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# Ecosystem Vulnerability Assessment under Climate Crisis: A Review

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**Abstract:** Climate affects every aspect of life on planet earth in a way that our existence is so dependent upon the climate and various processes driven by climate. Anthropogenic induced changing climatic conditions unprecedently altering global ecosystems. Anomalies in ecosystem processes including water and nutrient cycling and community dynamics are evident in agricultural as well as natural ecosystems. These abnormalities could have far-reaching implications at regional and global scales. Vulnerability is based on exposure and sensitivity of human and their systems; whereas adaptations are result of adjustments under susceptibility. Increased intensity, duration and frequency of extreme events, including heatwave, drought, flood etc will increase vulnerability of various ecosystems and biodiversity; even some ecosystems may face severe threats to their existence. Strict adaptation strategies may require on priority basis to save climate risk prone areas under scenario of changing climatic conditions. Afforestation considering environmental suitability and land competition issues may help to recover forest loss. The predicted impacts suggested regional strategies may require climate change adaptation and sustainable ecosystem management.

**Keywords:** Biodiversity; ecological system; climate change; sustainable development.

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## 1 Introduction

Fifth assessment report issued by Intergovernmental Panel on Climate Change has identified that human beings are interfering in the natural systems producing distinct changes in climate (Pachauri et al., 2014). The major determinants of climate change impacts are from higher exposure and vulnerability to climate related hazards. Socio-ecological systems recognize societies and their ecosystem as interconnected in their functions. People do not live in isolation; they have their dependence on the system they live in. In 21st century, vulnerability of different ecosystems is exacerbated due to climatic changes and low adaptive capacities of people (MEA, 2005). Although it is not certain how climate will affect different systems, but few known facts are proving that it is the single most aspect to influence life and livelihood in so many ways (Team et al., 2007). Most importantly climate is affecting additionally to the most vulnerable. Scientist has accepted that climate is influencing life on planet earth by changing rainfall pattern, weather shift and shifts in cropping time, rising sea level, receding glaciers etc. (IPCC 2001; Watson et al. 2001; Case and Lawler, 2016). The global climate risk index for year 2016 has ranked Pakistan on eighth number, stating high climate risk area due to prevailing risk factors and poor adaptation. Different ecosystem and their associated communities will have to adapt and response to changing climate and life (Bardget and vad der Putter, 2014). Climate vulnerability to the forest communities is a question of their survival as it will significantly affect flora distribution, forest productivity, effecting livestock, availability of certain medicines and local market as well (Hanewinkel et al., 2012). Case of agricultural ecosystem is not so different. Most of the rural population generally involved in agriculture and it is by far biggest and single source of income to them. Climate variability can influence negatively significant to the agricultural productivity and related economic activities hence threatening their livelihood

(Tilman et al., 2002; Tomich, 2011; Liang et al., 2015). Climate is infecting coastal communities as well; several studies have reported a downward shift due to rise in sea level and unpredicted changes (Salik et al., 2015; Khan, et al., 2008).

IPCC has explained climate change as a constant risk to human beings and their livelihood (IPCC, 2001; Watson 2002; Team et al., 2007). Whereas UNFCCC consider climate change attributed to human activities which alter atmospheric composition. There is high confidence in having higher vulnerability of human livelihood due to climate changes (Pachauri et al., 2014). The concepts of vulnerability, sensitivity, exposure, adaptive capacity or adaptation are strongly interconnected and linked to explanation of global changes (Fussel 2005; Fussel and Klein 2004). Vulnerability is function of exposure and sensitivity with adaptive capacity. Vulnerability to a system is degree of perturbation which leads to positive and negative transformation (Adger et al., 2003; Fussel and Klein 2002). The paper looks closely at vulnerability of human and environment system; highlighting life in different ecological setup. The paper has focused to explain the term vulnerability and climate change in different ecosystems where human and nature are linked and affected by positive and negative feedback loops of climate change.

### 1.1 Vulnerability

Vulnerability is defined as a state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt (Adger, 2006). There are basically two types of determinants of vulnerability: generic and specific. Specific determinants of vulnerability depend on the type of hazard and the specific context in where it is being used. For instance the causes of vulnerability to drought of a rural community present in semi-arid Africa will be different from the factors that make Norway, a rich industrialized nation, vulnerable to disastrous weather events such as floods and storms. Similarly their vulnerability will be evaluated using different factors as in this case for assessing the vulnerability of African rural community to drought, income data and isolation will be considered whereas for Norway factors like the efficient allocation of land resources and physical infrastructure shall be taken into account. On the other hand there are certain factors known as the generic determinants of vulnerability like poverty, health conditions, governance and economic differences which are useful in the sense that they help to assess the vulnerability at a national level and thus give a better idea about the vulnerability of a country and its adaptation measures in relation to climate hazards (Brooks et al., 2005; Füssel, 2007).

### 1.2 Component of vulnerability

Studies have supported three components of vulnerability that frame real connotation of the term (Fig. 1). Exposure is an extent when a subject or a system is in contact to the perturbation whereas Sensitivity is degree or extent of disturbance in a system or to a subject due to certain exposure. Adaptive capacity is the ability of a system to adapt of adjusts to a definite disturbance and copes with transformations (Smit et al., 2000; Cutter, 1996). In addition to these three key elements, a comparative analysis of different approaches for explaining vulnerability of a particular area suggests a number of other factors namely temporal variability, various contexts, scale-interdependency along with different scales and dimensions. In the conceptual framework of vulnerability, adaptation and adaptive capacity both play an instrumental role along with resilience (Hufschmidt, 2011). Changes in environment and sustainability science emphasize in depth understanding of the variations in the general functionality and composition of the biosphere. Therefore it is important to identify the extent of vulnerability of areas undergoing such changes. Studies have shown that vulnerability is solely not related to exposure to hazards but also depends largely on the sensitivity and resilience of the system exposed to such stresses (Turner et al., 2003). Proper identification and quantification of the extent of vulnerability of a system can be done using a large number of approaches. This is necessary to explain a variety of interactions involved in determining the vulnerability of a system. A holistic and harmonized approach towards vulnerability determination will be of great significance in reducing the vulnerability of a particular system and will also in turn help the decision makers in taking effective measures in the future (Eakin and Luers, 2006; Kelly and Adger, 2000; Brooks et al., 2005; Adger, 2006; Füssel, 2007; O'Brien et al., 2007; Peduzzi et al., 2009; Preston et al., 2011; Sebesvari et al., 2016).

### 1.3 Dimensions of vulnerability

Literature appraisal has helped in mentioning that for all vulnerability studies, dimensions should be known. Literature has supported three important dimensions i.e., scale, dynamics and diversity to be considered in vulnerability analysis.

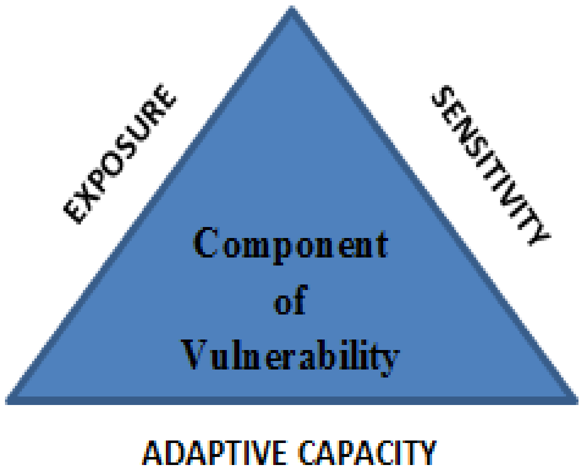


**Fig. 1. Components of Vulnerability**

Most of the vulnerability assessment studies are based on location (a community level), region (Asia, Central America etc.) scalar studies work on a specific area. Studies have highlighted dynamics of vulnerability (Liu et al., 2008; Frank et al., 2011) as an important parameter. In this case, some static variables calculated at global level may be ignored at dynamically coping capacities of a local level e.g. GDP of a country can be used to assess vulnerability at community level. Third dimension is diversity which indicates that measuring community level vulnerability can highlight diversity and heterogeneity of locals and their diverse environment. All these dimensions of vulnerability influence nature and societies living together (Seidl et al., 2011).

### 1.4 Adaptation

Adaptation is a very important factor that will play a crucial role in the climate change impacts regarding food production. Adaptation to the current climate change impacts requires not only minor changes like change in planting dates and crop varieties but rather some huge costly investments like highlighting climate risk prone areas and prioritizing them in order to successfully cope with the changing scenario. This demands cooperation and support from governmental organizations, researchers and farmers but unfortunately this issue has been not given due attention. Results from a study have shown that Southern Africa and South Asia including Pakistan, in absence of adaptation strategies, will have to suffer from severe impacts of climate change in terms of food insecurity (Lobell et al., 2008; Grimm et al., 2016).

## 2. Climate Change Ecology

One of the most difficult and challenging task today is the effective management and reliable prediction of the response at the species level to climate change (Harsch et al., 2017). Changes in phenology and natural distribution of plants and animals have been reported living in a wide range of habitats especially marine,terrestrial and freshwater (Grimm et al., 2016; Räsänen et al., 2016). These changes are chiefly associated with the climate change observed at the local and regional level. Species specifically living on the mountain tops and in polar areas also called range-restricted species have shown to have been harshly affected by the recent wave of anthropogenic climate change as they include many examples where the entire species have been wiped out whereas those like tropical coral reefs and amphibians,who have not become extent are already suffering from the severe negative impacts. In addition to this since species are responding to the global warming differently, resultantly particular interactions between plants and animals are also being affected for example plant-insect associations. Although certain genetic changes have also been observed in response to the climate change but an alarming fact is that this change is insufficient to adapt to the impacts of climate change at the species level (Walther et al., 2002; Parmesan, 2006; Parmesan and Yohe, 2003; Preston et al., 2011; Leroux et al., 2013; Grilli et al., 2017; Runting et al., 2017).

### 2.1 Vulnerability Assessment

The notion of vulnerability to climate change has been addressed and understood differently in numerous disciplines in addition to using varied assessment tools and methodologies. Such a large number of approaches helped a lot in developing different ways of understanding the concept of vulnerability and framing different analytical tools for effective evaluation of vulnerability towards climate change. A detailed analysis of the literature has shown that nine factors are of prime importance in vulnerability assessments viz. differential vulnerability, involving stakeholders, key elements of vulnerability such as exposure, sensitivity and adaptive capacity, human-environment and place-based analysis, various perturbations, different analysis scales, causes of vulnerability and ways how they interact, future analysis based on historical evidence and ways to deal with uncertainty (Soares et al., 2012).

Vulnerability = f (exposure + sensitivity / adaptive capacity) [1]

Since many different approaches are available for evaluating the vulnerability of a particular place to climate variability, one such approach is centralized around the determination of economic and social status of a society under study in order to identify the different aspects that create hindrance in developing effective adaptation and coping strategies. Using this concept of vulnerability, the vulnerability of coastal Vietnam is evaluated using resources availability and their provision to the local individuals (Kelly and Adger, 2000). The idea of vulnerability in the domains of climate science and policy is still developing. Over the course of many years, vulnerability concept and ways of assessments have evolved thus including important non-climatic factors related to climate change which also includes adaptive capacity and a major change of perspective by focusing on reducing the damages instead of merely estimating them (Füssel and Klein, 2006; Eakin and Luers, 2006; Füssel, 2007).

#### 2.1.1 Climate change induced vulnerability of ecosystems

There are many approaches available in literature which helps in assessing indigenous communities' vulnerability from climate change in different ecosystems. Most socio-ecological systems are exposed to and sensitive to changing climate and as a result develop certain adaptive capacities living in different environment (Ahmed and Reid, 2002; Baum et al., 2008; Field 2012). A framework is designed to picturesque the study (Fig. 2).

**Forest Ecosystem:** Importance of ecological services provided by forest is well recognized. Forest dependent communities are significant interest of many vulnerability based studies (Fisher et al., 2010; Seidl et al., 2011). Forest ecosystems are highly exposed to raising temperature and runoff from unpredicted rainfall (FAO, 2001). Satellite data of Earth Observation have highlighted forest loss of 2.3 million $km^2$ from 2000 to 2012, while forest gain observed was very low (0.8 million $km^2$). Forest lost in tropics is recorded at an alarming rate of 2101 $km^2$/year (Hansen et al., 2013). In most of forest, increasing temperature has resulted in pest and insects outbreak on economically important species, other extreme events are wildfires (Logan et al., 2003; Gan, 2004; Parkins and Mackendrick, 2007; Carina and Keskitalo 2008; Kaushik and Khalid, 2011;Lal et al., 2011; Seidl et al., 2011; Rawlani and Sovacool, 2011). Adaptive capacity in forest sector is actually linked with socio-economic of communities where economically better off locals adapt and cope in better way whereas economically weak do not get better coping strategies (Correia et al., 2017). Moreover, a study from the French forest suggest that after witnessing a rise in mean temperature, plant communities are responding by tolerating this change in climate. However, considering the fact that this climate change is expected to increase in the future, the ability of plants to adapt, migrate and withstand such a change is inadequate therefore this poses huge threats for the survival of forest plant communities (Bertrand et al., 2016). Climate change is also responsible for inducing increased aridity which can be devastating for plants and other biotic communities depending on them. One of the highly vulnerable species to climate change is the dioecious species in the sense that the female plants are more sensitive and vulnerable in terms of their gaseous exchange, overall growth and mortality rate as compared to their male counterparts. In addition to this, areas which are most likely to experience highest rates of climate change, male plants were also likely to dominate there. All such changes will definitely affect the general structure and composition of the communities along with the different ecological processes associated with them (Hultine et al., 2016; Mathys et al., 2017; Rogers et al., 2017; Scherrer et al., 2017; Steenberg et al., 2017). Promotion of afforestation considering environmental suitability and land competition issues is an important strategy for climate change mitigation. The predicted impacts suggested regional strategies may require climate change adaptation for forest ecosystem. Regional adjustments are also suggested for the sustainable forest management (Correia et al., 2017).

**Agricultural Ecosystem:** Climate change can be clearly attributed to the human activities on Earth. These activities mainly include use of fossil fuels and agricultural fertilization which adds up surplus amount of reactive nitrogen, about 150 $Tgyr^{-1}$, to Earth's surface (Greaver et al., 2016). Climate is a very crucial factor in the agricultural domain since change in climatic conditions can affect the agricultural productivity in many ways. Climate change calls for interactively assessing and quantifying vulnerability and employing suitable adaptation strategies in Nordic countries as well in order to better cope with the climate change and its disastrous impacts. A tool called Agro Explore was used to map and evaluate the agricultural vulnerability of Sweden to climate change and thus enabled the researchers to find out the factors and indicators of this vulnerability thus helping in effective agricultural management (Wiréhn et al., 2017).

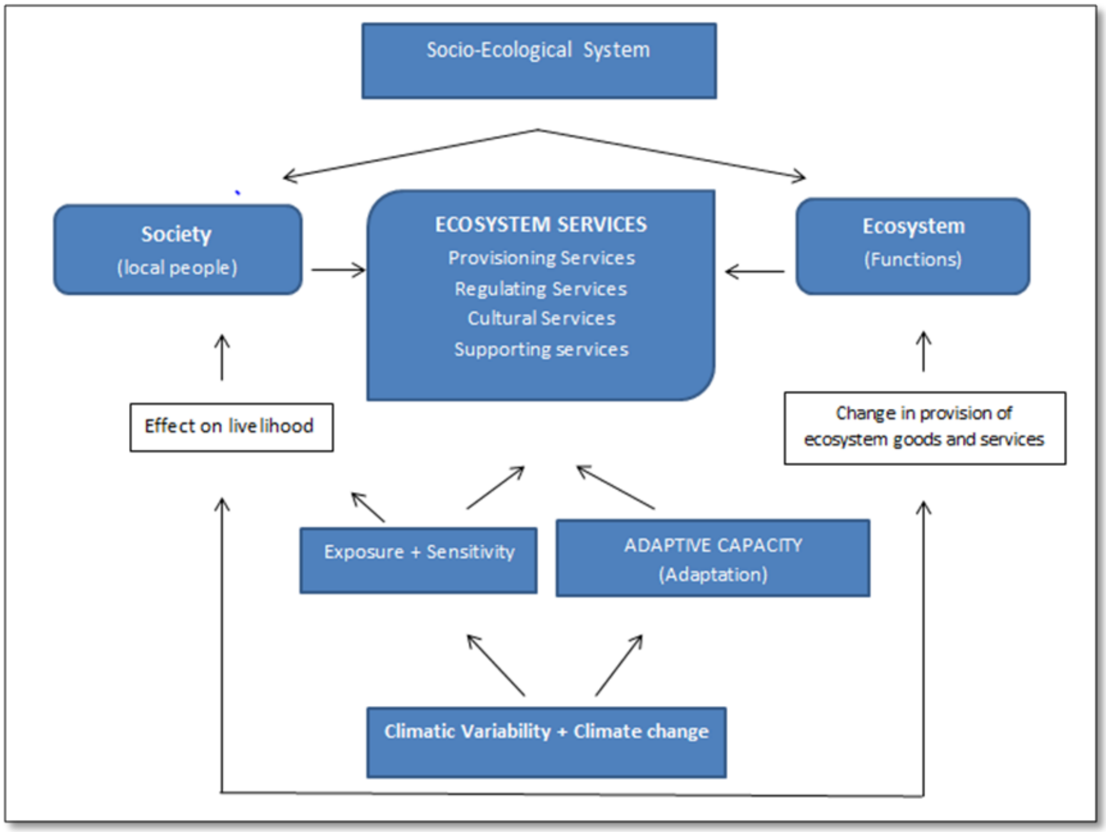


**Fig. 2. Socio Ecological System Nexus Climate Change**

Similarly, climate change has caused the agriculture in Australia to become highly vulnerable. In order to make effective policies for better adaptation of agricultural sector to the current scenario, it is important to identify and apply models for evaluating the vulnerability of this sector on a large scale to climate change (Pearson et al., 2011; Birkmann et al., 2013; Vermaat and Eleveld, 2013; Torres et al., 2015).

**Nutrient cycling:** One of the most prominent threats to the ecological ecosystems is climate change and nutrient cycling. Apparent is nitrogen accumulation resulting from human activities (Dirnböck et al., 2017; Giri and Saxena, 2017; Yuan et al., 2017). Anthropogenic activities causing significant nitrogen build up include excessive use of nitrogenous fertilizers in agriculture and burning of fossil fuels (Galloway et al., 2008; Hungate et al., 2003; Mosier et al., 1998). Although widespread application of nitrogenous fertilizer has caused a tremendous increase in the amount of food produced worldwide but on the other hand it has affected wide range of ecosystems in many ways. Clearly, the addition of this extra nitrogen through the anthropogenic activities has caused a huge change in the structure and working of these ecosystems globally. Moreover, due to global warming and resultant climate change, ecosystems are likely to be stressed due to changes in average temperatures and precipitation patterns in the future. This rise in global temperatures is most likely to change the climate patterns for all regions on Earth by the end of 21st century. Therefore, the cumulative impact of the increase in amount of nitrogen and climate change can have long term effects on the ecosystems and of course on the services that they offer to the humans worldwide (Greaver et al., 2016).

**Water resources and climate:** Water availability and its quality has been most significant issue of changing climate. As climate influence precipitation and temperature of an area that alters the natural water cycle and threaten sustainability. Water sector is highly exposed to extreme conditions like floods or droughts. Various studies have argued that the areas with high latitude will be more vulnerable to changing climate due to more dependence on agriculture and agricultural products for their livelihood (Sánchez et al., 2004; Milly et al., 2005; Team et al., 2007; Evans, 2009; Fussel, 2009). Furthermore, a study conducted using climate models, water budgets and digitized networks of river have found two very important facts firstly, a considerable portion of the world is facing water shortage and secondly increase in demand for water has been predicted for the next 25 years (Vörösmarty et al., 2000). Freshwater having good quality and of ample quantity serves as a very important commodity for fulfilling human and ecosystem needs. This relationship emphasizes the assessment of vulnerability of water using different indices like Scottish Water Quality Index and the Watershed Sustainability Index. Water vulnerability is quite difficult to assess due to the involvement of a wide range of social and biophysical factors but nevertheless the efficiency of these indices can be increased by including explicit indicators which signify adaptation and governance strategies on the part of the society (Plummer et al., 2012).

On the other hand, water released from melting glaciers poses a potential threat apart from flooding. The reason lies in the fact that glaciers release different chemicals into the glacial rivers and contaminate the environment (Nawaz et al., 2016). Polar ice caps are responsible for releasing large quantities of iron thus affecting coastal ecosystems. Presence of chemicals in glaciers has been attributed to different anthropogenic activities of the past for instance Himalayan glaciers and Glaciers of Tibetan Plateau discharge persistent organic pollutants and toxic mercury upon melting. Due to increase in the overall average global temperatures and changes in rainfall patterns resulting in extreme rainfall can accelerate the discharge of water from glaciers thus increasing the probability of release of large amounts of these harmful chemicals. The risk is further exacerbated by the coincident biomass blooms posing a huge threat for the environment. The release of glacial water can acutely damage many local habitats and the people living there but what is more disturbing is the fact that water containing toxic chemicals can have long-lasting effects on even distant environments. Therefore, these risks should be given their due importance while assessing glacial events and the possible disastrous impacts they can have if proper mitigation measures are not considered (Zhang et al., 2017).

**Coastal ecosystems:** Coastal communities are exposed to extreme events such as floods, tsunamis, heat wave and sea level rise. These exposures lead to a higher sensitivity to climate change and unforeseen rainfall. Most of coastal communities have shown low adaptive capacity due to lack of education and limited basic facilities. These are highly exposed and vulnerable to climate based hazards. (Salik et al., 2015; Gill et al., 2012; Nicolls et al., 2008). IPCC in its fifth assessment report has reported that there will be higher drought conditions around the world due to reduced precipitation and in some regions of world there will be even more floods. Water availability has become more serious issue due to ever increasing population (Pachauri et al., 2014). In terms of adaptation in water governance, several studies have reported adaptive capacity of communities through economic and societal modifications, infrastructure and institutional changes etc.

**Weeds:** Almost all rural communities are associated with agriculture ecosystem. Climate change affects the agricultural communities due to their direct dependence on climatic parameters i.e. precipitation, temperature etc. Agricultural sector is more exposed to climate based hazards from the biophysical environment which includes change in rainfall pattern, changes in seasonal temperature, alteration in sowing and harvesting of crops etc. many extreme events affect productivity of agricultural sector, e.g. floods, drought, sea level rise (Kelkar et al., 2008; Ford, 2009; Deressa et al., 2009; Krishnamurthy et al., 2011; and Rawlani and Sovacool 2011). Local agriculture studies have highlighted their sensitivity to changing environment and resulting extreme events. Few studies have worked on agriculture in plain areas where other have highlighted vulnerability of agriculture in mountainous region or coastal areas due to climate change (Gay et al., 2006; Acosta-Michlik and Espaldon, 2008; Knutsson and Ostwald, 2006; Ben Mohamed, 2010). In terms of adaptive capacities, different studies have focused on assessment of local community's adaptations strategies. These measures of adaptation may involve economic diversification, infrastructure management or indigenous knowledge based or either institutional mechanism.

### 3. Case of Pakistan

Pakistan show varied topography ranging from high peaks to low lying plains and Arabian Sea. Climate to date has affected almost all type of life occupying different ecosystems, e.g. coastal areas, forests, agricultural sector or mountainous areas. Each has their own vulnerability to climate change depending upon community's level of interaction and dependence upon resources. Pakistan's vulnerability is higher due to its socio-economic state, climatic conditions and poor adaptation practices (Iqbal et al., 2015). The country faced biggest ever floods in 2010, which hit the country's economy badly. From 1993 to 2002, country has seen 8.9 million affected people with 6037 died. Drought in Pakistan has affected 3 million people from 2000 to 2002 (Larsen et al., 2014). NDMA (2012) has reported history of cyclone in Pakistan from 1971 to 2007 affecting 2 million inhabitants.

## 4. Conclusion

Climate change vulnerability for different ecosystems is done to increase the scientific understanding of how climate affects life in forest, water, agriculture sectors etc. and how communities adapt and mitigate to changing climate pattern. The paper tried to explain climate and adaptation strategies in different sectors to explore multiple effects of climate change from exposure and sensitivity. Pakistan is a hazard prone country and hard hit by different disasters. There are key gaps in country's preparedness plans and adaptation strategies. There should be education and awareness among vulnerable communities of Pakistan to reduce and mitigate negative impacts of disasters and enhancing their resilience.

**List of abbreviations:** NDMA: National Disaster Management Authority.

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**Author Contribution:** LS and AT originated and intended the research, FS, MU and MF accomplished empirical analyses. MS assisted in proof reading. All the authors discussed the result and coordinated in manuscript preparation and revision.

## References

Acosta-Michlik. L. and V. Espaldón. 2008. Assessing vulnerability of selected farming communities in the Philippines based on a behavioral model of agents' adaptation to global environmental change. Glob. Environ. Chang.18: 554-563.

Adger, W. N., S. R. Khanand, N. Brooks.2 003. Measuring and enhancing adaptive capacity, Adaptation Policy Framework: A Guide for Policies to Facilitate Adaptation to Climate Change, UNDP.

Adger, W.N. 2006. Vulnerability. Glob. Environ. Chang. 16: 268-281.

Ahmed, M.T. and W. Reid.2002. Millennium ecosystem assessment: a healthy drive for an ailing planet. Environ. Sci. Pollut. Res. 9 (4): 219–220.

Bardgett, R.D. and W.H. van der Putten. 2014. Belowground biodiversity and ecosystem functioning. Nature. 515: 505.

Baum. S., S. Horton and D.L. Choy. 2008. Local urban communities and extreme weather events: mapping social vulnerability to flood. Australasian J. Reg. Studies. 14(3): 251-273.

Ben-Mohamed, A. 2010. Climate Change Risks in Sahelian Africa. Reg. Environ. Chang. 11(1): 109-117.

Bertrand, R., G. Riofrío-Dillon, J. Lenoir, J. Drapier, P. de Ruffray, J.-C. Gégout and M. Loreau. 2016. Ecological constraints increase the climatic debt in forests. Nat. Commun. 7: 12643.

Birkmann, J., O.D. Cardona, M.L. Carreño, A.H. Barbat, M. Pelling, S. Schneiderbauer, S. Kienberger, M. Keiler, D. Alexander, P. Zeil and T. Welle. 2013. Framing vulnerability, risk and societal responses: the MOVE framework. Nat. Hazards. 67: 193-211.

Brooks, N., W.N. Adger and P. Mick-Kelly. 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob. Environ. Chang. 15: 151-163.

Carina, E. and H. Keskitalo. 2008. Vulnerability and adaptive capacity in forestry in northern Europe: a Swedish case study. Clim. Change. 87: 219-234.

Case, M.J. and J.J. Lawler. 2016. Integrating mechanistic and empirical model projections to assess climate impacts on tree species distributions in northwestern North America. Glob. Chang. Biol. 23: 2005-2015.

Correia, R.A., M.N. Bugalho, A.M.A. Franco and J.M. Palmeirim. 2017. Contribution of spatially explicit models to climate change adaptation and mitigation plans for a priority forest habitat. Mitig. Adapt. Strateg. Glob. Change. https://doi.org/10.1007/s11027-017-9738-z

Cutter, S. L. 1996.Vulnerability to environmental hazards, Prog. Hum. Geogr. 20(4): 529–539.

Deressa, T.T., R.M. Hassan, C. Ringler, T. Alemu and M. Yesuf. 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Change. 19: 248-255.

Dirnböck, T., C. Foldal, I. Djukic, J. Kobler, E. Haas, R. Kiese, B. Kitzler. 2017. Historic nitrogen deposition determines future climate change effects on nitrogen retention in temperate forests. Climatic Change. 144(2): 221-235.

Eakin, H. and A.L. Luers. 2006. Assessing the vulnerability of social-environmental systems. Annu. Rev. Environ. Resour. 31: 365-394.

Evans, J.P. 2009. 21ST century climate change in the Middle East. Clim. Change. 92: 417-432.

FAO 2001. A. Perlis (ed.). Global Forest Resources Assessment 2000.FAO Forestry Paper 140, Rome, p. 512

Field, C.B., 2012. Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change. Cambridge University Press.UK, and New York, NY, USA.p.1-19

Fisher, M., M. Chaudhury and B. Mccusker. 2010. Do forests help rural households adapt to climate variability?evidence from southern Malawi. World Dev. 38(9): 1241-1250.

Ford, J.D. 2009. Vulnerability of Inuit food systems to food insecurity as a consequence of climate change: a case study from Igloolik, Nunavut. Reg. Environ. Change. 9(2): 83-100.

Frank, E., H. Eakin and D. Lopez-Carr. 2011. Social identity, perception and motivation in adaptation to climate risk in the coffee sector of Chiapas, Mexico. Glob. Environ. Change. 21: 66-76.

Fussel, H.-M. 2005. Vulnerability in climate change research: A comprehensive conceptual framework. University of California International and Area Studies Breslauer Symposium .34.

Füssel, H.-M. 2007. Vulnerability: A generally applicable conceptual framework for climate change research. Glob. Environ. Chang. 17: 155-167.

Fussel, H.M. 2009. New Results on the Influence of Climate on the Distribution of Population and Economic Activity. Potsdam Institute for Climate Impact Research.MPRA Paper 13788. Munich, Germany: University Library of Munich.2-26

Fussel, H.M. and R.J.T. Klein. 2002. Vulnerability and Adaptation Assessments to Climate Change: An Evolution of Conceptual Thinking, in UNDP Expert Group Meeting "Integrating Disaster Reduction and Adaptation to Climate Change", Havana, Cuba.

Fussel, H.M. and R.J.T. Klein. 2004. Conceptual Frameworks of Adaptation to Climate Change and their Applicability to Human Health. PIK Report No. 91, Potsdam Institute for Climate Impact Research, Potsdam, Germany.93.

Füssel, H.-M. and R.J.T. Klein. 2006. Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking. Clim. Chang. 75: 301-329.

Galloway, J.N., A.R. Townsend, J.W. Erisman, M. Bekunda, Z. Cai, J.R. Freney, L.A. Martinelli, S.P. Seitzinger, M.A. Sutton. 2008. Transformation of the nitrogen cycle: Recent trends, questions, and potential solutions. Science. 320(5878): 889-892.

Gan, J. 2004. Risk and damage of pine beetle outbreaks under global climate change. For. Ecol. Manage. 191): 61-71.

Gay, C., F. Estrada, C. Conde, H. Eakin and L. Villers. 2006. Potential impacts of climate change on agriculture: a case study of coffee production in Veracruz, Mexico. Clim. Change. 79: 259–288.

Gill, K., N.S hahzad, I. Ashraf, U. Saeed and F. Laghari. 2012. Impact of floods 2010 in coastal area of Pakistan-a case study of Kharo Chann, Thatta District. Rec. Zool. Surv. Pakistan. 21: 29-34.

Giri, B., B. Saxena. 2017. Response of Arbuscular Mycorrhizal Fungi to Global Climate Change and Their Role in Terrestrial Ecosystem C and N Cycling. In: Varma, A., Prasad, R., Tuteja, N. (Eds.), Mycorrhiza - Function, Diversity, State of the Art. Springer International Publishing, Cham, p. 305-327.

Greaver, T.L., C.M. Clark, J.E. Compton, D. Vallano, A.F. Talhelm, C.P. Weaver, L.E. Band, J.S. Baron, E.A. Davidson, C.L. Tague, E. Felker-Quinn, J.A. Lynch, J.D. Herrick, L. Liu, C.L. Goodale, K.J. Novak and R.A. Haeuber. 2016. Key ecological responses to nitrogen are altered by climate change. Nat. Clim. Chang. 6: 836-843.

Grilli, J., M. Adorisio, S. Suweis, G. Barabás, J.R. Banavar, S. Allesina and A. Maritan. 2017. Feasibility and coexistence of large ecological communities. Nat. Commun. 8: 0.

Grimm, N.B., P. Groffman, M. Staudinger and H. Tallis. 2016. Climate change impacts on ecosystems and ecosystem services in the United States: process and prospects for sustained assessment. Clim. Chang. 135(1): 97-109.

Hanewinkel, M., D.A. Cullmann, M.-J. Schelhaas, G.-J. Nabuurs, N.E. Zimmermann. 2012. Climate change may cause severe loss in the economic value of European forest land. Nat. Climate Change. 3: 203.

Hansen, M.C., P.V. Potapov, R. Moore, M. Hancher, S.A. Turubanova, A. Tyukavina, D. Thau, S.V. Stehman, S.J. Goetz, T.R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C.O. Justice and J.R.G. Townshend. 2013. High-resolution global maps of 21st-century forest cover change. Science. 342(6160): 850-853.

Harsch, M.A., A. Phillips, Y. Zhou, M.-R. Leung, D.S. Rinnan and M. Kot. 2017. Moving forward: insights and applications of moving-habitat models for climate change ecology. J. Ecol.: n/a-n/a.

Hufschmidt, G. 2011. A comparative analysis of several vulnerability concepts. Nat. Hazar. 58: 621-643.

Hultine, K.R., K.C. Grady, T.E. Wood, S.M. Shuster, J.C. Stella and T.G. Whitham. 2016. Climate change perils for dioecious plant species. Nat. Plants. 2: 16109.

Hungate, B.A., J.S. Dukes, M.R. Shaw, Y. Luo, C.B. Field. 2003. Nitrogen and climate change. Science. 302(5650): 1512-1513.

Kaushik, G., and M.A. Khalid. 2011. Climate Change Impact on Forestry in India. In: E. Lichtfouse, editor. Alternative Farming Systems, Biotechnology, Drought Stress and Ecological Fertilisation. Sustainable Agriculture Reviews 6. London, United Kingdom: Springer. 319-344.

Kelkar, U., K.K. Narula, V.P. Sharma and U. Chandna. 2008. Vulnerability and adaptation to climate variability and water stress in Uttarakhand state, India. Glob. Environ. Change. 18: 564-574.

Kelly, P.M. and W.N. Adger. 2000. Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation. Clim. Chang. 47: 325-352.

Knutsson, P. and M. Ostwald. 2006. A process-oriented Sustainable Livelihoods Approach: a tool for increased understanding of vulnerability, adaptation and resilience."Mitigation Adapt. Strateg. Glob. Chang: n/a-n/a

Krishnamurthy, P.K., J.B. Fisher and C. Johson. 2011. Mainstreaming local perceptions of hurricane risk into policymaking: a case study of community GIS in Mexico. Glob. Environ. Change. 21: 143-153.

Lal, P., J.R.R. Alavalapati and E.D. Mercer. 2011. Socio-economic impacts of climate change on rural United States. Mitig. Adapt. Strateg. Glob. Change. 16: 819-844.

Larsen, O., J. Oliver, and E. Casiles-Lanuza. 2014. Developing a disaster risk insurance framework for vulnerable communities in Pakistan: Pakistan disaster risk profile. Report No. 16. Bonn: United Nations University Institute for Environment and Human Security (UNU-EHS).

Leroux, S.J., M. Larrivée, V. Boucher-Lalonde, A. Hurford, J. Zuloaga, J.T. Kerr and F. Lutscher. 2013. Mechanistic models for the spatial spread of species under climate change. Ecol. Appl. 23(4): 815-828.

Liang, J., M. Zhou, P.C. Tobin, A.D. McGuire, P.B. Reich. 2015. Biodiversity influences plant productivity through niche-efficiency. Proc. Natl. Acad. Sci. 112(18): 5738-5743.

Lobell, D.B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon and R.L. Naylor. 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. Sci. 319: 607-610.

Logan, J.A., J. Regniere and J.A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Front. Ecol. Environ. 1(3): 130-137.

M. Iqbal, M. Ahmad, G. Mustafa. 2015 Impact of Farm Households' Adaptation on Agricultural Productivity: Evidence from Different Agro-Ecologies of Pakistan**.** Pakistan Institute of Development Economics, Islamabad, Pakistan.

Mathys, A.S., N.C. Coops and R.H. Waring. 2017. An ecoregion assessment of projected tree species vulnerabilities in western North America through the 21st century. Glob. Chang. Biol. 23: 920-932.

Millennium Ecosystem Assessment (MEA).2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Miller, S., S. Yoon, B.-K. Yu. 2013. Vulnerability Indicators of Adaptation to Climate Change and Policy Implications for IDB Projects. Policy Brief IDB-PB-184. Washington, DC, United States: Inter-American Development Bank.

Milly, P.C.D., K.A. Dunne and A.V. Vecchia. 2005. Global pattern of trends in stream flow and water availability in a changing climate. Nat. 438: 347–350.

Mosier, A., C. Kroeze, C. Nevison, O. Oenema, S. Seitzinger, O. van Cleemput. 1998. Closing the global N2O budget: nitrous oxide emissions through the agricultural nitrogen cycle. Nutrient Cycl. Agroecosyst. 52(2): 225-248.

National Disaster Management Authority of Pakistan (NDMA).2012. National Disaster Management Plan. Islamabad: NDMA.

Nawaz, U., S. Shahid, R. Ahmad, M.U. Ibrahim, A. Wajid, A. Manan and M.I. Qureshi. 2016. Indus Basin Irrigation System and climatic trends regarding glacial regimes and water runoff. J. Environ. Agric. Sci. 9: 28-36.

Nicholls, R.J, P.P. Wong, V. Burkett, C.D. Woodroffe and J. Hay 2008. Climate change and coastal vulnerability assessment: scenarios for integrated assessment. Sustain. Sci. 3: 89-102.

O'Brien, K., S. Eriksen, L.P. Nygaard and A. Schjolden. 2007. Why different interpretations of vulnerability matter in climate change discourses. Clim. Policy. 7: 73-88.

Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe, Q., Dasgupta, P., 2014. 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. Geneva, Switzerland, p. 151.

Parkins, J.R. and N.A. MacKendrick. 2007. Assessing community vulnerability: a study of the mountain pine beetle outbreak in British Columbia, Canada. Glob. Environ. Change. 17: 460-471.

Parmesan, C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. Annu. Rev. Ecol. Evol. Syst. 37: 637-669.

Parmesan, C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. Ann. Rev. Ecol. Evol. Syst. 37(1): 637-669.

Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nat. . 421: 37-42.

Pearson, L.J., R. Nelsonc, S. Crimp and J. Langridge. 2011. Interpretive review of conceptual frameworks and research models that inform Australia's agricultural vulnerability to climate change. Environ. Model. Software. 26: 113-123.

Peduzzi, P., H. Dao, C. Herold and F. Mouton. 2009. Assessing global exposure and vulnerability towards natural hazards: the Disaster Risk Index. Nat. Hazar.Earth Syst. Sci. 9: 1149-1159.

Plummer, R., R. de-Loë and D. Armitage. 2012. A Systematic Review of Water Vulnerability Assessment Tools. Water Resour Manage. 26: 4327-4346.

Preston, B.L., E.J. Yuen and R.M. Westaway. 2011. Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks. Sustain Sci. 6: 177-202.

Räsänen, A., S. Juhola, A. Nygren, M. Käkönen, M. Kallio, A. Monge Monge and M. Kanninen. 2016. Climate change, multiple stressors and human vulnerability: a systematic review. Reg. Environ. Chang. 16: 2291-2302.

Rawlani, A.K. and B.K. Sovacool. 2011. Building responsiveness to climate change through community based adaptation in Bangladesh. Mitigation Adapt. Strateg. Glob. Change. 16): 845-863.

Rogers, B.M., P. Jantz and S.J. Goetz. 2017. Vulnerability of eastern US tree species to climate change. Glob. Chang. Biol.: n/a-n/a.

Runting, R.K., B.A. Bryan, L.E. Dee, F.J.F. Maseyk, L. Mandle, P. Hamel, K.A. Wilson, K. Yetka, H.P. Possingham and J.R. Rhodes. 2017. Incorporating climate change into ecosystem service assessments and decisions: a review. Glob. Chang. Biol. 23: 28-41.

Salik, K.M., S. Jahangir, W.Z. Zahdi and S. Hasson. 2015. Climate change vulnerability and adaptation options for the coastal communities of Pakistan. Ocean Coast. Manage.112: 61-73.

Sánchez, E., C. Gallardo, M.A. Gaertner, A. Arribas and M. Castro. 2004. Future climate extreme events in the Mediterranean simulated by a regional climate model: a first approach. Glob. Planet. Change. 44(1-4): 163-180.

Scherrer, D., S. Massy, S. Meier, P. Vittoz and A. Guisan. 2017. Assessing and predicting shifts in mountain forest composition across 25 years of climate change. Divers. Distrib. 23: 517-528.

Sebesvari, Z., F.G. Renaud, S. Haas, Z. Tessler, M. Hagenlocher, J. Kloos, S. Szabo, A. Tejedor and C. Kuenzer. 2016. A review of vulnerability indicators for deltaic social–ecological systems. Sustain Sci. 11: 575-590.

Seidl, R., W. Rammer and M.J. Lexer. 2011. Climate change vulnerability of sustainable forest management in the eastern Alps. Clim. Change. 106: 225-254.

Smit, B., I. Burton, R.J.T. Kleinand J. Wandel.2000.An anatomy of adaptation to climate change and variability. Clim. Change 45: 223–251.

Soares, M.B., A.S. Gagnon and R.M. Doherty. 2012. Conceptual elements of climate change vulnerability assessments: a review. Int. J. Clim. Chang. Str. 4(1): 6-35.

Steenberg, J.W.N., A.A. Millward, D.J. Nowak, P.J. Robinson and A. Ellis. 2017. Forecasting Urban Forest Ecosystem Structure, Function, and Vulnerability. Environ. Manage. 59: 373-392.

Team, C.W., Pachauri, R., Reisinger, A., 2007. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, Switzerland. p.104.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, S. Polasky. 2002. Agricultural sustainability and intensive production practices. Nature. 418: 671-677.

Tomich, T.P. 2011. Agroecology: A Review from a Global-Change Perspective. Ann. Rev. Environ. Resour. 36: 193-222.

Torres, R., G. Azócar, J. Rojas, A. Montecinos and P. Paredes. 2015. Vulnerability and resistance to neoliberal environmental changes: An assessment of agriculture and forestry in the Biobio region of Chile (1974–2014). Geoforum. 60: 107-122.

Turner, B.L., R.E. Kasperson, P.A. Matson, J.J. McCarthy, R.W. Corell, L. Christensen, N. Eckley, Kasperson, J.X. , A. Luers, M.L. Martello, C. Polsky, A. Pulsipher and A. Schiller. 2003. A framework for vulnerability analysis in sustainability science. Proc. Nat. Acad. Sci. 100: 8074-8079.

Vermaat, J.E. and M.A. Eleveld. 2013. Divergent options to cope with vulnerability in subsiding deltas. Clim. Chang. 117: 31-39.

Vörösmarty, C.J., P. Green, J. Salisbury and R.B. Lammers. 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth. Sci. 289: 284-288.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg and F. Bairlein. 2002. Ecological responses to recent climate change. Nat. 416: 389-395.

Watson, R., 2002. The core writing team. Climate Change 2001: Synthesis Report. A contribution of Working Groups Ⅰ, Ⅱ and Ⅲ to the Third Assessment Report of the IPCC. New York: Cambridge University Press. United Kingdom, and New York, NY, USA, p. 398.

Wiréhn, L., T. Opach and T.-S. Neset. 2017. Assessing agricultural vulnerability to climate change in the Nordic countries – an interactive geovisualization approach. J. Environ. Plan. Manage. 60: 115-134.

Yuan, Z.Y., F. Jiao, X.R. Shi, J. Sardans, F.T. Maestre, M. Delgado-Baquerizo, P.B. Reich and J. Peñuelas. 2017. Experimental and observational studies find contrasting responses of soil nutrients to climate change. eLife. 6: e23255.

Zhang, Q., F. Zhang, S. Kang and Z. Cong. 2017. Melting glaciers: Hidden hazards. Science. 356(6337): 495-495.