. | Lampung | 2.26 | 2.95 | 2.71 | 0.92 | 0.37 | 22 |
| 9. | Bangka Belitung | 1.96 | 2.96 | 3.70 | 1.91 | 1.22 | 3 |
| 10. | Riau Islands | 2.33 | 2.82 | 3.21 | 2.24 | 1.10 | 5 |
| 11. | Jakarta SCR | 2.38 | 3.00 | 4.29 | 2.67 | 1.61 | 1 |
| 12. | West Java | 2.92 | 3.41 | 3.25 | 1.86 | 0.61 | 15 |
| 13. | Central Java | 2.85 | 3.07 | 3.14 | 1.59 | 0.57 | 17 |
| 14. | Yogyakarta SR | 3.03 | 2.81 | 4.06 | 2.43 | 1.16 | 4 |
| 15. | East Java | 2.36 | 3.14 | 3.17 | 1.93 | 0.82 | 9 |
| 16. | Banten | 2.70 | 3.24 | 2.86 | 1.81 | 0.59 | 16 |
| 17. | Bali | 3.02 | 2.75 | 3.27 | 2.13 | 0.84 | 8 |
| 18. | West N. Tenggara | 3.37 | 2.71 | 2.62 | 1.05 | 0.30 | 26 |
| 19. | East N. Tenggara | 2.84 | 3.22 | 2.03 | 1.31 | 0.29 | 27 |
| 20. | West Kalimantan | 2.40 | 2.69 | 2.45 | 1.61 | 0.61 | 15 |
| 21. | Central Kalimanta | 2.64 | 2.53 | 2.42 | 1.63 | 0.59 | 16 |
| 22. | South Kalimantan | 2.62 | 2.94 | 2.71 | 1.91 | 0.67 | 14 |
| 23. | East Kalimantan | 2.68 | 2.50 | 3.17 | 2.70 | 1.28 | 2 |
| 24. | North Kalimantan | 2.53 | 2.64 | 2.82 | 2.24 | 0.95 | 6 |
| 25. | North Sulawesi | 3.62 | 2.60 | 2.61 | 2.48 | 0.69 | 13 |
| 26. | Central Sulawesi | 3.40 | 3.00 | 2.92 | 1.20 | 0.34 | 24 |
| 27. | South Sulawesi | 3.02 | 2.34 | 2.80 | 2.27 | 0.90 | 7 |
| 28. | Southeast Sulawes | 2.47 | 2.52 | 2.39 | 1.88 | 0.72 | 11 |
| 29. | Gorontalo | 3.29 | 2.52 | 3.06 | 1.35 | 0.50 | 19 |
| 30. | West Sulawesi | 3.81 | 2.89 | 2.42 | 1.44 | 0.32 | 25 |
| 31. | Maluku | 2.54 | 2.56 | 2.42 | 1.63 | 0.61 | 15 |
| 32. | North Maluku | 2.40 | 2.58 | 2.31 | 1.30 | 0.48 | 20 |
| 33. | West Papua | 2.68 | 2.04 | 2.19 | 0.89 | 0.36 | 23 |
| 34. | Papua | 2.68 | 2.85 | 2.14 | 1.55 | 0.44 | 21 |
| | **National Average** | 2.84 | 1.79 | 2.73 | 2.79 | 0.70 | |

## Acknowledgements

The researcher would like to thank to the Indonesia Endowment Fund for Education (LPDP) as an institution that financed this research and also the Department of Geophysics and Meteorology, Bogor Agricultural University (IPB) that give much support to researchers.

### References

Adger WN. Social and ecological resilience: Are they related? Progress in Human Geography 2000; 24 (3): 347-364. doi: 10.1191/030913200701 540465

Anderies JM, Jansen MA, Ostrom E. A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society 2004; 9 (1): 18-27. doi: 10.5751/ES-00610-090118

Béné C. Towards a Quantifiable Measure of Resilience. IDS Working Paper 2013; 434: 27 pp. doi: 10.1111/j.2040-0209.2013.00434.x

Bogardi JJ, Fekete A. Disaster-Related Resilience as Ability and Process: A Concept Guiding the analysis of Response Behavior Before, During and After Extreme Events. American Journal of Climate Change 2018; 7: 54-78. doi: 10.4236/ajcc.2018.71006

Bossel H. Indicators for Sustainable Development: Theory, Method, Applications. Canada: International Institute for Sustainable Development (IISD), 1999.

Davoudi S. Resilience: a bridging concept or a dead end?. Planning Theory and Practice 2012; 13 (2): 299–333. doi: 10.1080/14649357.2012.677124

Doukakis E. Coastal vulnerability and risk parameter. European Water 2005; 11/12: 3-7.

Folke C. Resilience: The emergence of a perspective for social-ecological systems analyses. Global Environmental Change 2006; 16 (3): 253-267. doi: 10.1016/j.gloenvcha. 2006.04.002

Holling CS. Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics 1973; 4: 1-23. doi: 10.1146/annurev.es.04. 110173.000245

Hölscher K. Wittmayer JM, Loorbach D, Transition versus transformation: What's the difference?. Environmental Innovation and Societal Transitions; 2018: 27: 1-3.

Hoy WK, Miskel CG. Educational administration: Theory, research, and practice, 9th edition. New York: McGraw-Hill, 2013.

IPCC. Climate Change: Impact, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the IPCC, Cambridge, UK: Cambridge University Press, 2007.

IPCC. Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 2014; p. 117-130.

Kammouh O, Dervishaj G, Cimellaro GP. A new resilience rating system for Countries and State. Procedia Engineering 2017; 198: 985-998. doi: 10.1016/j.proeng.2017.07.144

Linkov I, Trump BD, Fox-Lent C. Resilience: Approaches to risk analysis and governance an introduction to the IRGC resource guide on resilience 2016. doi:10.5075/epfl-irgc-228206

Lloyd MG, Peel D, Duck RW. Toward a social-ecological resilience framework for coastal planning. Land Use Policy 2013; 30: 925-933. doi: 10.1016/j.landusepol.2012.06.012

Malone EL. Vulnerability and Resilience in the Face of Climate Change: Current Research and Needs for Population Information. Battelle Pacific Northwest Division (PNWD-4087), Richland, Washington, 2009. http://pai.org/wp-content/uploads/2009/08/Malone_resilience.pdf

Mardalis. Qualitative research methods (a proposal approach). Jakarta: Bumi Aksara Indonesia, 2003. (in Indonesian).

Metzger MJ, Rounsevell MDA, Acosta-Michlik L, Leemans L, Schröter L. The vulnerability of ecosystem services to land use change. Agriculture, Ecosystems and Environment 2006; 114: 69-85. doi: 10.1016/j.agee.2005.11.025

Nelson DR, Adger WN, Brown K. Adaptation to Environmental Change: Contributions of a Resilience Framework, Annual Review of Environment and Resources 2007; 32: 395-419. doi: 10.1146/annurev.energy.32.051807.09034

O´Brien K, Sygna L. Responding to climate change: The three spheres of transformation in: Proceedings of Transformation in a Changing Climate, 19-21 June 2013, Oslo, Norway. University of Oslo. p:16-23.

Patterson J, Schulz K, Vervoort J, Van der Hel S, Widerberg O, Adler C, Hurlbert M, Anderson K, Sethi M, Barau A. Exploring the governance and politics of transformations towards sustainability. Environmental Innovation and Societal Transitions 2017; 24: 1-16. doi: 10.1016/j.eist.2016.09.001

Polsky C, Neff R, Yarnal B. Building comparable global change vulnerability assessment: The vulnerability scoping diagram. Global Environmental Change 2007; 17: 472-48. doi: 10.1016/j.gloenvcha.2007. 01.005

Saaty TL. Theory and Applications of the Analytic Network Process, Pittsburgh, PA: RWS Publications, 2005.

Umar H. Administrative science research method. Jakarta: Gramedia Pustaka Utama, Indonesia, 2004. (in Indonesian)

UNU-EHS. Vulnerability: A conceptual and methodological review. Source No. 4/2006. http://collections.unu.edu/eserv/unu:1871/pdf3904.pdf

**Attachment 1.** Indicators of RI at provincial level

| Factors | Sectors | Code | Indicators |
|---|---|---|---|
| Exposure | Geography and demography | POP | Population density (people/km$^2$) |
| | | WAF | The population works in the agriculture and fisheries sector (%) |
| | | APF | The area of paddy fields (%) |
| | | PLA | Plantation land area (%) |
| | | VRB | Number of villages on the riverbanks (%) |
| | | TVS | Residential topography in valleys and slopes (%) |
| | | SES | Location of settlements on the edge of the sea (%) |
| Sensitivity | Settlements/ Infrastructure | EHD | Settlements experienced hydro meteorological disasters (%) |
| | | OAC | Occupancy area <7.2 m$^2$ per capita (%) |
| | | ACW | Access to clean drinking water (%) |
| | | ASF | Access to sanitation facilities (%) |
| | Food Security | CAL | Calorie intake <1400 calorie (%) |
| | | PCP | Protein consumption per capita/day (gram) |
| | Ecosystem | VEP | Number of villages experiencing environmental pollution (%) |
| | | AQI | Air Quality Index (%) |
| | | FCA | Proportion of forest cover in total area (%) |
| | Health | DFP | Dengue fever per 100.000 population |
| | | PHC | Percentage of population who has health complaints |
| | | TMB | Toddler mortality rate per 1000 births |
| | Water sources | WCA | Percentage of households and the presence of water catchment areas |
| | | AMR | Average monthly rainfall (mm) |
| | Agriculture & fisheries sector | RCP | Rice productivity (Quintal/ha) |
| | | AQP | Aquaculture productivity (tons/ha) |
| Incremental Adaptation | Economy | GDP | GDP ratio |
| | | GIN | Gini Ratio |
| | | VSI | Number of villages that have small or medium industries |
| | Human resource | HDI | Human Development Index |
| | | WPR | Workforce participation rate (%) |
| | | LSL | Level of satisfaction with 10 aspects of life (%) |
| | Environment and facilities / infrastructure | RBE | Percentage of Regional Government Budget for the environment |
| | | HSE | Households served by electricity (%) |
| | | RLA | The ratio of road length to area |
| | | SFE | Safety equipment |
| Transformational Adaptation | Practical | CCD | Construction of containment dams |
| | | NCC | Number of construction companies (large groups) |
| | Political | IDI | Indonesian Democracy Index |
| | | WIP | The involvement of women in parliament (%) |
| | | CPI | Corruption Perception Index |
| | Personal | RCP | Rural residents who use cell phones (%) |
| | | INT | The proportion of individuals who access the internet |
| | | NBM | The proportion of individuals who read newspapers/books/ magazines |

**Attachment 2.** Weighting and scaling indicators

| Code | Weight | Scale | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| **NON-EXPOSURE** | | | | | | |
| POP | 0.049 | > 200 | 800-1199 | 200-799 | 100-199 | < 100 |
| WAF | 0.120 | >40 | 30.1-40 | 20.1-30 | 10.1-20 | ≤10 |
| APF | 0.088 | >26 | 19.1-26 | 12.1-19 | 5.1-12 | ≤5 |
| PLA | 0.066 | >26 | 19.1-26 | 12.1-19 | 5.1-12 | ≤5 |
| VRB | 0.295 | > 40 | 30 - 40 | 20 - 30 | 10 - 20 | ≤ 10 |
| TVS | 0.219 | > 40 | 30 - 40 | 20 - 30 | 10 - 20 | ≤ 10 |
| SES | 0.163 | > 40 | 30 - 40 | 20 - 30 | 10 - 20 | ≤ 10 |
| **NON-SENSITIVITY** | | | | | | |
| EHD | 0.135 | >10.1 | 7.5-10.1 | 5.1-7.5 | 2.5-5.1 | ≤2.5 |
| OAC | 0.028 | >26 | 19.1-26 | 12.1-19 | 5.1-12 | ≤5 |
| ACW | 0.073 | <40 | 40-55 | 55-70 | 70-85 | >85 |
| ASF | 0.031 | <40 | 40-55 | 55-70 | 70-85 | >85 |
| CAL | 0.046 | >20 | 15-20 | 10-15 | 5-10 | <5 |
| PCP | 0.038 | <55 | 55-60 | 60-65 | 65-70 | >70 |
| VEP | 0.017 | >45 | 35-45 | 25-35 | 15-25 | <15 |
| AQI | 0.053 | <60 | 60-70 | 70-80 | 80-90 | 90-100 |
| FCA | 0.154 | <20 | 20-40 | 40-60 | 60-80 | >80 |
| DFP | 0.063 | >80 | 60-80 | 40-60 | 20-40 | <20 |
| PHC | 0.020 | >30 | 26-30 | 21-25 | 15-20 | <15 |
| TMB | 0.022 | >80 | 60-80 | 40-60 | 20-40 | <20 |
| WCA | 0.115 | <20 | 20-40 | 30-40 | 40-50 | >50 |
| AMR | 0.101 | <100 | 100-150 | 150-250 | 200-250 | >250 |
| RCP | 0.087 | <40 | 40-50 | 50-60 | 60-70 | >70 |
| AQP | 0.015 | <5 | 5-15 | 15-25 | 25-35 | >35 |
| **INCREMENTAL ADAPTATION** | | | | | | |
| GDP | 0.072 | < 10 | 10-20 | 20-30 | 30-40 | >40 |
| GIN | 0.154 | >0.45 | 0.40-0.45 | 0.35-0.40 | 0.30-0.35 | <0.30 |
| VSI | 0.092 | <0.5 | 0.51-1.0 | 1.0-1.5 | 1.5-2.0 | >2.0 |
| HDI | 0.189 | <65 | 65-70 | 70-75 | 75-80 | >80 |
| WPR | 0.115 | ≤ 60 | 60-65 | 65-70 | 70-75 | > 75 |
| LSL | 0.025 | <66 | 66-69 | 69-72 | 72-75 | >75 |
| RBE | 0.230 | <0.2 | 0.2-0.6 | 0.6-1.0 | 1.1-1.4 | >1.4 |
| HSE | 0.031 | <80 | 80-85 | 85-90 | 90-95 | > 95 |
| RLA | 0.052 | <0.2 | 0.2-0.5 | 0.5-0.8 | 0.8-1.1 | >1.1 |
| SFE | 0.039 | <1.5 | 1.5-2.5 | 2.5-3.5 | 3.5-4.5 | >4.5 |
| **TRANSFORMATIONAL ADAPTATION** | | | | | | |
| CCD | 0.052 | ≤ 25 | 25-50 | 50-70 | 75-100 | >100 |
| NCC | 0.040 | ≤ 1.6 | 1.6-2.5 | 2.6-3.5 | 3.6-4.5 | >4.5 |
| IDI | 0.066 | ≤ 64 | 64-68 | 68-72 | 73-77 | > 77 |
| WIP | 0.118 | < 5 | 5-15 | 15-25 | 25-35 | >35 |
| CPI | 0.091 | < 4 | 4.1-5 | 5.1-6.0 | 6.1-7.0 | > 7 |
| RCP | 0.154 | ≤15 | 15.1-20 | 20.1-25 | 25.1-30 | >30 |
| INT | 0.274 | <17 | 17-22 | 22.1-27 | 27.1-32 | >32 |
| NBM | 0.206 | <24 | 24-28 | 28.1-32 | 32.1-36 | >36 |