THE SCIENCE BEHIND GEOLOGIC HAZARDS AND THE ENVIRONMENT

Introduction

The Day the Earth Smiled.jpg
Figure 1.1 The Day the Earth Smiled. The arrow shows planet Earth and the moon as seen from Saturn.
On July 19, 2013, thousands of people gathered to celebrate and watch our planet taking 'a selfie' for the third time in history. The camera traveled on NASA's Cassini spacecraft, which photographed the Earth at a distance of approximately 898.4 million miles (1.45 billion kilometers) from Earth. The image shows a tiny dot, not distinct from other bright spots in the cosmic background. It reminds us that our Grand planet is a speck of dust in the immense universe. In Carl Sagan's words: "the Earth is a very small stage in the vast cosmic arena" (Sagan, 1994).

Our "Pale Blue Dot" is everything to us. It is truly all that we have. We depend on our planet and we will continue to do so, at least in the near future. This may be the reason timeless cultures refer to our planet as Mother Earth and maintain a relationship of reciprocity and gratitude. We have a responsibility to learn about our home. If we are to survive and thrive on this planet for millions of years, or at least until we can migrate to another planet, then we must take care of our home, and of one another. To use Carl Sagan's words:

"To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the Pale Blue Dot, the only home we've ever known."

Our lives are so intertwined with our Earth that even modest changes to the Earth's systems have shaped the course of civilization. Understanding Earth's systems and how they interact with us is vital for our survival and for a resilient future. The Geosciences study our planet's dynamics and materials. An understanding of the basic pillars of the Geosciences will allow you to understand the Earth's influence on you and of your influence on Earth, and this will be the focus of our first chapter. We can only preserve our world if we know something about it.

Welcome to this journey!

Learning Objectives
By the end of this chapter, you will be able to:

Explain how Earth scientists apply the scientific method to study geologic hazards and our environment.

Recognize the difference between science denial and science skepticism.
Define the links between increasing population and natural disasters.
Define unnatural disasters.
Define the stages of the demographic transition model.

1.1 Earth System Science
CAROLINA LONDONO MICHEL

The impact of human activities on the environment has never been more clear than now. Your generation may be the first one to be fully aware of the part we played in creating the many challenges facing humanity; to name a few: dwindling water reserves, widespread pollution, environmental degradation, changing climates, severe weather, and water shortages. And as our population grows, our demand for resources grows. The world needs knowledgeable people (i.e., YOU) making contentious decisions and conscientious choices. The world needs people that believe in a sustainable future and that act accordingly.

Human history records the creativity and ingenuity of people solving hard problems. The solutions to the current Earth-science-related challenges will also come from human creativity. However, as our modern society and its needs have become increasingly complex, so have the solutions. It will take a deep and subtle understanding of Earth's systems for future generations to feed, clothe, house, and provide high standards of living for all humans. We need policymakers, politicians, citizens, and businesses that are Earth science literate.

Earth Science Literacy Principles
Humans are part of the biosphere and significantly alter the Earth. Earth science literacy is an understanding of Earth's influence on you and of your influence on Earth. Science literacy is not something you achieve once and for all. Like science, scientific literacy is an ongoing process, continually reshaped and rewritten by new discoveries. An Earth-science-literate public, informed by current and accurate scientific understanding of Earth, is critical to the promotion of good stewardship, sound policy, and international cooperation. Earth science education is important for individuals of all ages, backgrounds, and nationalities (Wysession, 2009).

An Earth science-literate person

recognizes important connections between Earth's many systems
knows how to find and assess scientifically credible information about Earth
communicates about Earth science meaningfully
can make informed and responsible decisions regarding Earth and its resources

Earth System Science
Science is the systematic examination of the natural world's structure and functioning. Science is also a rapidly expanding body of knowledge, whose goal is to discover the most straightforward general principles that explain the enormous complexity of nature. These principles help scientists gain insights into the natural world and make predictions about future

change. But science is more than just a body of knowledge; science provides a means to evaluate and create new knowledge as unbiased as possible (Environmental Science – Simple Book Publishing, n.d.)

The scientific study of our planet and environment are fields of inquiry of the Earth and environmental sciences. Earth science is not a single science but an umbrella for academic fields studying different aspects of our Earth. For example geology, meteorology, oceanography, and geography are Earth sciences (also geosciences). Environmental science is a multidisciplinary field that studies environmental issues, most of the time caused by humans. The disciplines that contribute to environmental science are ecology, geology, meteorology, biology, chemistry, engineering and physics.

Earth and environmental scientists think of the Earth as a system. Instead of a collection of objects, our planet is a network of phenomena. Earth scientists seek to establish the connections, interactions, and interdependency between the planetary sub-systems or spheres: the lithosphere, the biosphere, the hydrosphere, and the atmosphere. Each sphere has individual parts or elements that do not exist in isolation. Instead, they exist in a relationship with one another. When the parts work together, a new "whole" emerges, which is more than the sum of its parts. Changes in part of one system can lead to new changes to that system or to other systems, often in surprising and complex ways. These new changes may take the form of "feedbacks" that can increase or decrease the original changes and can be unpredictable and/or irreversible. Deep knowledge of how most feedbacks work within and between Earth's systems is still lacking.

Watch this brief introduction to complex systems in this video. It will help you appreciate the intricate nature of studying Earth's systems, such as the climate system.
Earth's systems interact over a wide range of temporal and spatial scales. These scales range from microscopic to global and operate over fractions of a second to billions of years. These interactions among Earth's systems have shaped Earth's history and will determine Earth's future. Earth system science helps us understand how the Earth system worked in the past and how it might behave in the future (Wysession, 2009).

Earth is a complex system of interacting rock, water, air, and life.

The knowledge accrued by Earth and environmental scientists has practical applications AND critical implications for our civilization. Earth and environmental scientists hold keys to challenging problems that face humanity on topics such as climate change, dwindling water resources, widespread pollution, and intensifying geologic hazards. Earth and environmental scientists contribute to the flourishing and sustenance of humans on Earth and they do so through the scientific method.

Key Takeaways
The four major systems of Earth are the geosphere, hydrosphere, atmosphere, and biosphere.
Earth's systems interact over a wide range of temporal and spatial scales.

Earth's systems are dynamic; they continually react to changing influences.
Changes in part of one system can cause new changes to that system or to other systems, often in surprising and complex ways.
Earth's climate is an example of how complex interactions among systems can cause relatively sudden and significant changes.
Source: Earth Science Literacy Principles (2009).

1.2 How Do We Study the Earth?

Scientific method in Geosciences: Multiple hypotheses, multiple modes of inquiry
How is science made in the Earth Sciences? And why should you care? Even if you are not interested in becoming an Earth scientist, or any kind of scientist, understanding how science works is empowering. This is because science and scientific thinking are at the heart of our modern way of life and they influence every aspect of our lives. Understanding how science works can help you discern fact from fiction and inform your life choices and political decisions.

Backyard Geology

Image of an open crack in the middle, a Creosote tree on the side.
Figure 1.2.1 Earth fissures are deep and pose a hazard to humans and livestock. Geologists from the AZ Geological Survey have linked these cracks with excessive groundwater withdrawal. Unfortunately, these cracks cannot be filled or covered, they severely impact landowners and make the land very restricted in its uses.

Modern science is based on the scientific method, a procedure that follows these steps:

Formulate a question or observe a problem.
Apply objective experimentation and observation.
Analyze collected data and interpret results.
Devise an evidence-based theory.
Submit findings to peer reviewand/or publication.

Earth scientists use a large variety of scientific principles and methods to understand how our planet works.

1. Observation, problem, or research question

The procedure begins when scientists identify a problem or research question, such as a geological phenomenon that is not well explained in the scientific community's collective knowledge. This step usually involves reviewing the scientific literature to establish what is known and consulting previous studies related to the question.

Earth scientists can study processes they cannot observe directly. This could be because the events happen over long periods of time, happened long ago, or happened in a remote or inaccessible location. An example of the last one would be the Earth's core. To circumvent these challenges, Earth scientists have developed strategies to test their hypotheses. These strategies make up the scientific method of geosciences.

2. Hypothesis
Once the scientists define the problem or question, they propose an answer, a hypothesis.This hypothesis must be specific, falsifiable, and based on other scientific work. Earth scientists often develop multiple hypotheses, not just one, and gather data and evidence from these multiple lines. To test hypotheses, scientists use methods drawn from other sciences, such as chemistry, physics, biology, or even engineering.

3. Testing Hypotheses: Experiments and Revisions
Experimental setup shows a funnel with a viscous, black substance falling into a beaker, all covered by a glass.
Figure 1.2.2 Experimental setup at the University of Queensland. A petroleum product has been dripping since 1927 at a rate of 1 drop per decade. The goal is to study the viscosity of what appears to be a solid.

The next step is developing an experiment that either supports or refutes the hypothesis. Earth scientists conduct classic experiments in the lab. However, an experiment can take other forms, such as:

Observing natural processes and their products in the field and comparing them to those found in the rock record. For example, a sedimentologist studies how wind moves and forms dunes and different ripples in a desert. This knowledge helps her to interpret ripple structures preserved in rocks, and even to interpret dunes and aeolian processes from images collected on Mars!
Studying changes across time or space. For example, an atmospheric scientist analyzes how the composition of the atmosphere has changed since humans started measuring it and comparing it to geologic records and indirect observations of past atmosphere.
Using physical models. This is more akin to the "classic experiment. For example, a team of scientists builds a model for landslides using a long and steep ramp at a certain angle. The scientists then model slides changing the sediment to water ratio, changing the sediment type and the ramp angle.
Using computer models. For example, climatologists develop computational models to study the climate system and make predictions. These scientific models undergo rigorous scrutiny and testing by collaborating and competing groups of scientists around the world.
Considering multiple lines of evidence. To establish a scientific finding, all lines of evidence must converge. That means that all the results you collect using different methods must agree with the finding, the math must be sound, and the methods must be thoroughly described.

Regardless of what form an experiment takes, it always includes the systematic gathering of objective data. The scientists interpret this data to determine whether it contradicts or supports the hypothesis (step 2). If the results contradict the hypothesis, then scientists can revise it and test it again. When a hypothesis holds up under experimentation, it is ready to be shared with other experts in the field. The scientific community scrutinizes the findings through the process of peer review.

Examples. Multiple lines of evidence and collaboration.
Layers of dirt, showing a gray layer in the middle and right below a dark horizon.
Figure 1.2.3 A sequence of sediments deposited by a tsunami. Scientists look for different lines of evidence to determine what and how deposited these sediments.

To determine past tsunami events, scientists compare the deposits left by modern tsunamis to those found in the rock/sediment record, such as the one pictured above. But how can you be sure that a tsunami indeed deposited the sediment sequence and not a landslide, a delta, or a sudden flood? To resolve this uncertainty, scientists examine other lines of evidence, for example, are there fossils in the sediments? And if so, what type of organisms?; a landslide and a tsunami would not have fossils; what is the age of the sediments? a tsunami would show sequences that are of the same age instead of spanning over longer periods of time; what does that tell us about the deposition rate? a tsunami event piles up sediments almost instantly! and was this event recorded somewhere else? Tsunamis have been seen across the Pacific Ocean so their deposits can be found in distant coastal areas!

The North American west coast has experienced tsunamis and earthquakes every 400 years on average due to the subduction zone (see Chapter 2). Indigenous Nations living on the west coast record being nearly wiped out by tsunamis in their traditional stories. Geoscientists Brian Atwater and collaborators have documented +9 magnitude earthquakes off the coast of Washington, but the scientific community met their results with skepticism. They simply could not believe the existence of such strong earthquakes!. Such an earthquake would have triggered a tsunami that could be felt across the Pacific Ocean basin! At a society meeting with geologists from all over the world, the U.S. team found out from Japanese colleagues that Japan, which has a culture of incredibly detailed historical record-keeping, was similarly hit by tsunamis in the same time frame, and they had the dates to the day! The dates of the tsunami events, which were obtained with Carbon 14, showed a perfect match between continents. Centuries of recorded observations on both sides of the Pacific, and scientific collaboration, confirmed this discovery.

Tsunami by hokusai 19th century
Figure 1.2.4 The Great Wave of Kanagawa, painted by Hokusai in the 19th century in Japan may depict a tsunami.

4. Peer review, publication, and replication
Science is a social process. Scientists share the results of their research at conferences and by publishing articles in scientific journals, such as Science and Nature. Reputable journals and academic outlets will not publish an experimental study until they have determined its methods are scientifically rigorous, and the evidence supports the conclusions. Before they publish the article, scientific experts in the field (not part of the study) scrutinize the methods, results, and discussion; this is the peer-review process. Once a research group publishes an article, other scientists may attempt to replicate the results and use the findings to further their own research agendas. Replication is necessary to confirm the reliability of the study's reported results. A hypothesis that seemed compelling in one study might be proven false in studies conducted by other scientists. New technology can be applied to published studies, which can aid in confirming or rejecting once-accepted ideas and/or hypotheses.

5. Theory development
A portray of a man smoking a pipe
Figure 1.2.5 Alfred Wegener revolutionized science with the idea that continents have been drifting. This was the precursor of the theory of plate tectonics. Portray by Achton Friis. Public Domain in the United States.

In casual conversation, the word theory implies guesswork or speculation. In the language of science, an explanation or conclusion made into a theory carries much more weight because experiments support it and the scientific community widely accepts it. A hypothesis that has been repeatedly confirmed through documented and independent studies eventually becomes accepted as a scientific theory.

While a hypothesis provides a tentative explanation before an experiment, a theory is the best explanation after being confirmed by multiple independent experiments. Confirmation of a theory may take years, or even longer. For example, the scientific community initially dismissed the continental drift hypothesis first proposed by Alfred Wegener in 1912 (see Chapter 2). After decades of additional evidence collection by other scientists using more advanced technology, Wegener's hypothesis was accepted and revised as the theory of plate tectonics.

The theory of evolution by natural selection is another example. Originating from the work of Charles Darwin in the mid-19th century, the theory of evolution has withstood generations of scientific testing for falsifiability. It has been updated and revised to accommodate knowledge gained by using modern technologies, but the latest evidence continues to support the theory of evolution.

What is Science?

We covered the scientific method of geosciences. But science is a human endeavor, not the property or invention of one culture. For generations, indigenous peoples have accrued empirical knowledge of the natural world, including the lithosphere. Greg Cajete uses the name Native Science to refer to “the collective heritage of human experience with the natural world” (Cajete, 2000). Geologic expertise served tribal peoples in many of the same ways that Western geology serves modern civilizations. For example, Native Americans in Cascadia coded volcanic eruptions in stories. Oral history then transmits cross-generational awareness of volcanic hazards. The Muiscas in Colombia knew how to find, mine, and process the gold to make beautiful art pieces, and the Puebloans of the North American Southwest managed limited water resources using an impressive net of canals that we still use for our benefit. Western and Native scientists can collaborate to further our understanding of the Earth’s systems and to remember how to live well on our planet.

Science is a dynamic process. Technological advances, breakthroughs in interpretation, and new observations continuously refine our understanding of Earth. We will never stop learning about our Earth. As new findings are published, we must revise and update our scientific knowledge and discard ideas that are proven false by new observations. Science is a living entity.

In conclusion, Earth scientists do not use a single, all-encompassing “scientific method.” Instead, multiple modes of inquiry respond to the complexity and spatial and temporal scales of Earth systems.

“The unique thing about the geosciences is that the knowledge, skills, and methods are brought together, refined, and developed over time to make them most suitable for understanding the complex processes of Earth, its working in the past and the present, and its likely behavior in the future” (Manduca & Kastens, 2012.)

Key Takeaways
Besides the classical laboratory experiment, Earth scientists construct models or use indirect methods to study the Earth.
Scientific results are not valid or useful unless other scientists can reproduce them. Research results undergo scrutiny by the community before and after being published.
The study of geological and environmental issues requires multiple disciplines and the interplay of multiple methods.
Scientific thinking advances through collaboration and community.
GeoEthics
Hopetoun falls.jpg

Figure 1.2.6 The beauty of natural landscapes unspoiled by humans can serve as a reminder to act ethically.

Geoscientists must act in ethical ways to contribute to the welfare of human beings. The saying "with great knowledge comes great responsibility" holds true for Earth and environmental scientists. Earth scientists must uphold high standards in research and conduct. The research and reflection upon the values which underpin behaviors and practices between humans and Earth systems is the arena of "Geoethics" (Di Capua & Peppoloni, 2019). The International Association for Promoting Geoethics (IAPG) provides tools to "understand the complex relationship between human action on ecosystems and the decisions geoscientists make in the discipline that impact society, including improving the awareness of professionals, students, decision-makers, media operators, and the public on an accountable and ecologically sustainable development." Source: Di Capua et al., https://www.geoethics.org/geoethics-school

All of us human beings have responsibilities to Earth. We do not exist apart from this planet and our behaviors impact other people, other species, and the larger biosphere, hydrosphere, atmosphere, and lithosphere. Our actions impact the Earth's system. As you progress in your learning, strive to think critically and identify ethical issues. Do not be afraid to question and discuss your observations with your instructor and with peers. Just remember to do so respectfully, considering other points of view and practicing active listening.

1.3 Information Literacy

What's your source? Learning to identify reliable information

A Need for Skepticism

Scientific information and understanding will always be subject to uncertainty. Therefore, predictions will always be inaccurate to some extent. We must critically interpret all information and predictions in environmental science with uncertainty in mind. Apply critical thinking whenever learning about an environmental issue, whether it involves listening to a speaker in a classroom, at a conference, or on video, or when reading an article in a newspaper, textbook, website, or scientific journal. Because of the uncertainty of many predictions in science, and particularly in the environmental realm, a certain amount of skepticism and critical analysis is always useful.

Environmental issues and reducing the impact of geological hazards are acutely important to the welfare of people and other species. Science and its methods allow for a critical and objective identification of crucial issues, the investigation of their causes, and a degree of understanding of the consequences of environmental change. Scientific information influences decision-making about environmental issues, including whether to pursue expensive strategies to avoid further, but often uncertain, damage.

However, scientific information is only one consideration for decision-makers, who are also concerned with the economic, cultural, and political contexts of environmental problems. When deciding how to deal with the causes and consequences of environmental changes, decision-makers may give greater weight to non-scientific (social and economic) considerations than scientific ones, especially when there is uncertainty about the latter. The most critical decisions about environmental issues are made by politicians and senior bureaucrats in government, or by private managers, rather than by Earth and environmental scientists. Decision-makers typically worry about the short-term implications of their decisions on their chances for re-election or continued employment, and on the economic activity of a company or society at large, as much as they do about environmental damage. (Environmental Science – Simple Book Publishing, n.d.) That is why the United States struggled so much with the COVID-19 pandemic. On one end of the response was a focus on health science. On the other were economists worried about collapsing the economy. It was ultimately up to politicians to decide on how much the nation should "lockdown" and how much the nation needed to stay economically "open."

Introductory science courses usually deal with accepted scientific theory and do not include opposing ideas, even though these alternate ideas may be credible. This makes it easier for students to understand complex material. Advanced students will encounter more controversies as they continue to study their discipline.

Some groups argue that some established scientific theories are wrong, not based on their scientific merit but the group's ideology. This section focuses on how to identify evidence-based information and differentiate it from pseudoscience.

Science Denial

Science denial happens when people argue that established scientific theories are wrong, or not based on scientific merit but on subjective ideology—such as for social, political, or economic reasons. Organizations and people use science denial as a rhetorical argument against issues or ideas they oppose. Three examples of science denial versus science are:

Teaching creationism vs. evolution in public schools
Denying the relationship between tobacco smoke and cancer
Claiming that human activity is not linked to climate change
Video 1.3.1 Science denial and skepticism (9:16). Learn to recognize the difference!

Let us look at climate change. A climate denier explicitly denies or doubts the objective conclusions of geologists and climate scientists. Science denial uses three false arguments. The first argument tries to undermine the scientific conclusion's credibility by claiming the research methods are flawed, or the theory is not "universally accepted"—the science is unsettled. The notion that scientific ideas are not absolute creates doubt for non-scientists; however, let's not confuse a lack of universal truths with scientific uncertainty. Because science is based on falsifiability, scientists avoid claiming universal truths and use language that conveys uncertainty. This allows scientific ideas to change and evolve as more evidence is uncovered.

Video 1.3.2 Why do some people don't believe in climate science (7:33).

The second argument claims the researchers are not objective, and that they are motivated by ideology or economic agendas. This is an ad hominem argument in which a person's character is attacked instead of the merit of their argument. Science deniers claim researchers need to justify asking for funding, therefore they manipulate the results. Or they can claim that because the research funds came from the federal government, the researchers use their results to lobby for expanded government regulation. This shows a lack of knowledge of how funding science works.

The third argument is to demand a balanced view, equal time in media coverage, and educational curricula to engender the false illusion of two equally valid arguments. Science deniers frequently demand equal coverage of their proposals, even when there is little scientific evidence supporting their ideology. For example, science deniers might demand the dominant religious explanations to be taught as an alternative to the well-established theory of evolution. Alternatively, all potential causes of climate change are discussed as equally probable, regardless of the heavy body of evidence that shows one dominant cause of our current climate change.

Conclusions derived using the scientific method are different from those based on ideologies. Conclusions about nature derived from ideologies are outside the area of science research and education. For example, it would be inappropriate to teach the Flat Earth model in modern Earth science courses because the scientific method has disproved this idea. Unfortunately, widespread scientific illiteracy allows these arguments to be used to suppress scientific knowledge and spread misinformation.

The formation of new conclusions based on the scientific method is the only way to change scientific conclusions. We would not teach 'Flat Earth' geology and plate tectonics because Flat Earthers do not follow the scientific method. See video 1.3.3. That scientists avoid universal truths and change their ideas as more evidence is uncovered means that our knowledge evolves, not that the science is unsettled. Because of widespread scientific illiteracy, these arguments are used by those who wish to suppress science and misinform the general public.

Video 1.3.3 Arguments for Flat Earth vs. Round Earth (10:10).

In a classic case of science denial, beginning in the 1960s and for the next three decades, the tobacco industry and their scientists used rhetorical arguments to deny a connection between tobacco usage and cancer. Once it became clear scientific studies overwhelmingly found that using tobacco dramatically increased a person's likelihood of getting cancer, their next strategy was to create a sense of doubt about the science. The tobacco industry suggested the results were not yet fully understood, and more study was needed. They used this doubt to lobby for delaying legislative action to warn consumers of the potential health hazards. Those who deny the significance of human involvement in climate change currently employ this tactic.

Evaluating Sources of Information

Figure 1.3.1. Steps to fact check your information.

In the internet age, information is plentiful. Anyone exploring scientific inquiry must discern valid sources of information from pseudoscience and misinformation. Scientifically reliable information is derived through the scientific method and is as unbiased as possible. A valid inference or interpretation is based on objective evidence or data. Credible data and inferences are clearly labeled, separated, and differentiated. Anyone looking over the data can understand how the author's conclusion was derived or come to an alternative conclusion.

Scientific procedures are clearly defined, so the investigation can be replicated to confirm the original results or expanded further to produce new results. These measures make a scientific inquiry valid and its use as a source reputable. Of course, substandard work occasionally slips through, and retractions are published from time to time. An infamous article linking the MMR vaccine to autism appeared in the highly reputable journal Lancet in 1998. Journalists discovered that the author had multiple conflicts of interest and fabricated data, and the article was retracted in 2010.

In addition to methodology, data, and results, the authors of a study should be investigated. An author's credibility is based on multiple factors, such as having a degree in a relevant topic or being funded from an unbiased source.

The same rigor should be applied to evaluating the publisher, ensuring the results reported come from an unbiased process. The publisher should be easy to discover. Good publishers will show the latest papers in the journal and make their contact information and identification clear. Reputable journals show their peer review style. Some journals are predatory, where they use unexplained and unnecessary fees to submit and access journals. Reputable journals have recognizable editorial boards. Often, a reputable journal will associate with a trade, association, or recognized open-source initiative.

One of the hallmarks of scientific research is peer review. Research should be transparent to peer review. This allows the scientific community to reproduce experimental results, correct and retract errors, and validate theories. This allows the reproduction of experimental results, corrections of errors, and proper justification of the research to experts.

Citation is imperative to avoid plagiarism and also allows readers to investigate an author's line of thought and conclusions. When reading scientific works, it is essential to confirm that the citations are from reputable scientific research. Most often, scientific citations are used to reference paraphrasing rather than quotes. The number of times a work is cited is said to measure the acceptance the investigation has within the scientific community, although this technique is inherently biased (Environmental Science – Simple Book Publishing, n.d.)

Critical Evaluation of an Overload of Information

More so than any previous society, we live today in a world of accessible and abundant information. It has become remarkably easy for people to communicate with others over vast distances, turning the world into a “global village” (a phrase coined by Marshall McLuhan (1911-1980), a Canadian philosopher, to describe the phenomenon of universal networking). Technologies have facilitated this global connectedness for transferring ideas and knowledge – mainly electronic communication devices, such as radio, television, computers, and their networks. Today, these technologies compress space and time to achieve a virtually instantaneous communication. So much information is now available that the situation is often referred to as an “information overload” that must be analyzed critically. Critical analysis is the process of sorting information and making scientific inquiries about data. Involved in all aspects of the scientific process, critical analysis scrutinizes information and research by posing sensible questions such as the following:

Is the information derived from a scientific framework consisting of a hypothesis that has been developed and tested within the context of an existing body of knowledge and theory in the field?
Were the methodologies used likely to provide data that are objective, accurate, and precise?
Were the data analyzed using statistical methods appropriate to the data structure and the questions being asked?
Were the results of the research compared with other pertinent work that has been previously published? Were key similarities and differences discussed and a conclusion deduced about what the new work reveals about the issue being investigated?
Is the information based on research published in a refereed journal that requires highly qualified reviewers in the subject area to scrutinize the work, followed by an editorial decision about whether it warrants publication?
If the analysis of an issue was based on incomplete or possibly inaccurate information, was a precautionary approach used to accommodate the uncertainty inherent in the recommendations?
All users of published research have an obligation to critically evaluate what they are reading in these ways in order to decide whether the theory is appropriate, the methodologies are reliable, and the conclusions sufficiently robust. Because so many environmental issues are controversial, with data and information presented on both sides of the debate, people need to formulate critical judgments. Thus, people need a high degree of environmental literacy – an informed understanding of the causes and consequences of environmental damage. Being able to analyze information critically is a key personal benefit of studying Earth and environmental science.

1.5 Human Population and Sustainability

Human Population

The study of population has never been more important than it is today. We are close to 8 billion people on the planet, but most of this growth has occurred in the last 100 years, in developing nations. With a projected population growth of between 9-11 billion by 2050 and the effects of climate change on the environment, we can reasonably expect the impact of geological disasters to be greater.

The overall purpose of this section is to introduce the population distribution and population growth issues that can exacerbate geological processes and turn them into disasters and catastrophes. This course emphasizes a geographic perspective on population growth as a relative concept. This section also identifies the main reasons why people migrate over time: economic, political, cultural, and environmental.

Population Growth

The study of the human population has never been more critical than it is today. There are close to 8 billion people on the planet, but most of this growth has occurred in the last 100 years, mostly in developing nations. Humans do not live uniformly around the world, but in clusters because of the earth's physical geography. Environments that are too dry, wet, cold, or mountainous create a variety of limiting factors for humans. Two-thirds of the world's population is within three significant clusters: East Asia (China), South Asia (India and Indonesia, and Europe, with the majority in East and South Asia.

Video 1.5.1 How did we get so big so fast? (2:38). Our population reached 7 billion in 2011. Several videos brought awareness of this fact. Watch this demonstration that uses water and dripping vessels to simulate our population to try to answer, how did we get here? Note, in 2022 we are reaching the 8 billion count.

Neither people nor resources are distributed uniformly across Earth. Regarding population growth, geographers emphasize three elements: the population size, the rate of increase of world population, and the unequal distribution of population growth. Geographers seek to explain the patterns that exist and the changes between the patterns.

Human geography emphasizes a geographic perspective on population growth as a relative concept. Human-environment interaction and overpopulation can be discussed in the contexts of carrying capacity, the availability of Earth's resources, and the relationship between people and resources.

Demographers, scientists that study population issues, and other scientists say there is more to the story than pure population growth. Ecologists believe that humans have outgrown the Earth's carrying capacity. There are not enough of the world's resources to give every human a standard of living expected by most Americans. If all the people on the planet lived the average American lifestyle, it would require over three Earths, some people calculate five Earths. But, if we were to live as a Bangladeshi villagers then our planet could sustain 15 to 20 billion people (Eisntein, 2019). This means that "How we live is at least as important as how many we are"

(Einstein, 2019). As of March 22, the United States Census Bureau estimates that the world population is nearly 7.9 billion, with a growth rate of roughly 1.07 percent, or roughly 82 million people per year. The world population reached 6 billion in 1999 and 7 billion in 2011. If the current growth rate continues, the human population will reach 8 billion by 2023 and hopefully level off at roughly 10 billion by 2055. Between 2010 and 2050, world population growth will be generated mostly in developing countries. But will we ever get to 11 billion?

Video 1.5.2 Why the world population won't exceed 11 billion (16:36). In this segment of one of his lectures, famous Professor Hans Rosling uses statistics to summarize population growth and explains why the total human population will never reach 11 billion, as others predict and fear.

Distribution of the World's Population

Geography is a significant factor in population distribution. Humans only occupy five percent of the Earth's surface because oceans, deserts, rainforests, and glaciers cover much of the planet. Humans cannot live in many parts of the world due to moisture, temperature, or growing season issues. For example, 20 percent of the world is too dry to support humans. This mostly has to do with high-pressure systems around 30 degrees north and south of the equator where constant sunny conditions have created some of the world's largest deserts. Some of these include the Sahara, Arabian Peninsula, Thar, Takla Makan, and Gobi deserts. Most deserts do not provide enough moisture to support agriculture for large populations.

Regions that receive too much moisture also cause problems for human settlement. These are tropical rainforest regions located between the Tropic of Cancer (23.5 degrees North) and the Tropic of Capricorn (23.5 degrees South). The problem with these regions of the world has to do with the soil erosion due to high precipitation. High levels of precipitation hinder agricultural production because nutrients in the soil are washed away. This is partly why slash-and-burn agriculture occurs in these regions. Locals will burn part of the forest to put nutrients back into the ground. This only works for a short period because the precipitation washes away nutrients within a few years, so farmers move on to other parts of the forest with their slash-and-burn practices.

Additionally, regions that are too cold pose problems for large population clusters and food production. The cold Polar Regions have a short growing season, and many of the Polar Regions have limited amounts of moisture because they are covered by high- pressure systems (much like the desert regions). Thus, cold polar regions experience low temperatures and lack of moisture, despite access to snow, ice, and glaciers. Mountainous and highland regions lack population clusters due to steep slopes, snow and ice cover, and short growing seasons.

The term for areas where humans permanently settle is ecumene. Population growth and technology explode the ecumene of humans, which affects the world's ecosystems.

Future of Population Growth: Ethics and Politics

What is overpopulation? Most people equate overpopulation with crowding, but, in fact, density is irrelevant to questions of overpopulation. or example, we could pack all ~8 billion humans in California, but that is not desirable, sanitary, or sustainable. What is relevant is carrying capacity. We overpopulate an area when its long-term carrying capacity is being degraded by its current human occupants.

How many people can the earth support? That depends on people's lifestyles, which affects the rates at which they consume resources. In more affluent countries, people consume resources at a greater pace, residents eat a diet with more animal products, use more energy in homes, and produce more goods. So, if everyone lived as they do in wealthier countries, Earth's resources could support fewer people than the number currently living on the planet today. The average rates at which people consume resources like oil and metals, and produce wastes like plastics and greenhouse gases, are about 32 times higher in North America, Western Europe, Japan, and Australia than they are in the developing world. In the least developed countries, people use fewer resources but often suffer from malnutrition and fewer opportunities to lead healthy lives and contribute to their nation's economy.

Global demand for natural resources has doubled in the past 50 years. Our ecological footprint is a measure of how fast we consume resources and generate waste compared to how fast nature can absorb our waste and generate new resources. Scientists calculated that since the 1970s, our demand for resources has exceeded what the earth can regenerate in a year. It now takes 1.6 years to regenerate what we use in one year. Rather than consider how many people could live on Earth, we should consider a sustainable balance of people and resources that raises the standard of living around the globe without degrading the environment.

Video 1.5.3 Learn about an infamous overpopulation bet between two demographers (4:48).

Global Population Trends

A region's population will grow as long as its crude birth rates are higher than its crude death rates. A crude birth rate (CBR) is the total number of live births for every 1,000 people in a given year. So, a crude birth rate of 10 would mean ten babies are born every year for every 1,000 people in that region. Crude death rates (CDR) are the total number of deaths per 1,000 people in a year.

When comparing CBRs to CDRs, a region's natural increase rate can be determined. A natural increase rate (NIR) is the percent a population will grow per year, excluding annual migration. Usually, an NIR of 2.1 is required to maintain or stabilize a region's population. Any more than that and the population will grow, any less than a NIR of 2.1 causes population contraction. The reason the NIR percent is 2.1 and not 2.0 for stability is because not every human will pair up and have a child because of genetics, choice, or death before childbearing years. Once we know the NIR, we can determine the doubling time. Doubling time is how many years it would take for a defined population to double, assuming that NIR stays the same over time. Currently, about 82 million people are added to the world's global population every year.

A useful tool used by scientists that focus on demographics is a population profile, also called a population pyramid. A population profile visually shows a particular region's demographic structure concerning males and females and is often expressed in numbers or percentages.

Video 1.5.4 The population pyramid explained (5:00)

Environmental Impacts

There are many ways in which our large and growing human population impacts the global environment. Using resources faster than natural processes can replenish them is just part of the issue. Over the past 50 years, humans have altered ecosystems more rapidly and extensively than in any other comparable period in history, primarily to meet the rapidly growing demands for food, freshwater, timber, fiber, and fuel.

Climate Change: Our global temperature is on the rise due to the ever-increasing amount of greenhouse gases that are emitted through human activities, including fossil fuel use, deforestation, and livestock grazing. This warming is causing sea-level rise from Arctic ice melt, more extreme weather, and loss of habitat, including coral reefs. Population growth only exacerbates climate change, as more people demand more food and energy. With renewable energy supplying only a small fraction of total energy use, fossil fuel use is expected to expand for the foreseeable future.

Water Scarcity: About 35 percent of the world's people already face chronic water shortages. As the population grows, we need more water for agriculture and industry, as well as for domestic uses. A child born in the developed world consumes 30-50 times as much water as one born in the developing world. The worldwide supply of clean, accessible water is further reduced by pollution. In 2017, over 785 million people lacked access to basic water and sanitation services and over 884 million people did not have safe water to drink (CDC).

Biodiversity Loss: Nearly all the world's ecosystems are shrinking to make way for more humans and their homes, farms, factories, and shopping centers. Globally, 13 million hectares of forest (about the size of Costa Rica) were lost each year from 2000 to 2010, as much of it was cleared or degraded by human activities. Forests play an important part in climate change mitigation. Forests store a vast amount of carbon. When we cut down a forest to convert it for another use, we release carbon back into the atmosphere. The World Wildlife Fund's Living Planet Index shows a 30 percent decline in Earth's biodiversity since 1970; a 60 percent decline in the tropics. According to the World Conservation Union, 1 in 3 amphibians, 1 in 4 mammals, 1 in 8 seabirds, and 70 percent of plants are at risk of extinction due primarily to human alteration of their habitats.8 Humans depend on rich biodiversity for survival—food, medicines, climate regulation, and more.

Unnatural Disasters

Former UN Security General Kofi Annan has said, “The term natural disaster has become a misnomer increasingly. Human behavior transforms natural hazards into unnatural disasters.” Most deaths from natural disasters occur in less developed countries. According to the United Nations, a less developed country (LDC) is a country that exhibits the lowest indicators of socioeconomic development and is ranked among the lowest on the Human Development Index. Those who live in low-income environments tend to have the following characteristics:

Live in areas that are at a higher risk of geologic, weather, and climate-related disasters
live in areas that lack the economics and resources to provide a safe living infrastructure for its people
have few social and economic assets and a weak social safety net, and
lack the technological infrastructure to provide early warning systems
As human populations have grown and expanded, and technology has allowed us to manipulate the environment, natural disasters have become more complex and arguably more “unnatural.” There are a variety of ways humans have not only influenced but magnified the impacts of disasters on society. For simplification, this book will narrow it down to four: human population growth, poverty and inequality, environmental degradation, and climate change.

Video 1.5.5 What do we mean when we talk about development? (2:40).

What Will the Future Hold for People and the Planet?

We could achieve sustainability if the population stabilizes, if we use resources more efficiently and redistribute them uniformly and if we learn to live within the means of this planet. The good news is that the very conditions that will help the population stabilize are those that help people live longer, healthier lives, raise healthier children, and enjoy greater prosperity. These include universal education and gender equality, access to reproductive health care, and family planning services. Achieving ecologically sustainable lifestyles will take ingenuity and a sense of shared responsibility for the ecosystems that sustain us all. Richer nations will need to reduce their large footprints and emerging economies will need to find new models of growth to improve their citizens’ well-being in ecologically sustainable ways.

1.6 Earthlight

We opened our chapter considering the view of our planet from Saturn. We noticed how small it looked, how unremarkable in the vastness of the cosmos.

Let us now consider a new perspective. One that Dr. Proctor, a member of the Inspiration4 mission, brings us in her poem: Earthlight.

Video 1.6.1. Earthlight poem. Written and recited by Dr. Sian Proctor.

Earthlight
(transcript)

I thought the moonlight was my guiding light

Until that day, when my soul shimmered,

Eyes wide and dilated with realization,

For there, I was being bathed in Earthlight

Tasered by the pulsating Earth glow

My weeping ego quivers

Spellbound in awe at the cosmic chaos

Perched against the death

A clear beacon of hope and longing

Etched by complex molecules and spiraling DNA

Golden strands of energy cascading outward

Encapsulating hopes and dreams

Existence and affirmation

The baby's blanket ripped away

I howl at the sensation

Love struck in suspension

My mind struggles to comprehend

So much meta transcending time and space

Who will hear the cries of the generations?

AfroGaia simmers under the weight of memories

I hold court among the stars, and I testify to the cosmos

All our hopes set adrift

Let us be free in a sea of forgiveness

for what we have not seen

If only we could all be baptized by Earthlight!

Imagine

Recall the experience of being under a bright full moon. How does it make you feel? In your mind, imagine the full moon in a clear sky, in one of your favorite places on Earth.

Now imagine that you are part of a civilian flight. You open the capsule and find yourself bathed in Earth's light. How would that feel and look like? If you are inspired to do so, in a piece of paper write your thoughts or sketch your feelings. Depending on your artistic preferences, you may also try moving, dancing, singing or playing a tune that conveys the feeling.

Part of the Earth globe appears as a blue arc against a black background.

Figure 1.6.1 The Earth atmosphere reflects back the light from the Sun, giving our planet a beautiful shine, or Earth light

We may not be part of a civilian flight, but we can travel on the ship of our imagination. Let Dr. "Leo" Proctor's poem touch you. Let us consider the magnificence, beauty, and glow of our planetary home encountering the rays of our Sun. We may never experience it directly, but we are ALL surrounded by Earthlight, held by Earthlight, and filled with Earthlight.

Meet a Local Rock-Star

Sian Hayley "Leo" Proctor (born March 28, 1970) is an American geology professor, science communicator, and commercial astronaut. She was the pilot of the Crew Dragon space capsule, launched on September 15, 2021, for the Inspiration4 private orbital spaceflight. As the pilot on the Inspiration4 mission, Proctor became the first African American woman to pilot a spacecraft.

Sian is a geology professor at South Mountain Community College in Arizona, where she has been inspiring students for over 21 years. She is currently the Open Educations Resource Coordinator for the Maricopa Community College District (She supports books like this, Free and Open). She is also a Major in the Civil Air Patrol where she serves as the aerospace education officer for its Arizona Wing.

Besides all the wonderful credentials, Dr. Proctor is a space artist. She uses her afrofuturism space art to encourage conversations about women of color in the space industry. She is also one of The Explorer's Club 50: Fifty People Changing the World. Her motto is called Space2inspire where she encourages people to use their unique, one-of-a-kind strengths, and passion to inspire those within their reach and beyond. She believes we need to actively strive for a J.E.D.I. space: a Just, Equitable, Diverse, and Inclusive space as we advance human spaceflight.

Visit Dr, Proctor's website: http://www.drsianproctor.com/ for more.

1.7 Attributions and References

Creative Commons Resources for Chapter Text

The following resources have been used for research, starting points, and inspiration for this chapter. Unless otherwise noted in Attributed References or Media Assets, materials have been significantly reworked by this text's authors.

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4. Natural Disasters and Human Impacts by R. Adam Dastrup, MA, GISP is licensed under CC BY-NC-SA 4.0

5. Physical Geology – 2nd Edition by Steven Earle is licensed under CC BY-NC-SA 4.0

6. Geology by Lumen Learning is licensed under CC BY-NC-SA 4.0

7. Earth Science by Lumen Learning is licensed under CC BY-NC-SA 4.0

8. Essentials of Geographic Information Systems by Jonathan E. Campbell and Michael Shin is licensed under CC BY-NC-SA 4.0

Media Assets

Fig. 1.1 NASA/JPL- Caltech Science Institute. (2013)The Day the Earth Smiled.jpg [Photograph]. Wikimedia Commons. Retrieved February 4, 2021, https://commons.wikimedia.org/wiki/File:The_Day_the_Earth_Smiled.jpg#/media/File:The_Day_the_Earth_Smiled.jpg

An image showing our planet at Saturn's distance. The image makes the point of the tiny dot where we live.
1.1

Fig. 1.1.1 NASA / Apollo 17 crew. (1972). The Blue Marble. [Photograph]. Wikimedia Commons. Retrieved February 4, 2021,
https://commons.wikimedia.org/wiki/File:The_Earth_seen_from_Apollo_17.jpg

Picture of the Earth as seen from the moon.
1.2
Fig. 1.2.1. CWanamaker. (2014). Earth Fissure North of Hunt Highway – panoramio.jpg [Photograph]. Wikimedia Commons. Retrieved June 5, 2021
https://commons.wikimedia.org/wiki/File:Earth_Fissure_North_of_Hunt_Highway_-_panoramio.jpg

An image of an Earth fissure in Southern Arizona. Earth fissures are mass wasting processes related to subsidence. The terrain cracks due to groundwater overdraft.
Fig. 1.2.2 Mainstone, J. (2007). Pitch drop experiment [Photograph]. Wikimedia Commons. Retrieved June 5, 2021,
https://commons.wikimedia.org/wiki/File:University_of_Queensland_Pitch_drop_experiment-6-2.jpg

Experimental setup shows a funnel with a viscous, black substance falling into a beaker, all covered by a glass.
Fig. 1.2.3. Stozy10. (2013). Storegga tsunami deposits, Montrose basin (Maryton).jpg [Photograph]. Wikimedia Commons. Retrieved June 5, 2021,
https://commons.wikimedia.org/wiki/File:Storegga_tsunami_deposits,_Montrose_basin_(Maryton).jpg

A sequence of sediments of different colors to make student think about the different origins that these could have. They were deposited by a tsunami.
Fig. 1.2.4. Hokusai, K. (n.d.) The Great Wave off Kanagawa. [Modern recut copy]. Wikimedia Commons. Retrieved June 5, 2021,
https://commons.wikimedia.org/wiki/File:The_Great_Wave_off_Kanagawa.jpg#/media/File:The_Great_Wave_off_Kanagawa.jpg

An image of a famous art piece showing big waves off the coast of Japan.
Fig. 1.2.5. Friis, A. (1907). Alfred Wegener by Achton Friis.jpg. [Photograph]. Wikimedia Commons. Retrieved June 5, 2021,
https://commons.wikimedia.org/wiki/File:Alfred_Wegener_by_Achton_Friis.jpg

A portray of Alfred Wegener during one of his expeditions, painted by Achton Friis. The picture humanizes the scientist and shows how artists have also contributed to the history of science.
Fig. 1.2.6. Ilif, D. (2005). Hopetoun Falls. [Photograph]. Wikimedia Commons. Retrieved June 5, 2021, Retrieved Jun 5, 2021, https://commons.wikimedia.org/w/index.php?curid=43330268

A decorative image of a beautiful landscape to symbolize geoethics and how the responsible exercise of the geosciences can

1.3
Fig. 1.3.1. Indiana University East, campus library (n.d.) Infographic Information literacy. Retrieved April 12, 2022, http://s3.amazonaws.com/libapps/accounts/10280/images/howtofactcheck.jpg. CC-BY-NC 4.0

A diagram showing boxes of different sizes and colors, the larger the box, the larger the populations. The bigger boxes are China followed by India and USA.

1.4
Fig. 1.4.1. NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022).

Plot with months on the X axis, billions of dollars on the Y axis. Different lines are plotted to represent the years 2018, 2020, 2012, 2005, 2017 and 2021.
1.6
Fig. 1.6.1. (n.a.) Earth Science Stack Exchange [Photograph of the Earth from Space]. Retrieved April 26, 2022 from https://earthscience.stackexchange.com/questions/7283/how-high-must-one-be-for-the-curvature-of-the-earth-to-be-visible-to-the-eye

Part of the Earth globe appears as a blue arc against a black background.
Video 1.6.1. [Online Video] https://www.youtube.com/watch?v=9xNjyLjUu8w&feature=emb_imp_woyt&ab_channel=Dr.SianProctor, CC BY.

Dr. Sian Proctor shares her poem Earthlight based on her experience as a SpaceX Astronaut for the Inspiration4 Mission.
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Teacher Resources

1.1 Carl Sagan's Pale Blue Dot Video: https://youtu.be/wupToqz1e2g

1.2 International Association for Promoting Geoethics IAPG https://www.geoethics.org/

1.3 Interactive Media Bias Chart: https://www.adfontesmedia.com/interactive-media-bias-chart/

1.3 Professor Jeff Simpson Geonews: http://softpath.org/geonews.html Provides current Geonews with commentary

1.5 World population clock: https://www.worldometers.info/world-population/ An interactive website with live population counts and useful statistics such as Top 20 largest countries by population (live); plot for growth rate, historical world population data, population milestones, maps with world population density, etc.

1.5 United States Census Bureau https://www.census.gov/popclock/ is another good interactive website focused on the U.S. population

1.5 Population pyramid.net is another great interactive website that has the population pyramids for several countries in the world.