GENERAL ARTICLE

The Anthropocene– a 200 year record of human driven geological impacts: prelude to global climate changes and implications for South Asia

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Abstract: Human activities now rival natural geological processes in transforming the Earth's surface and initiating the current global warming phase and inevitable future climate change. The record of the past 200 years of this impact, which started off with the fossil fuel driven industrial revolution, is designated the Anthropocene. This article highlights how the change is occurring globally and also focuses on the possible effects on Sri Lanka and its people, especially with regard to water availability, soil degradation and nutrient depletion, food security, ecosystem disruption and the increasing intensity of natural hazards. A harmonious Earth system is conditional on achieving a stable population and sustainable use of resources. High population growth and poorly regulated exploitation of basic resources, which are essential for life, could result in civilizational overshoot and collapse as has happened in the past. Climate change is an undeniable reality and constitutes the most critical challenge to global society and its security. It is within the capability of modern science, technology and proven socio-economic policies to reverse the negative trends and achieve a sustainable world. This will require great political will and leadership by all nations.

Keywords: Anthropocene, climate change, human impacts, population, resources, sustainability.

INTRODUCTION

Definition and rationale for the Anthropocene

Since its beginnings about 4.5 billion years ago, (in the Hadeon Eon), the Earth has been shaped by a series of deep seated and surficial physical processes such as magmatic activity, the creation and destruction of landmasses and oceans (by the motion of tectonic plates), earthquakes, eustatic sea level fluctuations, biological evolution and extinction and by the activities of water, ice and wind. Superimposed on these timeless processes are the overarching impacts of natural climate changes orchestrated and modulated by the orbital astronomical cycles (the 100,000 year eccentric, 40,000 year tilt and the 19,000-21,000 year precessional cycles). Today, humans are the dominant agent that impacts on the global environment and is rapidly changing the physics, chemistry, biology and climate of the planet. Resource overconsumption and depletion, global warming, biome disruption and species extinction are the inevitable catastrophic changes that will transform the planet as a result.

Nobel laureate chemist Paul Crutzen[1,2] known for his pioneering research on the ozone-layer proposed the term Anthropocene (*anthropos* –Greek for human and *cene* for new geologic age) to signify this change. This primary role of humankind in geology and ecology in the last two centuries has resulted in the call by scientists for the term Anthropocene to be officially accepted by the International Commission on Stratigraphy[3]. The geological markers suggested for the base of the Anthropocene are the global sulphate pulse and tree-ring disturbance caused by the great Tamboura volcanic eruption of Sumatra in 1815. The start of the Anthropocene was proposed to be set around the late 1700s with the beginnings of the industrial revolution[1] (symbolised by James Watt's steam engine and coal powered energy generation). This is based on the distinct atmospheric carbon dioxide pulse that underlies the current global-warming phase. However, humans started altering the landscape long before that. The vast deforestation in the

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medieval Mediterranean and Near-Eastern regions by the then dominant civilizations converted the landscapes there into near deserts. The use of fire to manage their ecosystems in Australia and North America led to similar results. These were for the most part regional crises.

Around the year 1800 and onwards, however, we do see the beginnings of a quantum shift in human impacts on the environment on a more widespread or even global scale. This was caused by the spread of mass scale agriculture, which required the damming of rivers to store water in reservoirs, which in turn accelerated erosion; spread of transportation networks; widespread extinction and ecosystem disruption; the rising atmospheric CO_2 concentrations (now standing at ~383 ppm compared to 286 ppm before 1800) and methane levels caused by fossil fuel use and animal production and the resulting slow acidification of the oceans today with its devastating effects on the $CaCO_3$ system in seawater (c.f. on plankton, coral-reefs, shelled animals, fisheries etc.). Further, the use of fertilizer and agrichemicals cause point-sourced as well as dispersed contamination of freshwater aquatic and groundwater systems, and the development and testing of atomic and nuclear weapons have left their own radioactive isotopic signatures. In the Indian sub-continental region (and elsewhere), a new phenomenon-the formation of aerosol charged thick brown clouds (called ABCs) in the upper atmosphere has recently been recognized as probably the second most important factor after greenhouse gas emissions in contributing to climate change[4,5].

The purpose of this essay is to create scientific awareness as to the challenges facing global societies in the coming decades and formulate and implement proactive adaptation strategies to mitigate the predicted impacts. This could turn out to be a most challenging task for both scientists and world leaders.

Consequences

No natural biome on Earth has been left untouched. Today, humankind's total use of energy is about 10 % of the total energy processed by the biosphere and more than what the entire pre-oxygenic photosynthetic biosphere used[6]. The biosphere itself, at all levels from the genetic and cellular (i.e. plant and animal breeding, organ cloning and transplantation and stem cells in medicine etc.) to the landscape (i.e. deforestation and mass scale agriculture, spreading urbanization and wetland destruction, resource exploitation etc.) is very much a human product. The Earth is a unitary system within which the biosphere, geosphere, hydrosphere and atmosphere all interact and human activity is so pervasive and deep that the consequences affect the planet on a global scale today. For much of their existence on Earth, humans have been passengers in a vehicle; today they wish to command its direction and speed, but are unsure of the eventual destination. It appears that humans are not in full control of the sophisticated and complex craft and unable to gauge what the various instruments and indicators are telling them.

There is an ironic contradiction in all of this. The scientific and technological knowledge acquired over the last two hundred years far exceed, by orders of magnitude, what was learnt in all of previous human history. It is well within the capability of humans to reverse the existing trends and achieve a more sustainable Earth system before it exceeds environmental thresholds and flips over irreversibly. This needs the acceptance and implementation of certain inviolable fundamental paradigms, which the present global politico-economic systems may not have the moral imperative to act upon due to a crisis in political leadership.

To maintain an Earth system in environmental equilibrium and devoid of major human induced perturbations, it has to be emphasized that planet Earth is a finite entity with very finite natural resources and can sustain only a certain optimum number of people with minimum standards of civilized living and affordable access to clean water, food, energy, health and other material needs. The current water, energy and food crises illustrate this undeniable fact. Yet, the discourse on sustainable systems and global change has a glaring gap in that population growth is somewhat marginalized or its impact on resource availability and use is not adequately quantified. Historical conquests and conflicts were driven by the insatiable need to access resources and/or secure territorial space for growing populations (*lebensraum*), which reflected economic and political power. Historians call this the imperial imperative.

How many people can be sustained on Earth if the paradigms above are accepted? Demographic projections suggest ~9 billion by 2050 from the current 6.5 billion[5]. It is clear that system Earth is already having a crisis with 6.5 billion. Over one billion are without access to safe water and food and energy prices are unaffordable. These figures are bound to increase over time.

How humans have changed the Earth

According to the Center for International Earth Science Information Network (CIESIN) at the Earth Institute of Columbia University, USA about 83% of the Earth's land surface is influenced directly by human beings through human land use, access from roads, railways or major rivers, electrical infrastructure or direct occupancy by human beings. Urbanization has increased ten-fold in the past century. The human influence on the land's surface is measured as the "human footprint" (Figure 1).

In the past hundred years, there has been complete conversion of 15% of all ice-free land surfaces and the partial conversion of 55% of all ice-free land surfaces to human use. The loss of 60 % of the world's sensitive biomes, the wetlands, in the next 25 to 50 years will play a critical role in climate change scenarios. Wetlands store about 20% of the world's carbon although they constitute only about 6% of the Earth's surface. They store about 60% of the global carbon that is in the atmosphere today. As wetlands are destroyed by urbanization, infrastructure development, population growth, agriculture and drainage, groundwater extraction, irrigation pumping and peat extraction, the vast amount of CO_2 released becomes a major factor in raising global temperatures. The feedback is the progressive drying out of the wetlands. Wetlands have the seeds of their own destruction if interfered with and different wetlands are subject to different threats across the world. They also have a protective function where coastal communities are subjected to coastal flooding due to extreme meteorological conditions. It is clear why they should be protected from human impact, as conservation is preferable to the costly reclamation and restoration at a later date. Their role as important carbon sinks is not to be undervalued.

The fixation (conversion of atmospheric nitrogen into fertilizer) of 190 megatonnes of nitrogen per year (in 2005), compares with pre-agriculture terrestrial fixation of 150-190 megatonnes of nitrogen per year by natural processes while burning of fossil fuels and industrial processes release over 100 megatonnes of nitrogen oxides and ammonia into the atmosphere annually[7]. "Humans continue to transform the global nitrogen cycle very inefficiently, reflecting an increased combustion of fossil fuels and growing demand for nitrogen in agriculture and industry. Much anthropogenic nitrogen is lost to air, water, and land to cause many environmental and human health problems. Food production in many parts of the world is nitrogen-deficient, highlighting inequities in fertilizer use. Optimizing the need for a key human resource while minimizing its negative consequences requires an integrated interdisciplinary approach to decrease nitrogen-containing waste" (CIESIN). Some fertilizer runoff to the sea is returned to the land through the fisheries industry.

As much as 25% to 40% of total net primary productivity of the planet is appropriated for human use. Changes in the composition of the atmosphere and climate patterns result from disturbances to the carbon cycle and rising global temperatures. Most of the world's rivers are dammed to meet water, energy, and transportation needs. Today, there are >45,000 dams over 15 m high, capable of holding back ~6500 km^3 of water or about 15% of the total global annual river runoff [8]. Vastly altered sediment erosion and deposition patterns; the regulation of the flow of river systems for dams and reservoirs (needed for power generation and irrigation) and inland sand mining for the construction industry has resulted in severe coastal erosion (1-4 m per year in Sri Lanka) during monsoons as inadequate volumes of sand are reaching the shoreline to maintain coastal equilibrium.

The beginnings of a massive extinction of life is evident with about one species every 20 minutes[9]; 20% of all species will be gone by 2030 if the present rate continues[10]. Wholesale changes in biology could result from altered flowering times to new migration patterns. Acidification of the ocean threatens plankton that forms the lower levels of the food chain (this happens even now

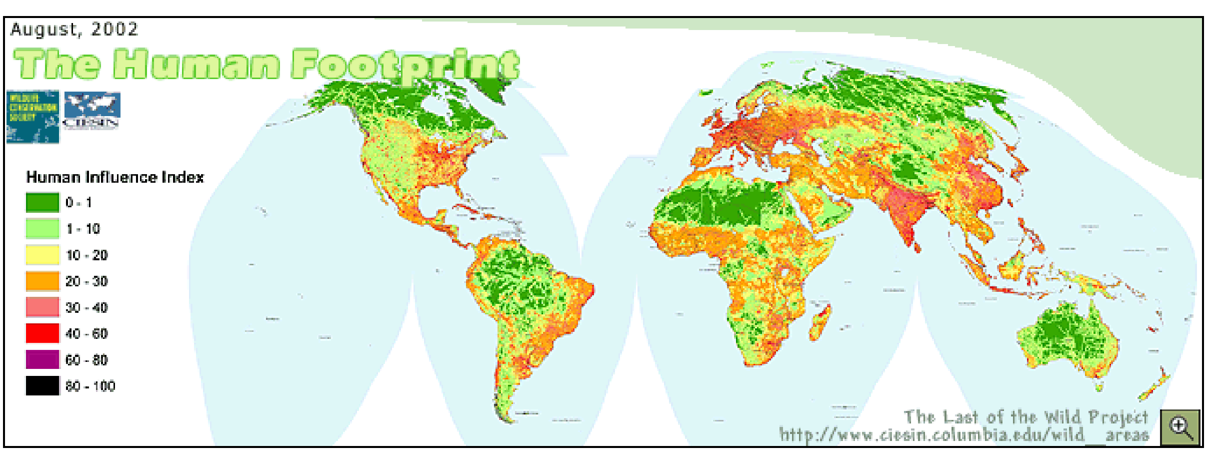

Figure 1: The Human Influence Index (HII) across the world. Note the high human footprint in the India-Sri Lanka region (courtesy of the the CIESIN Colombia University, USA).

regardless of climate change). Coastal anoxic (oxygen-depleted) zones are doubling every 10 years and now stand at over 400[11]. This is caused by excess fertilizer in riverine runoff, which results in increases in primary productivity and eutrophication.

The total biomass of the world's population is roughly 40 megatonnes of carbon. To put this into perspective: the biomass of all life is roughly 500 gigatonnes of carbon, the biomass of all wild vertebrates on land is roughly 5 megatonnes, and the biomass of all vertebrates in the ocean is about 50 megatonnes of carbon. We have eight times the mass of all wild land vertebrates and about the same biomass as all the fish and whales in the ocean. Domesticated animals have a biomass of roughly 100 megatonnes of carbon. The biomass of our animals is about 20 times the mass of all wild vertebrates on land, and 50% larger than the mass of all vertebrates in the ocean[6].

The mass of all motor vehicles is roughly 1,000 megatonnes and increasing. Machines now need more carbon every year than humans do. The global food harvest now amounts to about 1.3 gigatonnes (gt) of carbon per year, whereas almost 1 gt of fossil carbon is used annually to produce metals and plastic from which machines are assembled, and about 4 gt of carbon are used each year to power them[6]. These estimates are mind-boggling.

Agriculture induced civilizational collapse?

Soil depletion in the past 200 years is a good enough reason to dub this the Anthropocene Age. With more than half of all soils on Earth now being cultivated for food (and biofuel) crops, grazed or logged for wood, how the Earth's soils can be sustained is becoming a major scientific and policy issue[12,13]. Agriculture has so degraded regional soil fertility that the economic development of whole nations will be diminished without drastic improvements in soil management[14]. Recent compilations of data from around the world show that soil erosion under conventional agriculture exceeds both rates of soil production and geological erosion rates by several times to several orders of magnitude[13]. In the near future, modern agriculture and therefore global food security could face a severe crisis, compounded by climate change. Can prevailing agricultural practices safeguard both soil fertility and the soil itself while feeding the rising populations?

Although the experiences of past societies provide ample historical precedents for concern about the long-term prospects for soil conservation, data compiled in recent studies indicate that no-till farming could reduce erosion to levels close to soil production rates. Additionally, organic farming methods have been shown to be capable of preserving and improving soil fertility. Consequently, agricultural production need not necessarily come at the expense of either soil or soil fertility, even if short-term social and economic trade-offs can deprioritize soil conservation[13]. The loss of soils presents a fundamental scientific challenge as it is also an important temporary carbon-sink. Civilizations have declined in the past due to overpopulation, conflict, water scarcity, soil fertility depletion due to salinization and erosion and climate change, resulting in overshoot and collapse[15]. Examples are provided by the Akkadian and Mesopotamian civilizations (in Syria and Iraq respectively), several Meso-American civilizations (i.e. the Aztec, Maya and the Moshe in northern Peru), the Roman Empire in medieval times and many others. Soil has literally been treated like dirt in many parts of the world.

Effects on biomes

Biological communities of the Earth are organized into various biomes (such as, tropical rain forests, tundra, deserts, freshwater streams and lakes, grasslands, estuaries, and open Ocean), which are now influenced by growing populations. Nature and human systems are intertwined, with calls for replacing these established biomes with (62) new anthropogenic biomes[16]. Ecosystem processes in anthropogenic biomes are primarily a function of human populations and their interactions. Anthropogenic landscapes are complex mixtures of different land use and land cover classes.

The Millennium Ecosystem Assessment Report of 2005 discusses the limits to growth and points out that some resources are depleting faster than they can be replenished[17]:

1. At least 25% of important commercial fish stocks are over-harvested.
2. From 5% to possibly 25% of global freshwater use exceed long-term accessible supplies.
3. Some 15–35% of irrigation withdrawals exceed supply rates and is therefore unsustainable.
4. Reduction in stratospheric ozone is leading to increased UV radiation at Earth's surface and to possibly more skin cancer.
5. Changes to ecosystems have contributed to a significant rise in the number of floods, droughts and major wildfires on all continents since the 1940s.
6. Actions to increase one ecosystem service often cause the degradation of other services.

7. For every 2^0C rise in temperature a series of ecosystem changes have been predicted, until mass extinction sets in.

Sri Lanka in perspective

In Sri Lanka, the Anthropocene proper would have started when the forested hillslopes (with ~85 % forest cover) were cleared for plantation agriculture and industries (coffee, tea and rubber) starting around 1830 and the subsequent spread (from 1862) of the Ceylon Government Railway network to many parts of the country, which itself resulted in an internal migration and a rise in populations. The population has grown from < 1.5 million in 1800 to over 21 million today (not forgetting the 1-2 million deaths from the malaria pandemic). Urbanization and land filling has destroyed >50 % of the wetlands in the Western Province and more than 50 % of the coastal mangroves have been lost.

Perhaps the biggest crisis that will face Sri Lanka will be the ongoing losses in soil fertility across the country. Recent quantitative studies[18,19] indicate that in the central highlands and especially in the upper Mahaweli catchment (UMC), plantation agriculture related soil losses and spatially averaged sediment fluxes into rivers are in the range of 130-2100 $t.km^{-2}yr^{-1}$ and are as high as 7000 $t.\ km^{-2}yr^{-1}$ in some areas. This amounts to a loss of ~1m of soil per 250 years (Table 1). To these estimates must be added soil losses in agricultural areas outside the highlands and especially the rice growing areas of the country (~100 mm kyr^{-1}). This is in contrast to natural background rates (pre-anthropogenic) of sediment generation of 13-30 $t.km^{-2}yr^{-1}$ (5-11 mm kyr^{-1}) and integrated over a mean soil residence time of 60-150 ky. Soil is now being lost 10-100 times faster than is being produced by pedological processes. It is obvious that the 175 years of the plantation industries have virtually washed out the upper top soils and heavy fertilizer application has been made necessary to keep productivity high.

Landslides and debris-flows are now the greatest natural hazard in Sri Lanka[20]. Hillslopes that were stable for centuries under high minimum rainfall thresholds are now failing even with 100 mm per day. This is due to the cumulative effects of slope degradation over such a long period of time, brought about by poor land use management and the attendant soil conservation measures adapted during the development of the plantation industry[21]. Additionally, in recent times, vegetable and potato cultivation on steep, terraced slopes (as steep as 35^0) with excessive spray irrigation, which keeps the soil water saturated, is a major cause of soil loss during heavy rainfall (Figure 2).

The sediments generated by landslide activity have also become a major contributor to the rapid silting up of the hydropower reservoirs, thus reducing their generating capacity (Figure 3). Now one can imagine what predicted climate changes will do to the system (either wetter phases that will cause more soil losses and landslides or extended and recurrent drought phases, which could ruin the rain fed plantation industries). Today, landslides, gully formation and overland sheet wash are the major causes of soil loss in the highlands where agriculture related activity dominates land use[20]. In the past 30-40 years, these processes increased in intensity and frequency due to population growth (and housing) and infrastructure developments (such as road networks and construction). The end result is the loss of the vital plant nutrients to the ocean and hydro-reservoirs due to the high connectivity of the slopes to the stream networks.

Table 1: Land use and soil erosion rates in the central highlands[18,19]

Land use type	Area (km^2)	Soil loss ($t\ km^{-2}\ yr^{-1}$)	Bedrock erosion rate[1] (mm kyr^{-1})
Dense forest	356.6	100	37
Degraded forest / scrubs	35.7	2500	925
Degraded grasslands	41.9	3000	1110
Poorly managed seedling tea	454.8	5200	1924
Seedling tea with some conservation	252.7	1500	555
Vegetatively-propagated tea	114.9	200	74
Paddy	285.7	300	111
Home gardens	537.7	100	37
Shifting cultivation and tobacco	484.6	7000	2590
Market gardens	163.6	2500	925

[1] Converted into corresponding bedrock erosion considering density as 2.7 g/cm^3

Figure 2: A landslide revegetated with tea (left) and terraced vegetable plots (right). Photo: Senerath Bandara (NBRO).

Figure 3: Debris-flow/landslide coming down the hills near Minipe and flowing towards the Victoria Reservoir (beyond the trees). There are 14 such flows cutting across the main road (top right corner) within a 10 km stretch. Note the size of the boulders.

Water is the least regulated, most profligately exploited and cheapest natural resource. With current per capita water availability of ~2492 m^3 per capita per year, Sri Lanka does not face a severe water crisis at present. However, the likelihood of water scarcities in the future, especially at six district levels is a cause for concern. Population growth, rising living standards and per capita incomes, poverty alleviation and improved quality of life and changing life styles are all reflected in increased per capita water use. With a projected population of > 25 million by 2030 and the likelihood of climate changes, water availability for irrigation, agriculture and food production and domestic use could drop well below the recommended 50 litres/capita/day and with severe consequences for water security[22].

If water and soils are our primary concern (to ensure food security), then integrated water resources management of both surface and groundwater, proper land management and soil conservation, all under strict regulatory regimes becomes a necessity[22].

Regional impacts

Sri Lanka is a low emitter of greenhouse gases (GHGs) with its current state of economic development (compared to India and China– the main emitters). However, there are factors beyond her control and which affect the entire South Asian region. Chief among these is the atmospheric brown-cloud (ABC) phenomenon and high levels of aerosol-carbon above the region[4]. Emissions of fossil fuel SO_2 and aerosol carbon have increased 6-fold since 1930. The net effects of ABCs and GHGs cause decreasing surface solar radiation and surface evaporation and reduced surface and atmospheric temperature gradients above sea and land, all of which have resulted in a reduction of summer monsoon rainfall (SMR) above the northern Indian Ocean sub-continental region (including Sri Lanka). This has caused reduced rice harvests in the past two decades in India[23]. The average SMR decreased by ~5% from 1960-1998, compared to the mean of 1930-1960. The harvests across the main rice producing states reduced by 6 to 17 % over the period 1960-1998, leveling out around 2000. This has caused much concern among Indian agricultural scientists as regards food security. Frequent floods and droughts (a doubling of drought frequency in the coming decades[4]) will impact the entire agriculture sector productivity due to monsoon excesses (as in Bihar-2008) or weakening. The same agro-climate model is applicable to Sri Lanka, although no analyses have been done as yet.

An analysis of climate risks for crops in 12 food-insecure regions, based on statistical crop models (Food and Agriculture Organization database) and climate projections for the year 2030 from 20 general-circulation models (GCM) concludes that South Asia is a region that, without adequate adaptation measures, will be subjected to the severest negative impacts on crop production[24]. The region is characterized by broadly similar diets and agriculture systems, large food-insecure human populations and a major share of the world's malnourished (262 million or 30 %). The importance of a crop (s) to these populations is called hunger importance (HI). The HI for any crop is the product of the number of under- and malnourished individuals (~30 % in Sri Lanka) and the crop's percentage contribution to per capita calorie consumption. Already, the World Bank is applying risk-management strategies for incorporating climate change adaptation in their operations across the region. The impacts on our rain fed crops (tea, rubber, coconut, rice) will drastically affect livelihoods and food in general will be prohibitively expensive (it is already). Sri Lanka by 2030 could be a potential “climate change hot spot” (its small size and dense population is a disadvantage). What kinds of adaptations are required before 2030 and starting now?

Primarily, Sri Lanka will have to change immediately from the present wasteful, poorly regulated and sometimes anarchic irrigation water usage, to one where integrated water resources management is a priority[22]. By 2030, water could become a very expensive economic commodity. Adaptive strategies with regulatory controls in place will have to be thought out carefully for managing our water, soil and food resources. In South Asia, aquifers are being dangerously depleted and melting Himalayan glaciers will result in reduced fresh water availability in the rice growing areas[25]. In Sri Lanka, almost 95 % of the available water is used in agriculture and food production (contributing just 13 % to the GDP in 2007). She is also a net food importing country. Future water shortages (say a worst case 30% reduction in availability) will be a far greater threat than escalating food prices and energy costs.

A pessimistic view of the resulting impacts envisages a quasi-Malthusian? scenario as unsustainable water demands and poor soil management could eventually result in about 30 % of the population not having easy access to water and affordable food. The import trade in virtual water to ameliorate food scarcities in the future may not be possible in a climatic crisis[26]. Without adequate water they cannot grow enough food, nor will they have the means to buy it. Rice, maize and wheat contribute only about 50 % of the calorie intake in South Asia[24]. The impact on health will be drastic. Lack of access to clean and affordable water is the primary cause for the prevalence of widespread poverty in the developing world.

Basically, the strategy is to assume worst-case scenarios and target adaptation investments on those crops for which the models predict very negative outcomes or switch from highly impacted to less impacted crops (those with lesser water requirements?). Impacts will vary from country to country according to their resource potentials, resource management and country policies. Additionally, better water resources allocation and utilization, effective soil conservation, better application of new technologies and large investments in research into new crop varieties and better yields are required. In short, a new “green revolution” under a more severe climatic regime with risk-management strategies in place is needed.

The most dramatic evidence for climate change during the last few decades has been the continuing rise in atmospheric and ocean temperatures, thawing of permafrost in the tundra regions with GHG emissions and the break-up and melting of sea ice in the Arctic with the likelihood of ice free summers (forcing polar bears to forage on land). Now, at the beginning of 2008, it was reported that the tropical climate belt has also been widening during the last three decades with potential implications for subtropical societies and large scale atmospheric circulation systems such as jet streams and storm tracks[27]. This in turn will impact precipitation patterns and ecosystems, water resources and agriculture. The observed recent rate of expansion since 1979 is 2^0 latitude (= to 5% increase in tropical atmospheric volume), which will widen further with anthropogenic climate change. Six major tropical belt indicators (showed warming of the lower atmosphere and cooling of the stratosphere, increasing height of the tropopause, weakening of tropical circulations, poleward migration of storm tracks, an increase in precipitation and shifting of the low ozone values poleward) used in 16 climate model simulations indicated only a mean 0.5^0 latitudinal shift in 25 years, much smaller than the already observed shift of 2^0 latitude between 1979-2005[27]. The most vulnerable will be the populated semi-arid regions polewards of the subtropical dry-belts (i.e. the Mediterranean, southern Africa, South Australia, parts of South America and SW-United States), with lasting changes to their hydrological-cycles and agriculture. This means that the tropical zone defined by the fixed Tropics of Cancer and Capricorn at latitudes 23.5^0 N & S is only an astronomical and cartographic entity; meteorologically, the zone has expanded by $\sim 1^0$ latitude per decade since 1979. An ecosystem response would accordingly follow in time.

About 25% of the world’s population is below the poverty line in this age of over-consumption[28]. In South Asia, the figure is ~600 million and in India alone ~440 million, based on a minimum income of US$ 1.25 per day [29], suggesting that the structural adjustment and poverty alleviation programmes over the past 50 years were a failure. China alone was able to reduce poverty significantly (they were outside the WB/IMF programmes). However, the collapse of financial markets in 2008 has forced millions back into poverty in China, with no respite in sight. Whatever the final population levels, Sri Lanka would still be vulnerable as its arable land area, water and resource availability and food production would still be inadequate to meet the growing demands. If we critically look at the available data, then the planet may not be able to sustain more than about 5 billion people without drastic perturbations to the system.

DISCUSSION

The sum total of human activities cause "global climate changes", which have altered the Earth's carbon and energy budget and other processes from the stratosphere, through the atmosphere to the land and down to the bottom of the ocean. Ideally, if there were only about 5 billion people on Earth, we would not be changing the planet so drastically and change could be manageable. Water and food security could be assured. But the changes induced by six and a half billion people may be already too many and 9 billion would be catastrophic. The population is now increasing at the rate of ~80 million each year[28]. India alone adds 20 million annually (same as the total population of Sri Lanka or Australia in 2007). Countries that have stabilized population growth and have a high ratio of physical/financial resources to population and with good governance have a high human development index (i.e. Scandinavia and New Zealand). These countries will aim to achieve carbon-neutral economies in the future through the appropriate application of science and technology and viable socio-economic policies. There is an element of unobtrusive social engineering operating here, but without transgressing the basic freedoms, choices and democratic space of the people. For the planet as a whole, the prognosis for the future is quite bleak.

There is no short term solution to the developing crisis. An alternative scenario has to be planned out from now. That is, while taking corrective action to reduce long term cumulative impacts on biomes and reducing carbon emissions (a 50% reduction by 2050 may be too little too late), it is hoped that the next 100 years will also see a stabilization in global population growth to manageable levels. As resource availability, water, food and energy security become critically affected, there will be a heavy price to pay for the scarcity. Large investments will be required for prioritizing adaptive strategies to face climate change, remediation and recovery of the environment (i.e. such as through mitigation banking and carbon credits). It is time to put a value on nature, resources and services in both existing and anthropogenic biomes. What is the value of a hectare of land in a high biodiversity tropical rainforest with unknown genetic potential?

The developments in science, technology, medicine, health, education and housing etc. of the past century have undoubtedly been to the great benefit of the majority of humans in terms of a better quality of life. They have inevitably led to many negative feedbacks. Crutzen[2] correctly identified high population growth and unsustainable resource consumption as the driving mechanism for ushering in the Anthropocene age. It stands to reason that a more sustainable scenario will require more efficient use and conservation of remaining resources, a shift to the development of renewable and affordable energy mixes (such as solar, wind and biomass) and stabilization of global populations. A sustainable Earth system is only a mirage unless new and implementable policies are put in place by all governments to reverse the existing negative trends. If not, the tragedy of the commons will be the obvious fate for many nations. The year 2008 was declared the United Nations Year of Planet Earth, emphasizing the need for global concern and awareness of these effects and developing strategies to adapt to the predicted changes. It will require the world's most innovative scientists to tackle the developing crisis.

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