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Impacts of Climate Change on Water

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Abstract:
This paper reviews the effects of climate change on our water supply. We look at the melting of major ice caps globally and explore the effects that this will cause on water availability and use. Further, this paper serves to promote discussion on key elements to water management, which include regulating emissions, promoting green technologies, and encouraging water efficiency. The key finding lies in the need for greater discussion of water use for effectively minimizing the negative impacts of climate change on stakeholders while supporting specific policy objectives of water management.

Keywords: *Water management, climate change, energy policy, energy subsidies*

1. Introduction

Our current reliance on fossil fuels contributes to the single greatest anthropogenic cause of current climate change. Gone is our traditional idea of 'nature,' as it is largely now a product of civilization. Nature currently exists, affected by man, and the resulting combination is what we see and feel around us. Fossil fuel burning is the largest single factor in the current change in our Earth's natural processes.

Putting to rest some of the more extreme critics of global warming, a panel was formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to explore the problems associated with global warming. Three landmark reports- The First IPCC Assessment Report (1990), the Second Assessment Report (1995), and the Third Assessment Report (2001) were a collaboration of hundreds of scientists from all over the world on the issue of global warming. Given the assorted skills and backgrounds of this team of experts, the following section uses these reports above as a reference wherever possible.

The science of global warming is rather straightforward. The Earth is warmed to a comfortable level as a result of the sun's energy, of which only a fraction (about 30%) enters our atmosphere and warms the surface of the Earth. As more and more greenhouse gasses are released into our atmosphere, it creates a thicker layer of concentrated gasses around the Earth. After warming the Earth's surface, the sun's rays have lost some of their energy- transforming from infrared radiation to solar thermal radiation- and are reflected back toward space. At lower concentrations of greenhouse gasses, the lower-energy radiation escapes the Earth's atmosphere and re-enters space. Global warming occurs when a greater percentage of these rays are unable to escape the Earth's thicker atmosphere but rather are redirected back into the atmosphere. This increased energy on the Earth is what we call the greenhouse effect or global warming.

Increased greenhouse gases lead to higher temperatures on Earth. Man has increased greenhouse gas emission of CO_2 by 35%, CH_4 by 155%, and NO_2 by 18% since the late 1700s. Man has therefore accounted for at least a part of the global warming phenomenon we are privy to. Recent research has shed light on the extent of man's contribution to the problem, though it is still not universally agreed upon.

Effects of global warming are evident today. Nine of the ten warmest years on record occurred since 1995. And the 20th century was the warmest century on record, the 1990s its warmest decade, and 1998 its warmest year.
This increased temperature has melted ice, which in turn has raised sea levels and compounded the warming of the Earth via albedo, or changes in the Earth's surface reflectivity. Also, extreme weather has become more common and more powerful. Biodiversity has also been affected by climate change, particularly marine populations. Increased CO_2 in the atmosphere has been partially offset by the oceans absorbing about half of man's increased CO_2 emissions. This has led to increasing acidification of our oceans, rendering widespread coral destruction.

Future threats are even more profound. Heatwaves resembling the 2003 European heatwave possibly become the 'norm' every year. Increased hurricane damage threatens national economies. Increased methane released from permafrost and methane hydrates could seriously accelerate global warming.

2. The Cause of Global Warming-Greenhouse Gases

Increased levels of atmospheric greenhouse gas concentrations trap more of the sun's radiation. This, in turn, leads to higher temperatures on the surface of the Earth- both on land and water. The National Oceanic and Atmospheric Administration (NOAA) declared in May 2006 that their annual greenhouse gas index 'shows a continuing steady rise in the amount of the heat-trapping gases in the atmosphere.'

Greenhouse gasses include carbon dioxide (Co2), methane (CH4), and nitrous oxide (NO2) (see table 1- Greenhouse Gases). This section is concerned with these gases and why man has been producing greater amounts of these emissions.

Greenhouse Gas	Increase Since Late 1700s	1995- 2004 Increase	% of Global Warming	Cause of Increase
CO2	35 %	19 ppm	62%	Primarily emissions from combustion of fossil fuels, and also deforestation
CH4	155 %	37 ppb	20%	60% caused by human activity- rice agriculture, biomass burning, landfills, and ruminant farm animals 40% produced by wetlands and termites, as well as other natural processes.
Nitrous Oxide	18 %	8 ppb	6%	Around a third as a result of human activity- fuel combustion, biomass burning, fertilizer use, and industrial processes.
Others			12%	

Table 1: Greenhouse Gases
Source: World Meteorological Organization, 2006

2.1. Carbon Dioxide (CO2)

Carbon dioxide is a naturally occurring gas important to the life cycle of plants formed when carbon and oxygen combine. Plants breathe in carbon dioxide and use this as a base fuel for their production of food using photosynthesis. In addition, all life is based on carbon, meaning that every living thing has a base amount of carbon contained within its body mass. When living things die, bacteria break down the materials in the body- releasing the carbon into the atmosphere and nutrients into the soil. Upon being released, the carbon combines with free oxygen to form carbon dioxide. This is a major problem with deforestation- the loss of our forests releases great amounts of carbon dioxide into our atmosphere. (See insert 1- Role of Deforestation in Raising CO2 Levels)

Carbon dioxide is measured in the atmosphere in parts per million (ppm). It has varied throughout history. Variability in carbon dioxide over time can be partially attributed to variations in plant life on Earth. For example, carbon dioxide levels are much higher during ice ages when there is less plant life on the surface of the Earth. Within a given year, the carbon dioxide in the atmosphere also varies. The northern hemisphere contains far more land mass than the southern hemisphere- as a result, during the spring-summer seasons in the north, the plant life is flourishing. This means life itself contains carbon as well as the fact that the plant life is busy converting carbon dioxide into oxygen, in essence filtering the carbon dioxide out of the atmosphere. However, in the fall-winter seasons for the northern hemisphere, the death of the plants coupled with the end of most of the carbon dioxide used for photosynthesis raises CO2 levels.

Glaciers provide a frozen account of atmospheric gas concentrations. Ice cores are very similar to tree rings in that each tells a story of history. Upon freezing, water entombs atmospheric information, and we are able to accurately measure carbon dioxide levels at the time the water was frozen. Typical ice cores are removed from an ice sheet, most commonly from the polar ice caps of Antarctica, Greenland, or from high mountain glaciers elsewhere. These samples provide information concerning greenhouse gases over a great span of history.

For example, analyzing a 3.2 km long core of frozen snow in the region known as Dome C, CO2 levels, as well as past temperatures, were determined over the past 800,000 years (Amos, 2006). Dr. Wolfe from the British Antarctic Survey (BAS) stated that 'When carbon oxide changed, there was always an accompanying climate change.' When carbon dioxide concentrations were higher, the Earth warmed. Furthermore, the greatest increase in the ice core was approximately 30 ppm over a period of roughly 1000 years. The most recent increase of 30 ppm took place in a mere 17 years. Also noteworthy is that over the 800,000 years of history contained in the ice core, never did the concentrations of carbon dioxide eclipse 300 ppm. Man has altered the planet's atmospheric concentrations and thus the Earth's climate.

Prior to the Industrial Revolution, the carbon dioxide concentrations in the atmosphere were around 280 parts per million (ppm). Steadily increasing since the Industrial Revolution, atmospheric carbon dioxide levels were 367 ppm in 1999. 2005 saw a record level of 381 ppm. In fact, the United Nations meteorological agency stated that concentrations of not only carbon dioxide but also methane and nitrous oxide reached their highest ever-recorded levels in 2004, mainly due to human activity.

The increase in CO2 in the atmosphere comes from two main sources. The burning of fossil fuels releases 6 billion tons of carbon dioxide per year. This includes the use of oil, natural gas, and the burning of coal. Total emissions have been increasing. Deforestation is the second main contributor to increased carbon dioxide levels. Estimates vary as to the extent of carbon dioxide emissions resulting from deforestation but tend to fall at around 1.5 billion tons per year.

Man's need for increased land for agriculture has often come at the expense of forested land. This is a serious global warming threat, as forests store between 20 and 100 times as much carbon per hectare as does land growing crops. Over half of the 3.28 billion cubic meters of wood harvested worldwide was used for fuel (FAO, 2001). Of the roughly 1.5 billion cubic meters remaining, close to a third is used to make paper and paperboard. Between 1980 and 1999, world paper use increased by 86% (UN, 2001). Increasing paper and fuel use are coming at the expense of increased global deforestation.

This translates into the yearly loss of roughly 9 million hectares of forests worldwide, which is approximately the size of Portugal (FAO, 2000). Accompanying the loss of forested area is, of course, the release of huge quantities of carbon dioxide contributing to warming the planet- estimated between 1 and 2.5 billion tons of carbon to the atmosphere annually, or about 16.7%-42.5% of the CO2 produced by burning fossil fuels.

2.1.1. Nitrous Oxide (NO2)

Nitrous oxide is an extremely powerful greenhouse gas, producing 296 times the effect of CO2 has in producing global warming. Nitrous oxide also contributes to the ozone layer depletion, attacking ozone molecules in the stratosphere. It is naturally produced by bacteria, both in soil and in oceans. Humans do indirectly increase the amount of gas produced by the bacteria through cultivating soil, use of nitrogen-based fertilizers, as well as animal waste handling. In addition, the production of nylon, nitric acid, and the burning of fossil fuel in internal combustion engines releases nitrous oxide into the atmosphere.

2.1.2. Methane (CH4)

Methane is another greenhouse gas, causing 23 times the warming effect on Earth as carbon dioxide. Currently, methane is the second strongest contributor to global warming of the greenhouse gasses. It is produced naturally as well as produced by man. (See table 2- Emissions of Methane) Wetlands, which include rice production, produce a staggering 36.3% of the current emissions. This ranks second to man's contribution of 53.2%.

Natural Emissions	**CH4 Emissions (Teragram/yr)**	**Anthropogenic Sources**	**CH4 Emissions (Teragram/yr)**
Wetlands (including rice production)	225	Energy	110
Ocean	20	Landfills	40
termites	15	Ruminants (Livestock)	115
hydrates	10	Waste Treatment	25
		Biomass burning	40
Total Natural Emissions	290	Total Anthropogenic Emissions	330

Table 2: Emissions of Methane
Source: Houweling et al. (1999)

The future impacts of methane are daunting. Methane is the principal component in natural gas, an energy source that is expected to grow significantly in the future. Population increases as well as a standard of living increases- and accompanying meat demands- will require additional livestock and rice, which will also increase methane production. Environmental sources of methane- with methane hydrate and permafrost melting being prominent- represent a significant threat to vastly increased methane levels in the future.

2.2. Methane Hydrates

Methane hydrates, also called methane clathrate or methane ice, is a form of water ice that contains a large amount of methane within its crystal structure. Immense amounts of methane have been found under sediments on the ocean floors. Most studies estimate the size of the methane hydrate deposits of the oceans at 10,000 gigatons. For comparison, the total carbon in the atmosphere is around 700 gigatons. Theories suggest that should global warming cause them to heat up sufficiently, all of this methane could be suddenly released into the atmosphere.

Methane hydrates are fickle molecules, liable to melt whenever the pressure drops slightly, or the temperature creeps upward. The ocean is a potentially enormous methane time bomb, with some experts claiming that this source of methane was a factor in ending the last ice age. With sea levels expected to rise and warm in the future, it is unclear how the added pressure and higher temperature will affect the methane clathrate in oceans.

Permafrost

Methane is also found on land in continental deposits at less than 800 m in Siberia and Alaska. Most of the methane-releasing permafrost is in Siberia. As temperatures rise, methane is released. Therefore, higher temperatures release more methane, which in turn heats the atmosphere, and the cycle is reinforced. Amounts of methane released in these areas are currently understated, with recent studies showing that amounts in regions of Siberia being up to five times greater than previously estimated. Current emissions estimate of 3.8 teragrams/year from Siberian permafrost are currently low when compared to global methane production, yet raise questions as to what future increases in Arctic temperatures will do to exacerbate methane emissions.

3. The Effects of Global Warming- Ice Cover

Melting ice, like many global warming factors, is part of a feedback loop. Every surface reflects sunlight to a different degree, which is called albedo. For example, a white surface reflects a large portion of the sun's rays back into space, whereas a dark surface absorbs much of the sun's rays and, thus, its energy. This explains why a person wearing a white shirt on a given summer day will be cooler than someone who wears a dark shirt. Melting ice accelerates global warming by absorbing more of the sun's energy.

Ice tends to reflect much of the sun's rays. This allows the ice to remain cooler, meanwhile keeping the surface of the Earth cooler as well. The ice at the poles tends to reflect much of the sun's radiation back into space, upwards of 90%. However, as more and more ice melts, it is replaced by blue water. This water absorbs the heat that was previously reflected by the ice, which creates net warming on Earth. More warming means more ice melting, which in turn creates additional warming.

Another example of the idea of albedo can be found in the study of snowflakes. As snowflakes fall through the atmosphere, they collect tiny particles of soot, predominantly produced by burning diesel and biofuels, which absorb solar energy. This decreases the overall reflectivity of snowflakes, and when they land on ice shelves, for example, they decrease the albedo of glaciers. Though this may seem insignificant, one estimate is that it accounts for a quarter of the global warming observed in the 20th century.

Though the overall effects of albedo remain disputed, the effects of melting ice on albedo are well known. As ice melts, more energy is absorbed by the water and land, which replaces it. The greater the amount of ice that melts, the greater is the corresponding effect on Earth's albedo, and the world gets warmer.

The Earth's ice cover is melting in more places and at higher rates than at any time since record-keeping began. (see table 3- Examples of Ice Melt) Global ice melting accelerated during the 1990s, the warmest decade on record. Losses in 1997-1998 were 'extreme' according to the World Glacier Monitoring Service. Four of the most important ice sheets - Arctic ice, Antarctic ice, the Himalayas, and the Greenland Ice Sheet- will be discussed.

Ice Melt & Location	Measured Loss
Arctic Ice- Perennial Ice	9% loss per decade since 1979 In 2004-2005, 14% loss
Arctic Ice- Seasonal Ice	Over the past 4 decades, loss of nearly 50%
Antarctic Ice	36 cubic miles yearly
Himalayan Ice	67% of Himalayan glaciers are retreating at an alarming rate, mainly due to climate change
Greenland Ice Sheet	2005, 54 cubic miles lost May 2004- April 2006, melting increased 250%

Table 3: Examples of Ice Melt

3.1. Arctic Ice

In 2000, Dr. McKenna reported being able to sail all the way to the north pole- arriving to find no ice at the north pole. This is a stark change from prior visits, which found the North Pole covered in 3 meters of ice during the summer.

The Arctic is warming nearly twice as fast as the rest of the globe. In Alaska, Western Canada, and Eastern Russia, average winter temperatures have increased by as much as 3-4 C in the past 50 years. Robert Corell, chair of a 4-year study of temperature in the Arctic region, describes the Artic as 'experiencing some of the most rapid and severe climate change on Earth' and expected to 'increase substantially in the years to come.' The Arctic is projected to warm by 4-7 C by 2100 (ACIA, 2004).

This increase in temperature over the past 50 years has simultaneously occurred with a decrease in Arctic ice. The Arctic has two types of ice cover- thick perennial ice, which resists summer melting, and thinner seasonal ice, which melts in the summer and freezes in the winter. The year-round Arctic ice has been retreating at an average rate of 9% per decade since satellite records began in 1978.Recently; however, this ice melt has been increasing. Between 2004-2005, perennial ice shrunk 14%, the size equivalent to Texas. And in 2006, 5-10% of the perennial sea ice which survived the summer melt was fragmented by late storms. This made possible a voyage from Spitzbergen in northern Siberia to the North Pole without difficulty.

Over the last four decades, the Arctic sea ice has thinned by 42% and has shrunk in area by 6%. The net overall effect has been the loss of nearly half the Arctic Ocean ice mass. In 2002, the Arctic sea ice hit record lows. Experiencing Arctic sea ice diminishing in winter by about 2.5% per decade for the past quarter-century, 2004-2005 saw a 2.3 percent decrease and a 1.9 percent decrease in 2005-2006. In one region of the eastern Arctic, winter sea ice has shrunk by about 40% in the past two years. 2004-2005 saw a decrease of 6% per year of maximum winter Arctic ice, with greenhouse gases being the likely cause. Though not influencing sea levels due to the fact that it already displaces water, the decrease in sea ice could have profound effects, particularly on marine animals.

The melting of the Arctic could have a more profound effect on the climate of Europe and, to a lesser degree, of North America. The Great Ocean Conveyer Belt is a great ocean current that carries as much water as 100 Amazon Rivers as it circulates from tropical waters to cooler, northern waters. It is a crucial factor in shaping the Earth's climate. This water stores huge amounts of heat as it travels through warm tropical waters, and it redistributes this heat to northern areas. It produces an overall effect comparable to a million nuclear power plants providing energy to Europe. This flow is the reason why Norway is some 20 C warmer than Manitoba, though they lie at similar latitudes.

The cool water which melts from the Arctic ice could disrupt the Great Ocean Conveyer Belt, disabling the sinking of water which is ultimately the engine of the heat distribution system. This slowing or elimination of the Great Ocean

Conveyer Belt could lower Europe's average temperature by 5-10 C, and parts of eastern North America would be lowered as well.

Abrupt changes in the Great Ocean Conveyer Belt are not unprecedented. The period of time known as the Younder Dryas was named after an Arctic wildflower that flourished in Europe and the U.S. some 12,700 years ago. The Conveyer Belt was disrupted and lowered temperatures in the North Atlantic region by nearly 5 C. This made the U.S. and Europe habitable for the Younder Dryas. A similar drop in temperature occurred again about 8200 years ago. The Great Ocean Conveyer Belt has plunged the North Atlantic region into an ice age before and threatens to do so again.

3.2. Antarctic Ice

Antarctica is covered by a landmass roughly the size of Canada. This huge mass is covered by an ice sheet 2.3 kilometers thick and is relatively stable. However, a research team led by Eugene Domack found that the Antarctic has been undergoing greater warming than anywhere on Earth. Most of the ice loss so far has occurred along the edges of the Antarctic peninsula. Some 75% of the 400 mountain glaciers are in retreat on the Antarctic peninsula. Overall, on the peninsula, the extent of seven ice shelves has declined by a total of about 13,500 km2 since 1974. This value excludes areas that would be expected to calve under stable conditions. During the 1990s, three ice shelves fully disintegrated- the Wordie, Larsen A, and Prince Gustav. Two others are in full retreat- the Larsen B and the Wilkins. The Larsen B ice had been relatively intact since the last ice age, at least 10,000 years ago. During the period between January 31st and March 7th of 2002, the Larsen B ice shelf collapsed and broke up. A mountain of ice, 3250 km2 of ice 200 m thick broke off, an area roughly the size of Rhode Island.

Scientists have been debating whether the Antarctic ice sheet is expanding or shrinking overall due to the increased snowfall in the center of the ice sheet while coastal regions are more vulnerable to melting. A recent study based on findings from two NASA satellites found that as much as 36 cubic miles of ice per year are being lost from the Antarctic ice sheet due to global warming. Data shows that Antarctica is losing more ice- mainly through the calving of icebergs- than is being replaced by snowfall.

3.3. Himalayan Ice

The Himalayas pose a unique problem to the world. The rising of sea levels and resulting changes to Earth's albedo as a result of melting Himalayan ice are less of a concern than the loss of a water supply for hundreds of millions of people. The Himalayas have the largest concentration of ice outside the polar caps. Providing 8,600,000 cubic meters of water annually to the region, it is aptly named the 'Water Tower of Asia.' Himalayan Glaciers feed seven of the major Asian rivers- Ganga, Indus, Brahmaputra, Salween, Mekong, Yangtze, and Huang ho, providing year-round water to hundreds of millions of people. Without glacial water flows, these areas face water issue of unprecedented proportions

Sixty-seven percent of glaciers are retreating at a startling rate in the Himalayas, and the major cause has been identified as climate change. The Himalayan region has risen by 1 C since the mid-1970s, twice as fast as average warming for the northern hemisphere. There are 3,250 glaciers in the Nepalese Himalayas, and 2,315 of them contain glacial lakes that are increasing in size at varying rates. Other studies have found that this has dramatic negative effects on biodiversity, people and livelihoods, and possible regional food security. Additional study of the Himalayan ice mass needs to be done to assess the current state of retreat these glaciers are experiencing. A new weather station has been installed on the longest Himalayan glacier in the Everest region of Nepal for this reason.

If the massive snow/ice sheet in the Himalayas continues to melt, it will affect the water supply of most Asian countries- including Pakistan, India, Bangladesh, Thailand, Viet Nam, and China. In northern India, a region already facing severe water scarcity, an estimated 500 million people depend on the tributaries of the glacier-fed Indus and Ganges rivers for irrigation and drinking water. But as the Himalayas melt, these rivers are expected to initially swell and then fall to dangerously low levels, particularly in summer.

The rapid melt of the glaciers threatens widespread flooding, followed by drought. Following an initial surge in glacier runoff, melting ice will eventually lead to less and less water entering the region's waterways, leading to hundreds of millions of people suffering from water issues. The melting of Himalayan glaciers has prompted environmental campaigners and lawyers to appeal to UNESCO to place Everest National Park on the World Heritage Danger List. They warn that many Himalayan lakes could burst. Some Himalayan lakes have already burst, causing loss of life and damage to many areas.

3.4. Greenland Ice Sheet

The Greenland Ice Sheet is the largest mass of land-based ice outside of Antarctica, with 8 percent of the world's ice. If it were to melt, sea levels worldwide would increase by 23 feet. In 2005, 54 cubic miles of ice were lost in Greenland, as compared to 22 cubic miles in 1996. The melting ice in 2005 could support current freshwater usage in Los Angeles for 200 years. This water translates into raising global sea levels by 0.5 mm per year, or 17% of the total rise in sea levels.

Other studies have shown the Greenland Ice Sheet shrank at a rate of about 239 cubic kilometers per year (58 cubic miles) from Apr. 2002- Nov. 2005, with the ice melt accelerating during the last 18 months. A second report stated that the rate of ice-melt increased by 250% during a period from May 2004- April 2006 compared to April 2002- April 2004. Though the current acceleration is confined to southern Greenland, if global warming is, in fact, the cause, the accelerated melting could spread to northern Greenland as well.

The natural changes in temperature and weather which affect Greenland are known as the North Atlantic Oscillation and is a possible explanation to the current variability we currently witness in Greenland. An important study in 2005 found that the North Atlantic Oscillation couldn't account for Greenland's current warming trend. The study, however, found that the warming rate in Greenland was 2.2 times faster than the global norm- which is in line with the U.N. climate models.

3.5. Rising Sea Levels

Currently, sea levels are rising by 3 mm per year. From about 3,000 years ago until the start of the 19th century, sea levels raised from 0.1-0.2 mm per year.

The IPCC 2001 Assessment projects that sea levels could rise by as much as 1 meter during the 21st century. This would cause more than a third of Shanghai to be underwater, two-thirds of the Marshall Islands and Kiribati would be underwater, as well as affecting critical areas of world food production. For example, Bangladesh would lose half of its rice production areas- the basic food for the country's 140 million inhabitants. The displacement of potentially hundreds of millions of people worldwide would result from the increase in sea levels by 1 meter, as projected in the 21st century.

In October 1987, Maldives president Maumoon Abdul Gayoom addressed the United Nations General Assembly describing his country as an 'endangered nation.' Though the Maldives have done little to contribute to the global warming trend the Earth is currently experiencing, it is one of the countries that will be most affected. On the island nation of Tuvalu, the changes in sea level have created some of the Earth's first climate refugees- relocating to New Zealand and Australia.

4. Conclusion

Global warming poses a threat to all life on Earth. Melting ice has been found to be increasing at record rates. This contributes to the global warming problem itself by raising the amount of the sun's energy that the Earth absorbs. The melting ice causes sea levels to rise, decreasing the amount of land on Earth- and threatening coastal communities and islands as well as food production. The possible disruption of the Great Ocean Conveyor Belt could cause serious consequences for most of the northern hemisphere.

The human impacts of the large-scale melting of ice may be most acute with respect to the melting of the Himalayan glaciers. Hundreds of millions of people rely on the glaciers for their source of water in areas already hydrologically impoverished and featuring high population growth.

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