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ASSURING TOMORROW

Human Impacts on Geological Events

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This white paper is designed to provide analysis of relevant, publicly available information on threat and hazard events/trends and their potential impacts to the interests of the United States, both at home and abroad. This product is not intended to be an all-encompassing assessment of the subject.

Introduction

When seeking to prepare for and mitigate the effects of natural hazards, it is important to take a holistic view of the frequency and severity of said hazards. To do so, analysis must begin with a review of historical events. This provides insight into which hazards a specified area may generally expect to experience. However, the frequency and severity of natural hazards is not consistent, and changes can occur over time. These changes may be short-term (such as an El Nino season) or long-term. Long-term changes due to human causes are already evident in many types of natural hazards and are projected to be seen in even more. While many people are familiar with the manmade changes seen to meteorological events such as temperature increases and sea level rise, less well-known are the changes to geological events. This paper will examine the human impacts to geological hazards and how they may change in the future.

Earthquakes

Record keeping for earthquakes has become more refined and advanced in recent years. This has led to an increase in the number of recorded events over history, not due to a change in frequency, but a change in detection capabilities. Furthermore, earthquake rates experience normal fluctuations. However, there has been a detected change in earthquake frequency due to human activity. In regions where oil and gas production take place and wastewater disposal wells are present, earthquakes have been increasing in frequency.[1,2]

In order to generate and capture oil and gas, the permeability of the location's shale must be increased, permitting the gas or oil to flow through the shale to an extraction well. To do this, hydraulic fracturing, or fracking, is often used. Fracking is the deliberate creation of very small earthquakes to increase local shale permeability. While these earthquakes are generally at a magnitude less than zero, larger earthquakes have been detected. The largest earthquake known to be induced by hydraulic fracturing in the United States was a magnitude 4 earthquake in Texas.[3]

Fracking fluids and saltwater are usually generated by the same process that permits the gathering of oil or gas. These excess fluids are often disposed of via injection into deep wells. This subsurface injection can trigger damaging earthquakes. Additionally, the fluid waste generated by oil and gas disposal is eliminated via wastewater disposal; a separate process in which these fluids are injected deep underground far below ground water or drinking water aquifers. Wastewater disposal triggers even larger earthquakes, with the largest recorded thus far being a magnitude 5.8 earthquake that occurred near Pawnee, Oklahoma in 2016.[3]

In recent years, Oklahoma has become the most active state for earthquake activity, passing California. This is due to the high amount of wastewater disposal within the area. At one point in time, in the early 2000's, Oklahoma had two to four earthquakes a year. Between 2014 and 2017, Oklahoma recorded more than 2,400 earthquakes of 3.0 magnitude or higher.[4,5]

Sinkholes

Sinkholes are one of many forms of ground collapse, or subsidence. Land subsidence is a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials. The principal causes of land subsidence are aquifer-system compaction, drainage of organic soils, underground mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost.[6]

There may be strong correlations between increasing air temperatures and the formation of sinkholes, particularly as there is a correlation between sinkhole collapse and peak drought periods. In a study of sinkhole formation focusing on Florida, researchers found that for every 0.1 degrees Celsius rise in global temperature, the number of sinkholes increased between 1-3%. Furthermore, increasing temperatures are leading to more rapidly thawing permafrost, and therefore increasing the chances of sinkhole occurrence.[7]

Observed sea level rise may also have impacts on the formation of sinkholes as saltwater encroachment into groundwater from the rising tides may contribute to underground corrosion. Sinkholes are common where the rock below the land surface is limestone, carbonate rock, salt beds, or rocks that can be naturally dissolved by circulating groundwater. Therefore, any encroaching seawater may further weaken natural voids and gaps underground, contributing to the formation of sinkholes. Additionally, an increase in local precipitation may also increase the corrosion rate of karst terrain.[8,9,10]

Oil and gas extraction and the subsequent wastewater injection may also lead to increases in sinkhole events. A Texas study showed that oil and gas drilling activity caused the area in which it took place to become unstable and weakened. Scientists note that this unstable ground may lead to sinkholes.[11]

Erosion

Throughout the U.S., local sea level rise, wind, strong wave action, coastal flooding, and other natural processes could lead to the erosion of rocks, soils, and sand. In addition to natural events, human activities, such as removing trees and plants, plowing fields, and overgrazing by livestock, can significantly increase erosion rates. Agricultural practices and removing vegetation could impact roots that stabilize sediment and soil, thereby exposing soil surfaces with little or no vegetation to erosion by wind or water. Furthermore, urbanization and paving land with concrete could exacerbate water runoff, raising the rate of erosion. On the coasts, development and construction along the shoreline have reduced sand dunes, weakened bluffs and banks, and decreased beach widths. The rise of beachfront development over the past century has further exposed coastal communities to winds and high waves and disrupted the movement of sediment.[12,13,14,15]

Various manmade solutions have been designed to combat erosion; however, research indicates that some mitigation structures could inflict additional problems. For instance, coastal harbors and jetties can decrease erosion by trapping sediments; however, they also can increase erosion rates on adjacent coastlines. Furthermore, hard structures, such as groins and breakwaters, are utilized to ensure sediment on the beach defends the upland area from normal storm conditions. However, while hard structures are designed to retain sediment moving along the shore and slow down local erosion, poorly designed structures could interfere with natural water currents, prevent sand from shifting along coastlines, transfer erosion issues farther down the beach, and unintentionally divert stormwater and waves onto other areas.[12,14,15]

In addition to hard structures, many communities utilize beach nourishment, a process that adds sediment onto or directly adjacent to a beach to serve as a buffer against erosion. Beach nourishment allows sand to shift and be transported by waves and currents like a natural beach while also absorbing wave energy, defending upland areas from flooding and mitigating erosion. However, beach nourishment in an area could adversely impact some natural resources, ecological features, and habitat conditions. Furthermore, research notes that extracting and transporting sand for beach nourishment, also known as sand mining, has a significant carbon dioxide footprint. Ultimately, instead of hard structures alone or in combination with beach nourishment, non-structural solutions such as increasing building setbacks, elevating structures, and implementing zoning restrictions could decrease the negative effects of erosion. However, these processes cannot slow down the rate of erosion.[15,16,17]

Landslides

Landslides, the down-slope movement of a mass of rock or debris, can be caused by local topographic, geological, and anthropogenic conditions or natural hazards such as hurricanes, earthquakes, volcanoes, and heavy rainfall. Human-caused landslides often result from activities such as the construction of roads and structures without proper grading of slopes and poorly planned adjustment of drainage patterns. In addition, other agricultural and construction activities can destabilize and weaken slopes, such as irrigation, deforestation, excavation, and leakage. [18,19,20,21]

Furthermore, wildfires leave hillsides with no trees or vegetation to stabilize slopes. Wildfires have been increasing across the globe due to rising temperatures. These burned hillsides are susceptible to significant debris flow, especially when precipitation occurs. For example, following the 2018 wildfires in Montecito, California, debris flows in the area resulted in 23 fatalities, 167 injuries, and over 400 homes damaged. According to experts, burned areas could be more susceptible to increased debris flows from one (1) to five (5) years following a fire.[22]

Some research indicates that other human-caused landslides have increased over time. A study of worldwide landslides from 2004 to 2016 found that construction works, mining, and unregulated cutting of hills resulted in the most landslides caused by humans over the period. According to the study, fatal landslides were most frequently observed in settlements, along roads, and in areas with a significant number of precious resources. Poorer countries also were found to be disproportionally affected by these fatal landslide events.[23]

Furthermore, research indicates that landslides could occur more frequently in the coming years due to climate change. According to experts, rising temperatures associated with human climate impacts could increase the frequency and intensity of wildfires and droughts, potentially leading to a rise in landslides. For instance, researchers in certain mountainous areas of Europe and Alaska have recorded more frequent rockfalls as average temperatures increased annually. Additionally, some scientists indicate that warming temperatures are heating permafrost, which can weaken rock faces and lead to rockfalls. [22,24]

Given that landslides often are caused by precipitation, some researchers predict that landslide activity over the next few decades could be influenced by climate change's impact on changing precipitation patterns worldwide. Though changes in precipitation patterns are not uniform, a general increase in extreme precipitation events can likely be expected. Finally, rising sea levels may also increase erosion on coastal bluffs, destabilizing the area, and resulting in collapse events. [22,24,25]

Outlook

As this paper has outlined, human-induced changes to the environment have already begun to impact numerous geological hazards. Moving forward, these changes are likely to increase the severity and/or frequency of events, though some mitigation efforts may lessen this. Human impacts to these hazards can come from a multitude of sources: emission rates, energy needs, urban expansion, or resiliency measures, to name a few. This outlines the importance of understanding not just the hazard history of an area, but also the actions that may contribute to hazard impacts in the future. RMC's Intelligence & Analysis Division continues to develop and refine its climate analytics capability set in order to serve a variety of client needs.

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