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Abstract. This study presents a part of an ongoing research on construction in developing countries and the need to operate within planetary boundaries for sustainable development. It is a desk-research and it uses the already established planetary boundary concept to provide insights on the negative consequences of construction activities on planet earth. Some of the harmful effects of construction activities include: production of re-suspended dust particles and bituminous aerosols during construction, emission of greenhouse gases from embodied energy in buildings, rapid loss of biodiversity, unsustainable disposal of domestic and industrial waste into oceans and other water bodies and the unsustainable use of limited fresh water. The paper concludes that continued unsustainable construction activities will have devastating and irreversible effects on a planetary scale.

Key words: aerosols, climate change, construction, planetary boundaries, sustainability, sustainable development

1. Introduction

The construction industry creates the infrastructure that society needs to function. It provides shelter for homes, commerce, agriculture, health care, tourism and transportation. The construction sector has a strong influence on economic activities because of its linkage with other industries in terms of demand and supply. As a result, it significantly boosts Gross Domestic Product (GDP) in many countries. However, the activities of the construction industry have negative effects on man, the environment and the earth's systems at large. Specifically, construction activities affect the ecosystem, natural resources and man at 67.5%, 21.0% and 11.5% respectively [1]. Construction activity is a leading cause of environmental pollution particularly in developing countries where there is an overdependence on fossil fuel as alternative source of energy. The construction sector also generates about 50% of all the greenhouse gases produced globally [2]. Construction activities use large quantities of natural resources particularly fresh water, timber, sand and limestone. For instance, water consumption index per building area in China is about 0.46 ton [3]. Moreover, construction generates considerable amount of waste which ends up as landfills. These landfills emit toxic fumes which constitute great environmental concerns [4]. Developmental activities such as construction work also destabilize critical components of the earth's system (like the atmosphere and biosphere) and cause irreversible environmental changes that are harmful to human well-being [5]. Hence, the planetary boundaries concept was introduced to define safe operating limits within which humans can carry out developmental activities [5, 6]. However, evidence of the effects of construction activities on a planetary scale is important for the development of sustainability policies that can guide construction activities [7] in order to protect planet earth from tipping off beyond safe zones. This research is a review of the effects of construction activities on the planetary boundaries. It is part of an ongoing research on construction in developing countries and the need to operate within planetary boundaries for sustainable development.

2. Construction Activities and the Planetary Boundaries

The earth has been in existence for thousands of years without any major perturbations from nature. However, increase in the developmental activity driven by population growth is pushing the planet to a point where it may be difficult for the earth to sustain both itself and the lives on it. The planetary boundary concept is based on the belief that human activities can trigger irreparable environmental changes on a planetary scale that will have devastating consequences on man and the planet [8]. [5] advanced the planetary boundary concept and identified nine (9) areas in which human activities are altering the earth's systems. These areas/boundaries are: climate change, ocean acidification, stratosphere ozone depletion, interferences with global phosphorus and nitrogen cycles, rate of biodiversity loss, global freshwater use, land system change, aerosol loading and chemical pollution.

2.1 Climate Change

Atmospheric aerosols and atmospheric carbon dioxide ($C0_2$) are the two major causes of climate change. However, atmospheric aerosols have been found to have a greater impact on climate change [5, 6]. Atmospheric aerosols can absorb or scatter solar radiation resulting in global climatic changes [9]. Moreover, hydrophilic aerosols act as cloud condensation nuclei which can reduce precipitation efficiency [10]. Light absorbing aerosols can increase the warming of ambient air [9] which consequently leads to global warming. Furthermore, the construction industry produces significant amounts of aerosols in the form of re-suspended dust particles during construction activities [11] and bituminous aerosols from asphalt work [12]. Atmospheric $C0_2$ also influence climate change by absorbing heat from the sun and reflecting it back to the earth gradually over time. As for atmospheric $C0_{2,}$ some are soaked in by the oceans, but large amount remains in the atmosphere for a very long time resulting in global warming and ultimately changing climate pattern. Fossil fuel also has been seen as one of the major producer of atmospheric $C0_2$ likewise the construction industry consumes significant amounts of it inform of energy in buildings. Construction related greenhouse gas emissions are expected to reach 26% by 2030 with about 15.6 billion tons of $C0_2$ [13].
Building materials also emit significant amounts of $C0_2$ as a result of embodied energy. Embodied energy is the total energy expended in material production including upstream processes such as raw material extraction and transportation [14]. Refurbishment and renovation work also emit $C0_2$. [15] noted that interior renovations alone can account for as much as 20 %-30 % of initial embodied energy. Unless drastic measures are taken, $C0_2$ from construction activities may likely trigger climate change, and push the earth beyond safe boundaries.

2.2 Ocean Acidification

Ocean acidification is a phenomenon used to describe the absorption of atmospheric $C0_2$ by ocean surface layer. This reduces Ocean acidification reduces sea water PH and increases ocean acidity [6]. However, atmospheric $C0_2$ is the major cause of ocean acidification. Inland $C0_2$ in the form of Nitrogen and Phosphorus is as a result of unsustainable disposal of urban waste from agricultural, industrial and domestic sources which also contributes to ocean acidification. Furthermore, pollution of the sea water causes the growth of algae [16] which decays after blooming seasons, thereby generating $C0_2$ and acidifying sea water [17]. This has negative direct impacts on marine species and ecosystems particularly on calcifying organisms such as coral reefs, shellfish and zooplankton [17]. Ocean acidification also affects the economic activities of coastal regions particularly tourism and fisheries. Continued unsustainable disposal of urban waste into oceans and water courses can push the earth to a point where it can no longer sustain both aquatic and terrestrial life.

2.3 Stratospheric Ozone Depletion

The stratosphere houses the ozone layer which filters ultraviolet rays form the sun. This developmental activities produce harmful gases that deplete the ozone layer. [18] noted that some chemicals used in building construction and facility operation has been thinning out the ozone layer. The major gases responsible for the depletion of the ozone layer are chlorofluorocarbons (CFCs) used in refrigerators, air conditioners, foam blowing and aerosols; and Halons in fire suppressants. However, after the discovery of a gigantic hole in the ozone layer over Antartica, there has been a ban on CFCs. This action has significantly reduced the depletion rate of the ozone layer [5]. Stratospheric ozone depletion is one of the planetary boundaries that humans have been able to maintain through responsible and sustainable actions.

2.4 Interference with the Global Phosphorus and Nitrogen Cycles

Nitrogen (N) and Phosphorus (P) are major biological nutrients that drive sudden shifts in earth's sub-systems [5]. Even though fertilizer application is a major human activity interfering with global N and P cycles [6] industrial waste and fumes from fossil fuel also contain Nitrogen and Phosphorus which leads to pollution [5]. Unsustainable disposal of industrial and domestic waste end up in water bodies which leads to eutrophication. Fumes from generators used as alternative source of energy contain nitrogen which pollutes the atmosphere. Construction work such as landscaping depends on Nitrogen based fertilizers to enhance the growth of flowers, turfs, shrubs and trees. However, most of the Nitrogen compounds accumulate in the environment while others end up polluting waterways and coastal areas. Phosphorus inflows into water bodies can also be harmful to both aquatic and terrestrial life. Croplands generate the greatest volume of phosphorus inflow into water bodies [5]. Croplands also include landscaped urban areas which are a product of construction activities. Phosphorus is also found in detergents and sewage effluents which are generated in urban areas [19]. If domestic and industrial effluents are allowed to run into water courses without being treated or recycled, life formation on planet earth will find it difficult to cope sometime in the near future.

2.5 Rate of Biodiversity Loss

Biodiversity is important for sustaining the continued functioning of the ecosystem and also for preventing the planet from going beyond safe limits [20]. However, human perturbation has caused significant loss of biodiversity (especially terrestrial habitats, like soil). [21] noted that soils represent one of the most important reservoirs of biodiversity. Construction activities affect biodiversity in several ways, this includes: soil sealing, soil compaction and fragmentation.

Soil sealing- is a situation where the earth is covered with non-permeable or low permeable layers [22]. This also include the removal of top soil which is a necessary operation during construction and this leads to loss of soil organisms, incessant flooding [23] and erosion [24].
Soil compaction - occurs as a result of the impact of construction load on the soil. Soil compaction reduces soil pore size, increases bulk density and reduces soil absorptive capacity [25].
Fragmentation- is the isolation of habitants and disruption of ecological corridors [22]. Construction activities fragments habitants and isolate them from one another and as a result, the ecosystem is exposed to the dangers of external pressure, acidification, eutrophication and drainage [26].

2.6 Global Fresh water use
Fresh water use is one of the nine planetary boundaries that must not be transgressed if the earth must continue to exist [27]. Fresh water sustains both terrestrial and aquatic life. It is used in agriculture, manufacturing and other developmental activities including construction. Of all human activities altering global scale river flow, construction activities represents a significant proportion. For instance, buildings consume a global average of 30% fresh water over an entire life cycle [28]. Water use in construction can be in three forms: water used in manufacturing the construction material, water used in the actual construction process and water used when construction work is in operation. While the construction industry continues to compete with other industries for limited fresh water, drought (due to climate change) and population increase are exerting great pressure on existing water resources. This indicates that the planet may not be able to supply enough water to meet demand in the future.

2.7 Land system change
Land plays essential functions in maintaining the ecosystem. It is home for all terrestrial biomes including forests, wood lands, savannas, grasslands, shrub lands and tundra [6]. Land system can be altered in two ways: by changing the potential end use of the land or by embodied land use [22]. Embodied land use refers to the use of land components, for instance, limestone as raw material in the manufacture of other products like cement. Land system change may also occur when forest biomes are converted to non-forest biomes and this can have negative consequences on the ecosystem. Forest biomes particularly tropical and boreal forests play crucial roles in balancing the planet's carbon budget by soaking in $C0_2$ from the atmosphere. However, conversion of forested systems for other purposes is occurring at an alarming rate [5]. Therefore continuous unsustainable removal of forests for construction activities would increase the volume of $C0_2$ in the atmosphere and expose humanity to more greenhouse gas effects.

2.8 Aerosol Loading
Aerosols are liquid or solid particles in the atmosphere [29] which play a significant role in climate change dynamics and urban health. In climate change, aerosols influence the amount of solar energy on the earth by absorbing or scattering the sun's radiation. Atmospheric aerosols can have devastating effects on human health, animals and plants [30]. Aerosols in the atmosphere (comprising mainly of Ozone, Sulphur dioxide and Nitrogen Oxide) results in

over 2 million deaths yearly [31]. However, construction activities have been seen as major producers of atmospheric aerosols. Re-suspended dust particles in the atmosphere are generated from construction activities [11]. Bituminous aerosols and polycylic aromatic hydrocarbons (PAHs) aerosols are emitted during asphalt work [12]. Moreover, the construction industry consumes large quantities of fossil fuel both in the manufacture of building materials and as a source of alternative energy. Emissions from this fossil fuel can increase Aerosol Optical Depth (AOD) loading, consequently decreasing solar radiation [6]. This situation has a negative effect on climate and precipitation, further pushing the earth into unsafe boundaries.

2.9 Chemical Pollution

Chemicals and other engineered materials have the potential for causing unwanted geophysical and biological effects [6]. These chemicals pollute the environment and affect humans and the ecosystem on local, regional and global scales [5]. The construction industry generates several million tons of construction wastes globally. In the United States alone, construction waste accounted for about 136 million tons [32]. Many of these wastes end up in landfills where they are burnt. However, the emissions from landfills contain over 200 different dioxin compounds which generate large amounts of $C0_2$ [33]. Atmospheric $C0_2$ is the major pollutant causing the greenhouse gas effects and unsustainable disposal of construction waste will trigger chemical pollutions which can result in perturbations on a planetary scale.

Conclusion

The paper reviewed the effects of construction activities on the nine planetary boundaries. It noted that re-suspended dust particles from construction activities and bituminous aerosols during construction work produce significant amount of atmospheric $C0_2$: a leading cause of this is climate change. Embodied energy in buildings is a significant source of $C0_2$ emissions while unsustainable disposal of domestic and industrial wastes end up in water courses and negatively affects both aquatic and terrestrial life forms. The unsustainable use of land for construction purposes is a major cause of rapid loss of bio-diversity and construction is competing with other developmental activities for limited fresh water.

In developed countries steps are being taken to reduce the negative effects of developmental activities on man and the environment. In developing countries steps have to be taken because they are more vulnerable to sustainable development challenges. Hence the following recommendations are suggested:

1. There has to be more awareness about the effects of development activities on the health and wellbeing of human life on the earth as a planet.
2. Government, academia, the private sector and human rights activists in developing countries should take the lead in climate action to stem the tide of climate effects on the planet.
3. Weak institutions have to be strengthened to improve political will for the fight against climate change effects.

4. Most importantly, governments of developing countries should lobby for climate finance to combat environmental challenges threatening the wellbeing of their people and the sustainability of the planet.

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