NATURAL HAZARDS, ENVIRONMENTAL DEGRADATION, AND THE URBANIZATION OF PLANET EARTH

Perspectives on the Ethical Challenges Geoscientists Face in an Uncertain World

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"We know that human communities will always have to face natural hazards, whether floods, droughts, storms or earthquakes. But today's disasters owe as much to human activities as to the forces of nature. Indeed the term 'natural' is increasingly misleading."

Kofi Annan
Former Secretary-General, United Nations (September 1999)

1. INTRODUCTION

Environmental degradation is no longer an issue that concerns only environmental activists. The concern has become a part of mainstream culture, across the political spectrum. But as if the environment itself isn't enough for us to worry about, there is another aspect of how human activities are affecting our lives on planet Earth that receives less attention: the interaction among *natural hazards, environmental degradation, and urbanization* (Figure 1). This is an insidious problem because comprehending it requires thinking about processes occurring on geological time scales interacting with processes occurring on the human time scale, and humans are not typically wired to think in geological time.

Natural disasters are inevitable consequences of life on a dynamic planet. We cannot hold back nature from occasionally unleashing its powerful forces on a vulnerable human population. But human actions that cause environmental degradation, as well as the ever-increasing population and built environment in hazard-prone regions, are worsening the devastation wrought by nature.

Geoscientists can help the public and decision makers to address these issues because they are trained to think differently than the general population: "[Geoscientists] take a long view of time, and they expect low-frequency, high-impact events [and] have internalized the vastness of the age of the Earth and relative brevity of human history" (Kastens, *et al.*, 2009). But they can only help if they transmit that perspective in a manner that gives the public an accurate picture of what we do *and don't* know about these hazards.

As we illustrate in the examples discussed here, this nexus of natural hazards, environmental degradation, and urbanization is a complex problem that does not tend to yield simple, straightforward scientific answers as to where and when it will actually result in harmful (or perhaps even tragic) effects. In the face of this uncertainty, a challenge for geoscientists is to find the right balance between realistic assessments of the dangers and an appropriate level of caution in how to present those assessments to the public so as not to cause unnecessary alarm. As geoscientists, we are both aware that there are rarely certain answers to the question of how resources should be dedicated to mitigating potential hazards, and yet are also aware that potentially life-and-death policy decisions must be made despite the absence of scientific certainty. As researchers, ethical questions arise regarding how to publicly report research results in ambiguous situations, how to educate the public regarding what is and is not known about hazardous situations, and how to adequately warn both policy-makers and the public about these hazards that affect society. The nexus of natural hazards, environmental degradation, and urbanization provides a rich context for exploring these ethical challenges.

For simplicity, we will refer to this interaction among the three phenomena – natural hazards, environmental degradation, and urbanization – as the problem of "hazards, environment, and urbanization." In this paper, we present three examples that provide provocative illustrations of the challenges of living on a planet where this dangerous mix is having an increasing effect on human civilization:

- The magnitude 7.6 earthquake that occurred in Pakistan in 2005, a case where a natural hazard was exacerbated by environmental degradation.
- The magnitude 7.9 earthquake that occurred in China in 2008, a case that illustrates how human activities may trigger natural hazards.
- Earthquakes in the New York City area, a case where a relatively moderate natural hazard is exacerbated by urbanization and thus becomes a significant concern.

We need to distinguish between a natural *hazard*, i.e., the potential for a harmful natural event to occur, versus the *risk* associated with that natural hazard, i.e., the potential for harmful effects on people and/or property to occur due to exposure to that hazard (e.g., Kasperson and Kasperson, 2001; Stein, 2007). In our first example, human actions increased the risk from a known hazard, in the second human actions may have caused a natural hazard event to occur sooner than it would have under natural conditions, and in the third a low hazard presents substantial risk due to urban development.

Placing these examples in a broader context, we next present the general framework of how human civilization exists, as historian Will Durant said, "by geological consent", always in the shadow of the long-term geological processes that occasionally unleash the Earth's internal forces in the form of violent events.

2. HUMAN CIVILIZATION, LONG-TERM GEOLOGICAL PROCESSES, AND NATURAL HAZARDS

Geological processes occur on a wide range of time scales (Figure 2), from the inexorable, long-term Earth processes that occur on the time scale of plate tectonics (millions of years) to the so called "Anthropocene" time scale (past few hundred years) to even more rapid events such as earthquakes that occur on time scales of minutes to seconds. The Anthropocene is the name proposed by Crutzen (2002) to refer to the current geological period, during which human activities are having a significant effect on the global environment. In the case of earthquakes, the long-term geological processes suddenly cause violent shaking of the ground for a matter of seconds to minutes. When devastating earthquakes occur in areas where environmental degradation and urbanization exacerbate their effects, they provide a dramatic reminder of just how vulnerable we have become to the hazardous interaction of long-term geological processes with human activities on the Anthropocene time scale.

Throughout history, humans have always been victims of the Earth occasionally unleashing its internal forces in the form of violent events. But now we are living in the Anthropocene in which environmental degradation, and the trend over the past centuries for increased urbanization, means that these natural hazards are often occurring in areas where people have been made more vulnerable to their effects. A case in point is the magnitude 7.6 earthquake that struck Pakistan in 2005, killing about 89,000 people (Petley, et al., 2006).

3. TRAGEDY IN PAKISTAN, OCTOBER 2005: EARTHQUAKE TRIGGERED LANDSLIDES ALONG DESTABILIZED SLOPES

The tragic Pakistan earthquake of 2005 was caused by the slow motion (on a time scale of many millions of years) of the Indian plate moving northward and colliding with the Eurasian plate to form the great Himalaya Mountains (e.g., Fujiwara, *et al*., 2006; Hough *et al*., 2009). On October 8, 2005 some of the stress built up from that motion was released in the form of a massive earthquake beneath the area surrounding the city of Muzaffarabad, Pakistan. As in most cases where massive earthquakes occur near population centers, most of the deaths were caused by collapse of buildings, and a tragic result was that thousands of children died in schools that collapsed due to inadequate construction (GeoHazards International, 2009) .

But something else also happened here. A considerable proportion of the fatalities were caused by landslides triggered by the earthquake, and the landslide-induced devastation appears to have been exacerbated by slopes that were destabilized by years of logging and deforestation (e.g., Kamp *et al.*, 2008).

This earthquake provides a dramatic example of how human modification of the environment has the potential to increase the devastation from an earthquake. About 30% of the approximately 89,000 fatalities resulting from this earthquake were a direct or indirect result of landslides triggered by the earthquake (Petley, et al., 2006), many of which would probably not have occurred if the slopes had not been destabilized by years of logging and deforestation.

But how are we to respond to this type of situation? In the immediate wake of these kinds of tragedies, there is a heightened interest in mitigating the problems, such as the effects of logging and deforestation on slopes in areas where large earthquakes are prone to occur. But such a response is never as simple as it might seem in the immediate aftermath of an earthquake. Many areas where large earthquakes occur depend on logging (and/or other activities that also exacerbate the seismic hazard) to support their economy. How do we know (in advance) when it is reasonable to hold back economic development for the sake of protecting people from a hazardous event that might not occur for another 100 or 200 years (if at all)?

One might imagine that all we need to do is to identify locations along tectonic plate boundaries and focus all of our resources on mitigating earthquake hazards problems at those locations. But finding locations on Earth that can be assured to be safe from earthquakes is far more difficult than one might imagine from the textbook version of the theory of plate tectonics, and its relationship to earthquakes. Although the theory of plate tectonics is remarkably successful at explaining the general pattern of earthquake locations on a global scale, it is not a perfect predictor of where all large earthquakes are likely to occur for two reasons. First, plate tectonics is an idealized model, most applicable to oceanic settings, where the crust is relatively thin and homogenous. Particularly on the continents (where people live), the Earth's crust is more complex geologically and the deformation resulting from plate motions tends to be spread over larger areas than a single fault. Even at relatively well-defined plate boundaries on continents, such as the San Andreas Fault in California, the actual locations of earthquakes is almost always quite diffusely distributed, with earthquakes that are quite large and damaging often occurring at significant distances from the plate boundary itself. For example, there have been recent significant and damaging earthquakes that occurred quite far from the mapped trace of the San Andreas fault, such as the 1992 Landers, CA earthquake (magnitude 7.3) and the 2002 San Simeon, CA earthquake (magnitude 6.6).

Second, there is the enigma of "intraplate" earthquakes – earthquakes (that can be quite large and damaging) occurring far from plate boundaries. In fact, one of the largest earthquakes in the history of the United States occurred in the middle of the continent, near the town of New Madrid, MO in 1811. This earthquake, with a magnitude between about 7.0 and 8.0, was widely felt across most of the central and eastern U.S., with damage reported as far away as Charleston, SC and Washington, DC (e.g., Hough and Bilham, 2006). If an earthquake of that size were to occur near a major eastern U.S. city today, the devastation could be enormous.

Intraplate earthquakes remain a poorly understood phenomenon. (For a fuller discussion of this topic, see for example Kafka, 2000). Thus, there is always the problem of "surprise" earthquakes that occur in areas where few seismologists would have imagined they could. Given all of this uncertainty, exactly where on Earth might we decide to ban all of the human activities that might exacerbate earthquake hazards, such as logging on steep slopes, or the construction or expansion of cities? And yet, we do know that as the growing human population creates dense urban development and expands into previously uninhabited areas, our exposure of risk from Earth's seismic hazard increases apace, and risk becomes even more severe when combined with human activities that might exacerbate earthquake hazards.

Furthermore, there is the tradeoff between mitigating these types of environmental problems and attending to more immediate needs. Should governments spend money on mitigating a problem like precarious slopes in areas where earthquakes *might* trigger landslides, versus attending to more immediate needs such as feeding the hungry, or building adequate homes, schools and hospitals? Even when policy-makers do decide that the right priority is to spend additional funds on mitigating earthquake hazards, the question of where to begin remains. There are more earthquake-prone places around the world where environmental degradation exacerbates earthquake risk than we are ever likely to be able to remedy. What would be our culpability if geoscientists convinced policy-makers to allocate funds to resolve the deforestation situation in Muzaffarabad, for example, and then a "surprise" earthquake caused slope failure (and great human tragedy) in some other city that was deemed a less immediate hazard for large earthquakes to occur?

With all of this uncertainty, geoscientists are challenged on multiple levels. It is exciting for us as researchers to be working at the frontiers of knowledge, but at those frontiers our understanding of earthquake and other Earth processes is not complete enough to provide absolute answers about environmental and natural hazards. And yet that doesn't mean that we are "off the hook." We are called upon to be "experts" for a public hungry for certainty in an uncertain world. The way that seismologists address this situation is through the development of "seismic hazard maps" (e.g., Global Seismic Hazard Assessment Program, 1999). The idea is to try to at least determine the *probabilities (and associated uncertainties)* of future earthquake ground shaking occurring at a given point on the Earth's surface. Rather than attempting to predict whether or not a specific magnitude earthquake will occur at some location, earthquake hazard mapping estimates the level of ground shaking that could occur at a given location from all possible future earthquakes at all possible distances from that location. Given a set of all the possible earthquakes and magnitudes that could affect a given location, one can estimate the probability that a certain level of ground shaking will occur at that location during some period of time (such as over the next 50 years). Of course, a sophisticated methodology for processing the latest knowledge about a process is still ultimately limited by the uncertainties associated with that knowledge base. A great deal of intellectual energy (and dispute) goes into the development and refinement of these hazard maps, and it still remains at least to some extent a high-stakes guessing game.

High quality earthquake hazard maps, based on the best available knowledge to date, can help with defining priorities regarding where to focus resources for mitigating problems of hazards, environment, and urbanization. But in the end, mapping of hazard probabilities is still in some ways both an art and a science. Hazard maps will change as new theories and new information become available, and deciding where to focus on mitigating these problems will be a moving target for the foreseeable future. We might advocate focusing resources on a certain area because it is currently at a particularly high level of hazard on a seismic hazard map, and then five years later have to deal with the possibility that a new hazard map puts that area at a significantly lower hazard. And sometimes human activities can actually affect the earthquake hazard itself, as in the case of "reservoir induced earthquakes."

4. TRAGEDY IN CHINA, 2008: A CASE OF RESERVOIR INDUCED SEISMICITY?

One of the most deadly earthquakes of modern times occurred in Sichuan, China on May 12, 2008. This magnitude 7.9 earthquake resulted in 88,000 fatalities, many of which were due to the collapse of buildings in the epicentral region (USGS, 2009a). Particularly tragic, again, were the deaths of thousands of children in schools that collapsed due to poor building construction (Amnesty International, 2009). Given the devastating effects of this earthquake, it is well remembered as a natural disaster of epic proportions exacerbated by inadequate building construction; but there is something else, less well-known, that is also "not so natural" about this earthquake: the possibility that the earthquake was triggered by the filling of the reservoir behind Zipingpu Dam, a few kilometers away from the epicenter of the quake (Kerr and Stone, 2009).

Reservoir induced seismicity (RIS) is a phenomenon that has been known to seismologists for a long time. An early example of RIS occurred when 221-meter-high Hoover Dam was built on the Colorado River in Nevada in the 1930s. The area near Hoover Dam was considered to be an area of low seismicity prior to this time. Then, as the Lake Mead was filling with water, a magnitude 5.0 earthquake struck the area in 1940 (Lay and Wallace, 1995). This earthquake caused only minor damage, but reservoir induced earthquakes have also been known to cause significant damage (e.g., DeBoer and Sanders, 2005). One of the clearest cases of reservoir induced seismicity was a magnitude 6.5 earthquake that occurred in 1967 near the Koyna Dam in India, killing about 180 people and injuring about 2,000 (e.g., Gupta, *et al.*, 1969; Chopra and Chakrabarti, 1973).

The excess weight of water can modify the stress in the Earth beneath a reservoir sufficiently to trigger an earthquake to occur before it would have occurred under natural conditions. Although there still remains uncertainty as to whether the Sichuan earthquake was indeed reservoir induced, eight years before the devastating earthquake seismologists from the Chinese Earthquake Bureau warned that the dam should not be built because it would be too close to a major fault (International Rivers, 2009), which could cause earthquake-induced dam failure and subsequent catastrophic flooding downstream. Assuming that this is a case of reservoir induced seismicity, it is important to recognize that the earthquake would likely have occurred anyway; it was just triggered by the reservoir to occur months, years, or possibly even millennia earlier than it would have occurred naturally.

Of course, it also could have turned out that the government heeded the warnings and did not build the dam, but the earthquake occurred anyway. In fact, the difference between a reservoir inducing versus not inducing an earthquake might very well depend on fine-scale details of the fault geometry and the distribution of stress in the area beneath the dam - so fine a level of detail perhaps, that no geotechnical assessment could have discerned the difference. Although it is difficult to discern in advance what the effect of constructing a dam will be on the earthquake hazard, building dams near seismically active faults always involves risks that must be carefully evaluated and incorporated into dam design plans.

As in the case cited earlier of logging and deforestation, ought we to advocate for banning dam construction everywhere there might be geological conditions that are favorable to producing reservoir induced earthquakes? Shortly after the devastating Sichuan earthquake environmental activists in China wrote an open letter to their government urging it to review plans for building additional dams in earthquake prone regions (International Rivers, 2009). But there are very many places that are prone to earthquakes, and many of those places also happen to be places where people need the water supply, flood control and hydroelectrical energy that dams can provide. Also, one could imagine a situation in which water and energy shortages were caused by a decision not to build a dam because, based on the best knowledge at the time, it seemed like a case where it might trigger earthquakes, but later analysis revealed that the proposed dam is not likely to trigger earthquakes. But even beyond the question of RIS, there is always the problem of earthquakes that are not reservoir induced causing dam failure. Thus building of dams, which is necessary to support economic development, can result in increased earthquake risk even if the resulting reservoir does not cause an earthquake to occur sooner than it would naturally.

Another problem is that it is usually much easier to discern in retrospect that the conditions appear to have been right for a reservoir to induce an earthquake than to find, before the earthquakes happen, all locations where this situation is likely to occur. While one could fantasize about a massive scientific and political project to identify all locations where reservoirs might trigger earthquakes and stop the construction of dams at those locations, it is hard to imagine how such a project could actually get funded, and how the supporters of such an endeavor would be able to convince the world that that is where we should be putting our efforts. So, we are left in a situation in which there seems to be a very good case that RIS, and/or building dams that don't cause RIS, are human activities that might bring on a natural hazard or increase the risk associated with a hazard, but how to go about mitigating the problems is not straightforward.

5. EARTHQUAKE HAZARDS IN NEW YORK CITY: WHEN URBANIZATION TURNS MINIMAL HAZARDS INTO POTENTIALLY SIGNIFICANT HAZARDS

Nowhere is the conundrum of how to find the right balance between caution and alarmism more acute than in the case of major cities built in areas where large earthquakes are clearly possible, but not a certainty. A case in point is the New York City (NYC) area, where an earthquake of magnitude 5.3 occurred in 1884, and larger earthquakes, while not certain, are also possible (e.g., Kafka, *et al.*, 1985). For the NYC area (as well as for all intraplate regions) understanding the cause of the earthquakes, the largest earthquake that could possibly occur there, and the relationship between geologically mapped faults and the earthquakes is one of the most vexing problems in all of seismology (e.g., Stein, 2007). But, given the enormity of the devastation and economic loss that could occur if there was ever to be a major earthquake in the NYC area, seismologists should not be complacent about trying to understand this problem. As seismologist Nick Ambraseys quipped, “Earthquakes don’t kill people – buildings kill people!” The better we can understand earthquake processes in NYC (and other megacities in intraplate regions), the better we will be able to help society prepare for potentially devastating earthquakes impacting these cities.

What makes this problem so vexing is that, although we know that large and damaging earthquakes have occurred in intraplate regions, unlike the situation in plate boundary regions, we do not have a complete, well verified, theory to explain why intraplate earthquakes occur where they do (e.g., Stein, 2007). And just as important, a scientific theory consists of an hypothesis proposed to explain a phenomenon, plus a reliable data set to test that hypothesis. But in the case of the NYC area (as well as all other intraplate regions), we only have a very short record of seismicity (at best a few hundred years) which is a randomly observed snapshot of a long term (millions of years) geological process. Based on that short sample, seismologists try to discern what the long term relationship is between the seismicity, geological faults, and the occurrence of potentially damaging earthquakes. We observe at most a (likely incomplete record of) a few hundred years of seismicity in the NYC area, plus a less-than-complete mapping of geological faults in the area. And it is possible (if not likely) that short the record of seismicity is a reflection of some very small detail of a very long-term process. This is like analyzing the performance of your stock portfolio over a ten minute period of time, and deciding whether to buy or sell based on that short record. While it may be possible that those particular ten minutes gives an accurate representation of the long-term performance of your investments, more likely it is not.

This is the situation we face in trying to understand the earthquake hazard in the NYC area, and yet the issue of earthquakes in urban environments is a major component of the problem of hazards, environment, and urbanization, and the seismic hazard in a city like New York cannot be dismissed. One of the most obvious human modifications of the Earth’s surface is the construction of giant urban agglomerations, of which NYC is the largest in the United States, and among the top several in the world. Construction of these megacities represents a major change to the environment on an ever-increasing percentage of the Earth’s land area. Hough and Bilham (2006) argue that since a significant percentage of the world’s urban agglomerations are now located near regions of known seismic hazard, there is a very good chance of an unprecedented one million fatality earthquake hitting a major urban area during the next century. This dangerous mix of large-scale urbanization and seismic hazard constitutes, according to Hough and Bilham, “a new experiment for life on Earth.”

To put this “new experiment” in context, in all of recorded history only one natural hazard (floods) has caused more fatalities in a single event than earthquakes. While there have been floods that have resulted in more than a million fatalities, so far only one earthquake comes even close to causing that many fatalities: the 1556 earthquake in Shensi, China, which is reported to have killed about 830,000 people (USGS, 2009b). The great death toll is thought to be a result of many of the people living in caves in unstable hillsides which collapsed. Only three other earthquakes in recorded history are reported to have killed more than 200,000 people, and none of those exceeded 300,000 fatalities (USGS, 2009b): Tangshan, China 1976 (255,000 fatalities); Aleppo, Syria 1138 (230,000 fatalities); Sumatra 2004 (228,000 fataliites). But according to Hough and Bilham, the emergence of “supercities” has increased tenfold since 1700, and more than 40 of those supercities are located within 120 miles of a major plate boundary or a historically damaging earthquake epicenter. Our planet now has many more supercities than ever before where a major earthquake could cause a million fatalities. Because of the ever-increasing density of the built enviroment, earthqaukes may soon have the dubious distinction of joining floods as the two types of natural hazards that can potentially cause a million-plus fatalities.

This is a very sobering prediction for major urban agglomerations that have been built in highly active earthquake zones, but there is also the more subtle and insidious problem of major cities, such as New York, that have been built in areas of more moderate seismic hazard that might have been only a seismologist's curiosity if a major urban center was not built there. The moderate hazard assumed for such areas is based on the very low (but not zero) probability that a major earthquake could occur there. But the tragedy that would ensue from a major earthquake in New York City would be so severe due to the dense built environment there, that the earthquake hazard in New York City must be considered seriously.

But just how great an earthquake hazard is there in NYC area? Since an earthquake of magnitude 5.3 is already known to have occurred there (the 1884 event), we should certainly be prepared for a future earthquake of that size in this region. No earthquakes greater than magnitude 5.3 are known to have occurred in the NYC area in historical times (e.g., Kafka *et al.*, 1985), but events as great as magnitude 6 and 7 are known to have occurred in other parts of the central and eastern U.S. (e.g., Hough and Bilham, 2006). So, one could argue that it is appropriately conservative to consider the possibility of a magnitude 6 (if not 7) in this area. Tantala et al. (2003) estimated that if a magnitude 6 earthquake were to occur today at the same location as the 1884 earthquake (i.e., offshore, about 15 km south of Kennedy Airport) it would cause a loss of about \$39 billion. For a magnitude 7, the loss is about \$197 billion, which is higher than the approximately \$81 to more than \$100 billion loss estimates for Hurricane Katrina (US National Weather Service, 2006). If it were to be located closer to downtown Manhattan, or at some other critical location, the loss would undoubtedly be much greater. And this brings us to the next big (and highly speculative) question of just where in the NYC area might a large earthquake occur?

On August 25, 2008, The *New York Times* published a news article entitled "Study Maps Faults for New York Quakes" in which they reported that "researchers at the Lamont-Doherty Earth Observatory at Columbia University analyzed earthquakes [in the New York City area] . . . and *mapped out a family of faults responsible for most of the earthquakes*" (emphasis ours). A reader unaware of the nuances and complexities associated with intraplate earthquakes would likely conclude from this article that the solution to this very complex problem of where future NYC area earthquakes are likely to occur, and what faults are responsible for those earthquakes, is just around the corner. The article, however, neglects to note that the identification of faults that are responsible for earthquakes in intraplate environments is one of the most complex and unresolved problems in all of seismology (e.g., Stein, 2007). The faults observed on the Earth's surface in these regions typically show geological evidence that they were active millions to billions of years ago, but whether such ancient structures are responsible for modern seismicity remains a great unknown.

One of the major reasons why this problem is so vexing is that it is plagued by what risk theorist and former financial trader Nassim Taleb calls the "narrative fallacy" (Taleb, 2007): the tendency for people to invent (and then believe) a post-hoc story to explain an observation such that it fits a coherent pattern linking cause and effect, when in fact the true story is far more complex, uncertain, and perhaps ultimately impossible to know. This is a problem that plagues a great deal of geoscience research, but it is particularly relevant to the case of trying to distinguish inactive from active faults in intraplate environments. We observe a (very short) record of seismicity, plus a map of geological faults in the area, but except for a small number of cases worldwide, none of those faults have been observed to rupture in a modern-day (i.e., non-geological time) earthquake. It is tempting, though, to invent a "story" explaining how observed seismicity is related to observed faults, but any such stories are plagued by the narrative fallacy.

The *New York Times* article about earthquakes in the NYC area goes on to say that "the study found a previously unidentified boundary, *likely a fault*, that runs 25 miles to Peekskill, N.Y., from Stamford, Conn., passing within a mile of Indian Point [nuclear power plant]" (emphasis ours). Given the complexity of the problem addressed in this study, we argue that this should be considered a case where astronomer Carl Sagan's adage applies: "Extraordinary claims require extraordinary evidence." It would, in fact, be quite extraordinary if the relationship between mapped faults and earthquakes in the NY City area (or in any intraplate environment) was actually resolved by a research team to the point that one could narrow down the causative earthquake-fault relationship such that this kind of statement about the Indian Point power plant merits being announced as "news."

These reports in the *NewYork Times* highlight one more time scale that must be considered in this discussion: the news media time scale. As the journalist John Schwartz noted, "Science is a long movie, and the news media generally take mere snapshots." The media wants to get stories out in hours (or even minutes), and scientific research works on a much longer time scale. The Earth continues to evolve on a time scale of millions of years, humans are modifying the environment on a time scale of tens to hundreds of years, and scientists are methodically working to understand the true hazards on a time scale of at least decades. Scientific research involves a give-and-take process, involving publishing, critiquing, responding to critiques, revising, and awaiting other researchers to continue investigating, until the peer review process converges on a complete (for the time being) theoretical understanding of the phenomenon in question. But the media wants to tell the story within hours of a natural disaster, or within weeks of the publication of a supposed "discovery" in a scientific journal.

Herein, then, lies the big disconnect between what the public wants to know and what geoscientists can actually provide. The public wants to know: Is there a seismically active fault passing near that nuclear power plant? Is this particular location where logging and deforestation is occurring on a mountain slope going to experience a major earthquake? Will the construction of a dam at this location trigger a major earthquake? Geoscientists can estimate probabilities of such things, but can rarely provide the level of certainty that the public wishes they could. How then should geoscientists explain these uncertain results to the public in such a way that they are adequately alerting people to a potential hazard, while at the same time not alarming them any more than necessary (and not implying a greater level of certainty than their research really confirms). This balance is difficult to achieve.

On one extreme it could be argued that when the evidence is anything less than a "smoking gun," it is best to be very cautious and not make any public statements at all on the issue, so as not to alarm the public about a hazard that might not really exist. On the other extreme, one could argue that if scientists have the slightest hint of evidence that there is the potential of a significant danger, then it is the responsibility of scientists (and journalists) to warn the public. In fact, one could argue that it is ethical to even exaggerate the danger of a natural hazard if that would increase public awareness of the problem and thus encourage people to do something to mitigate it. Achieving the right balance in these matters is an ethical challenge that geoscientists must face when dealing with issues at the intersection of hazards, environment, and urbanization.

6. FINAL REFLECTIONS

The examples described above merely scratch the surface of understanding how environmental degradation and urbanization sets us up for a new era of vulnerability to natural disasters. It is quite likely that this nexus means that it is only a matter of time before we will see enormous natural disasters that affect major urban populations on a scale that humanity has never seen before. And yet there are no clear answers to just how geoscientists, political leaders and journalists can provide a balanced approach to informing the public about both the real hazards that exist and the uncertainties associated with the devil that lurks the details. Furthermore, the examples explored in this paper only address one of the many significant natural hazard/risk fields that are affected by human activities, including hurricanes and extreme heat waves or cold snaps, floods and droughts, volcanoes and landslides, tsunami and windstorms, pestilence and disease, and many others.

Cases like the 2005 earthquake in Pakistan and the 2008 earthquake in China, as well as news stories that alarm the public about hazards they didn't even know existed, may be effective for marketing environmental consciousness, but the fear generated by these events can lead to unrealistic assessment of the true hazard. How do we responsibly convey the seriousness of the types of problems discussed here without turning caution into alarmism? How do we harness the power of the teachable moments in the days after a natural hazard without becoming alarmists for our own environmental cause at the expense of other more immediate and pressing needs? How do we communicate the new and evolving vulnerability from multiple interactive changes occurring together in a complex system involving human and natural systems?

These and related questions illustrate the ethical challenges that geoscientists will increasingly face in dealing with the interaction of natural hazards, environmental degradation and urbanization, and a public hungry for certainty in an uncertain world. It is in dialogue with ethicists, moral theologians, theological ethicists, and other professionals who deal with the ethical side of these issues that physical and social scientists can best explore the implications of scientific research on natural hazards, environmental degradation and urbanization.

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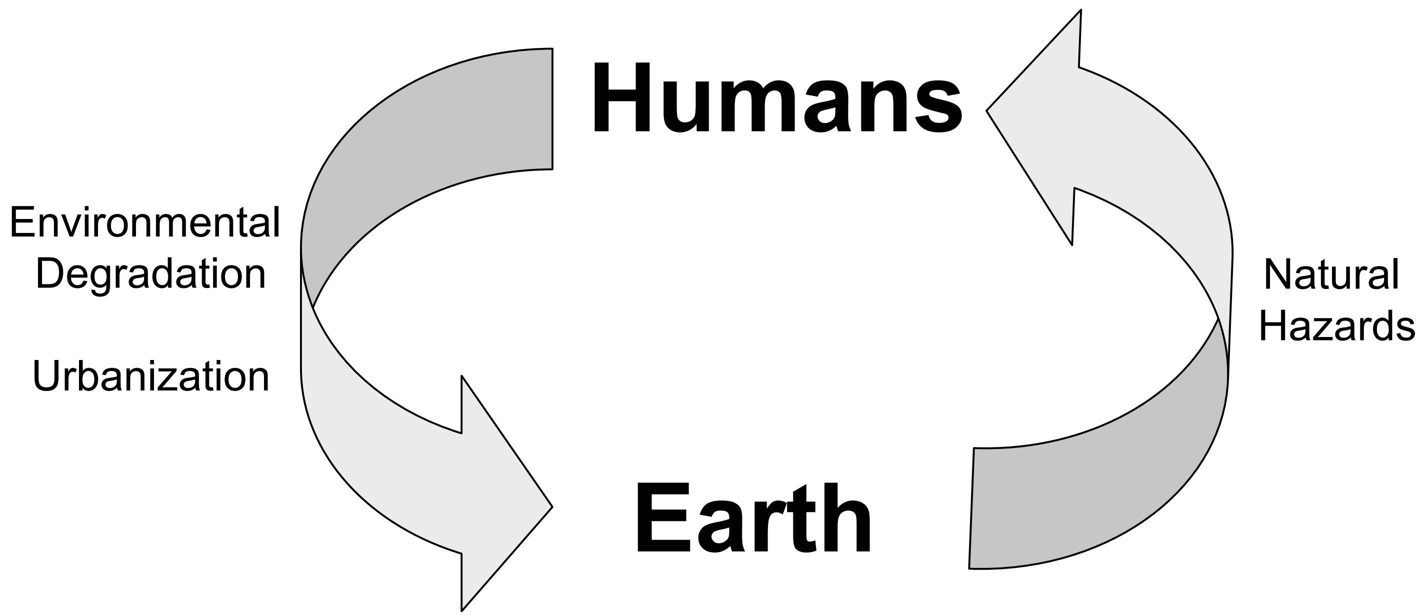

Figure 1: The interaction of Natural Hazards, Environmental Degradation and Urbanization. Human activities modify the environment in ways that create situations where environmental degradation and urbanization in hazard prone regions are worsening the devastation wrought by nature.

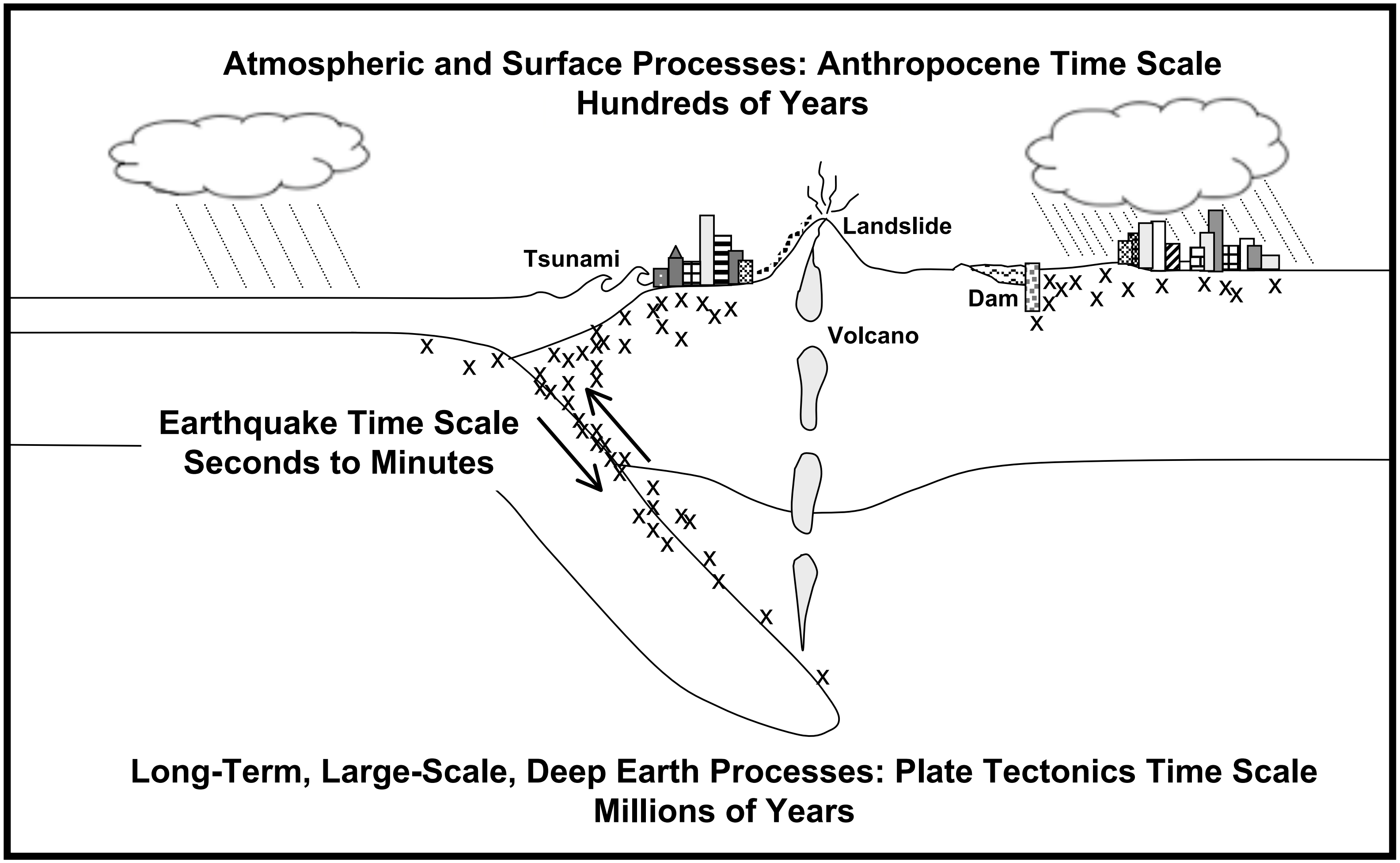

Figure 2: The interaction of Natural Hazards, Environmental Degradation and Urbanization involves processes occurring on a wide range of time scales, ranging from seconds to millions of years.