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Climate Change

The analysis of the effects of climate change on geologic natural hazards

Bita Javidfakhr

Department of Geology, Faculty of Sciences, University of Zanjan, Zanjan, Iran; E-mail: bjavid@znu.ac.ir

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ABSTRACT

Climate is one of several integrated drivers of change that should be considered in understanding the vulnerability and related risk management options. Active tectonics and climate change are supposed to be key parameters in evolution of large slope movements in mountain belts. The relationship between active tectonics and rock slide development is obviously evidenced in the seismic zones. Climate change influences various environmental aspects and it can generally exacerbate geological hazards. One of the challenges faced by the scientific community comprises understanding the fundamental signals of change in the climate system and the environmental effects. This paper aims to analyze the effects of climate change on different geologic natural hazards. It is suggested to develop the adaptation strategies, challenges, and recommendations to avoid the damages. The quantification of the risks posed by climate change is possible, but there are many restrictions. The adaptation strategy can provide helpful insights to inform policy design and implementation of resilience ideas in risk management. The management index should combine and manage the pattern and process to identify geographic locations at greatest threat from climate change. Such efforts would help society to reduce risks, take advantage of opportunities and cope with changes in an integrated manner.

Keywords: climate change, earthquake, hazard, adaptation, tectonic

1. INTRODUCTION

Earthquakes, floods, droughts, sandstorms and dust storms, rapid wet debris flows, snow avalanches, landslides, and extreme weather events are the chief threats posed by natural hazards. In tectonically active regions, the effects of huge earthquakes, and perhaps volcanic eruptions, extend beyond a single beach ridge system and can become a regionally significant motivation for both immediate and delayed environmental responses [34]. Wells and Goff, [37] reported that multiple large earthquakes over hundreds of years were in charge for the region wide formation of frequent sand beach ridges over 100 km of coast line.

Global climate models suggest that the earth is likely to experience a change in the probability of weather-related hazards including an increase in heat waves, floods and storms. Extreme weather conditions may also cause health hazards. Climate change has been responsible for erratic weather patterns, and increased frequency and intensity of extreme weather events as evident globally with the greatest effects in developing countries and particularly in the poor countries. Environmental degradation and climate change are directly related to many natural hazards, like flood and drought, which can be understood as a human security issue.

Climate change adaptation is a developing discipline and we should concentrate on the methods most efficient and effective to develop and implement strategies for helping people to cope with a changing climate. Scientific community and policy makers are now concentrating on adaptation measures which are critically important in addressing the impacts of continuing climate change. Since climate change is a global issue that disturbs various human settlements, the impacts are expected to be more severe in large cities[45].

2. LANDSLIDE HAZARD

Landslides are one of the most deadly natural hazards on the earth, not only due to an important increase in extreme climate change caused by global warming, but also quick economic development in topographic relief regions. Increased pore groundwater pressure due to meltwater drainage or heavy rainfall are the main climatic factors thought to influence fault and slope stability, especially during periods of climate change.

Detailed studies of the last decades reveal the influence of the Tibetan Plateau on the climate system, since its uplift seems to have imposed the northern hemispheric atmospheric circulation pattern, particularly the onset of the Asian monsoon systems [33]. Short-term fluctuations and related events could be better and more precisely documented, but may have been superimposed by local processes that are not always linked to climate. In subtropical humid monsoon climate regions, rainfall directly removes soil nutrient due to the lack of vegetation-mediated soil and water conservation, as disturbed sites with steep slope and crude soil caused by rock falls and landslides have reduced ability to control surface water infiltration [see 24].

Earthquakes may activate the landslides during which sediments are removed from slopes and transported by fluvial action. Offsets of Last Glacial Maximum moraines in the south-western Alps and of recent alluvial sediments and fault breccia in this region have been identified along active seismic faults by Jomard [19] and Larroque et al. [23]. Jomard [19] suggested that these features are related to gravity movements. The occurrence of strong earthquakes may result in rock falls and landslides from the valley sides. Strong earthquakes often activate numerous landslides and destroy vegetation cover as observed in the eastern Tibet Plateau [39, 40]. The mentioned factors can lead the landscape and vegetation get fragile. In general, there is a good correlation between the magnitude and distribution of ground shaking by an earthquake and the density of resultant landslides [30]. Potential high magnitude seismic events or multiple low-magnitude earthquakes can activate landslides as large gravity mass movements taken up in the same age range as recent fault activity [e.g. 31].

Change of rainfall due to climate change raises groundwater levels in inland regions, where rainfall increases. Subsequently, liquefaction risk posed by rising groundwater levels increases in inland regions where local heavy rains increase. Ground liquefaction caused by earthquakes can be an effective factor for the building collapse risk [41]. Soil quality is the base for improving sustainable land use management and evaluating the sustainability of soil management practices, providing fast warning signs [see 24].

3. SEA LEVEL RISE

Sea level rise results from climate change and variations in the frequency and intensity of rains. Those influences magnify high risks in areas prone to liquefaction, particularly in coastal zones. The fluctuation of groundwater levels in coastal zones caused by a sea level rise or climate change-induced rainfall should be predicted to avoid the damages [41]. The sea level rise influences seashore and riversides, the same process as does the variation of inland precipitation. Variations of rain intensity and frequency increase in areas of high liquefaction risk. The numerous data indicate that lake level changes are also caused by a change in the hydrological balance resulting from climate change [27]. The decrease of the water table also can be caused by climate change.

The climate of the Holocene has been shown to be extremely variable, fluctuating between stable climates and periods of rapid climate change. Generally, when the climate stabilizes, a new phase of notch formation restarts back at sea level cutting a continual notch until conditions convert unsuitable once more. Well-preserved coastal notches are assumed to have been lifted beyond the reach of waves by seismic uplift events. Cooper et al. [8] suggested that notches may have multiple causes.

Tidal notches can be used as regional markers to measure the amount of net coastal movement since the abrupt mid-Holocene sea level slow down [4]. The exact timing of notch inception varies with local uplift rate; therefore they may constitute a regionally variable marker. They [4] suggested that earthquake clustering seems more likely mechanism of tidal notch uplift; as local indicators of differential fault offsets as well as the relative palaeoseismic expression of coastal-bounding faults. However, the majority of Mediterranean notches express a cumulative record of multiple coseismic events not simply a few large ones. They considered the fact that coseismic uplift is generally an order of magnitude too low and also too many earthquakes have occurred in the Holocene to correlate with the observed notch intervals. Therefore, they discounted any direct correlation between notches and individual seismic events. Consequently, Cooper et al. [8] considered the preservation of notches as relict features of regional climate stability superimposed on tectonic uplift, precisely explaining the disparity between the notches' elevation and the potential coseismic amount of uplift.

Boulton and Stewart [4] analyzed different models, suggesting that if climate is the dominant control on the notch formation, the timing of notches will concentrate in periods of climatic stability. It should be taken into account that if tectonic uplift is the dominant control, notches will have an even spread of ages determined by local tectonic and seismic histories.

Palaeoseismic and instrumental records strongly indicate that in many regions earthquakes occur in clusters of ruptures along several adjacent faults separated by long periods of quiescence as a result of phase locking [9, 32]. The emergent tendency for earthquake faulting to be strongly clustered in time and space offers an important new perspective on how coastal notches may reflect palaeoseismicity.

Tamura [34] suggested that the growth rates of beach ridge systems reflected fluctuations in river sediment discharge to the coast and the Aeolian sand flux due to onshore winds, while both of which could be affected by climate change. According to the statements [34] any inferred relationships between beach ridges and sea level cyclic fluctuations and climate are based on weak assumptions that were not validated by strong chronological evidence.

At the land-sea interface, geodetic measurements can provide improved constraints on sea level change that are critical to prepare for and try to reduce the rising rate which is the result of climate change.

4. LAND SURFACE TEMPERATURE CHANGE AND TECTONIC ACTIVITY

The historical records indicate that major earthquakes do not occur in isolation, and instead generally arise in clusters. Such clusters of tectonic events tend to happen in a short period of time and in places which are not far apart. The map for co-seismic change in gravity was drawn using the data from the gravity recovery and climate experiment satellites for the 2004 Sumatra-Andaman earthquake [14 and 44]. It is possible to achieve information about tectonic activity from land surface temperature derived from satellite remote sensing data. The method permits us to transform isolated observations of the surface into a field and a development process as a supplementary means [5, 6 and 25]. The temperature variation related with tectonic activity is probably contained in the temperature residual (ΔT) after the normal annual variation field is subtracted from the total field. ΔT can be influenced by many factors such as sunspots, atmosphere, monsoons, vegetation, human activity [18], and the earth's internal activity. It should be considered that short-term variations in ΔT are usually produced due to effect of climate changes. Long-term variations may contain thermal information associated with tectonic activity. The tectonic activities are accompanied with material movements and energy transfer, which must change the state of thermal radiation on the earth.

The land use/land cover changes recognized after seven major disturbances were observed as the cumulative impact of the Chi-Chi earthquake and typhoons and not human activity [7]. Their finding indicates that the changes in land cover induced by the typhoons and the earthquake during the study period negatively affected the ecosystem's functions. The increase in the retention rates after the earthquake demonstrates the cumulative impact of the earthquake and typhoons. There are generally several factors significantly influence vegetation distribution and ecological conditions. One can be the arid and windy climate with a large temperature difference between day and night. The other factor is active tectonics characterized by frequent earthquakes [35, 36].

Jiang et al. [18] suggested that lacustrine sediments in a tectonically active region may have a continuous record of earthquakes. Sedimentation features observed in the field surveys, material provenance, and high resolution grain size and susceptibility records could be analyzed to understand the formation process of fine lacustrine sediments in relation to palaeo earthquake events [18]. Changes in climate may also cause changes in grain size and susceptibility recorded within a section.

5. CLIMATE EVOLUTION

Based on Evenstar et al. studies [10], since ~14 Ma (middle Miocene), deposition of gravels associated with slight fluvial departure and climate change appears to have formed progressive completion and eventual abandonment of the Atacama plain [e.g. 10, 20]. Present-day climate conditions in the Atacama Desert at the Pacific seaboard of central South America are arid to hyper-arid. Global Cenozoic climate cooling processes formed their maximum drying effects in South America on its Pacific margin and centered at the middle latitudes of the Atacama Desert, which is coincident with the Central Andes located core of the Andean orogeny[16].

The spatial and temporal characteristic of palaeoclimate evolution in China during the last deglaciation has been studied [26]. The evolution of Central Depression Basin and the eventual establishment of the Atacama Bench recorded the climate evolution toward the present-day hyper-aridity in the Atacama Desert (≤5 mm/yr of precipitation) and more generally the climate change over the western seaboard of central South America [2]. They consider the geologic evidence throughout the Pacific seaboard of South America to be convincing, representative for a sharp increase of aridity, which indicates a climate change at continental scale. They also analyzed morphologic and structural characteristics of the Atacama Bench to characterize the interplay of tectonic evolution with Cenozoic climate change throughout the Pacific seaboard of the growing Andean orogeny [16].

It has for long been supposed that tectonic uplift of coastal regions (for example in north Chile), is relatively old and cannot be correlated with younger incision processes, which would be controlled by wetter climate conditions [2, 11].

6. CLIMATE CHANGE ADAPTATION

As climate researchers notify that global warming will probably increase the frequency and intensity of extreme weather events (e.g., floods, droughts, tropical cyclones and heat waves), integrating strategies for natural hazards risk reduction is an important part of climate change adaptation [17]. Adaptation can be proactive or reactive in order to mitigate the damages associated with unwelcome external change [15, 17 and 21], and it is meanwhile essential for a system's resilience. The practical evidence for reactive risk-mitigating innovations can inform the current endeavors in integrated assessment modeling of climate change, and suggests the possibility of considering adaptation [13, 22] as a function of previous hazard losses.

The adaptive governance literature [42] emphasizes that local initiatives, which are generally neglected in top-down governance, are important to have cohesive dealing with climate change. McCarthy [28] suggested that local science management partnerships are critical to have most effective adaptation planning and implementation. He claimed that climate adaptation solutions should be carefully planned for effectiveness under a range of possible climate scenarios. Another important point is that climate adaptation plans are perhaps most effective if they are developed by local science-management partnerships rather than being developed independently by off-site experts.

As the severity of catastrophic damages can be a motivation for risk-mitigating innovations, Miao and Popp [29] argued that observed human and monetary losses experienced by a country from natural catastrophic hazards are endogenous. The baseline hazard is important for perceived risk, because people living in a region known to be at risk for certain hazards are more likely to possess some level of risk perception [see 38].

Due to the close correlation between the temporal variability in ecological phenomena and climatic variability, the extent to which the climate may affect disturbance regimes and final various ecosystem responses must be studied. The organizations involved in land planning and hazard management seriously prioritize the assessment of the ways landscape changes affect the dynamics of ecosystem functions and the services they provide, particularly large-scale changes induced by successive physical disturbances [7]. Yasuhara et al. [41] suggested that among possible adaptation measures existing against climate-change induced geo-hazards; geo-synthetics will be more powerful options in the near future for protection of coastal zones.

Non-governmental associations also have developed comprehensive guide for the climate change adaptation in natural resource conservation organizations [12]. It should be considered that the governmental role is in this issue is critical and needs special attention. For instance, the government of Afghanistan has designed a National Adaptation Program of Action for Climate Change. Their major objectives are as follows: (1) to identify and prioritize projects and actions that will help communities adapt to climate change; (2) to seek overlapping and mutually reinforcing collaborations with existing multilateral environmental activities and (3) to bring climate change considerations into the national planning process [1].

Atoki [3] showed how the framework of adaptive governance originated from the environmental management and climate change issues can be used to understand governance dynamics natural hazard management.

Nature's adaptation to climate change is facilitated by reducing conventional pressures on biodiversity such as intensification of land use, fragmentation of habitats and pollution. Different advanced techniques can be applied to extend our knowledge about the environmental water requirements of groundwater dependent ecosystems in response to interactive changes in groundwater attributes, and human-induced disturbances. It should be noted that both water quantity and quality are important to maintain habitat and biodiversity for groundwater management.

7. DISCUSSION AND CONCLUSION

Landscape, the climate and catastrophic geological processes such as earthquakes, tsunami, landslide and volcanic eruptions, are generally the major natural elements which strongly influence the existence of human beings. The climate and weather variations represent that geo-hazards tend to increase over time. We generally expect that the already visible increases in weather related loss events will continue in the future as climate change will proceed. The assessment for the grade of effects due to climate change on the liquefaction risk is important to reveal the geological hazards posed by earthquakes in an area. Local and indigenous knowledge is significant to aggregate the resilience of coastal and small island communities to hydro-meteorological hazards and the impacts of climate change.

Data should be continuously collected in a long-term period, and the same metrics must be compared to provide a reliable basis for evaluating program outcomes. The information can be integrated into a set of systematic indicators, frameworks and processes to permit for the future improvement of catastrophe prevention strategies and the appropriate provision of the hazard prevention education resources.

However, we should pay more attention to the vulnerable people and their livelihood throughout the hazard management cycle. Future studies should concentrate on measuring the value of the program in terms of resource inputs and costs against potential damage reduction in order to establish logic for long-term continuation of different programs. Climate change should be a part of the general awareness and should start to be taken into account in different municipal spatial planning.

Future research needs to provide more understanding of the global climate change and its different impacts. Interdisciplinary aspects such as incorporating risk management for climate changes or other natural hazards, in the future planning should be prioritized.

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