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CLIMATE CHANGE AND INCREASED PREVALENCE OF NON-COMMUNICABLE DISEASES: A REVIEW

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ABSTRACT: Climate change through its effect on weather, anthropogenic emissions, distribution and types of air irritants is expected to increase exposure to air pollutants such as Carbon monoxide, Sulphur dioxide and Ozone. In addition, climate change is proposed to increase the risk of cardiovascular diseases (CVDs) directly through air pollution, extreme temperatures and indirectly via changes in diets. This is projected to increase morbidity and mortality from NCDs tremendously in low and middle income Countries. The purpose of this study was to review existing literature on impact of climate change on NCDs, identify gaps in existing studies, to stimulate further research interest in the field. This was a literature survey in which PubMed, ScienceDirect and Google scholar databases were searched using keywords; Climate change, Mitigation, Health, Non-Communicable Diseases, Diabetes, Cancers and Cardiovascular diseases (CVDs). Little research has been done on climate change and NCDs; therefore, data is lacking or inadequate if at all. Out of a total of 3,204,565 hits only 65,815 articles were specific to climate change and health, out of which only 35 were directly relevant to the survey. Results from this review indicated that climate change has led to increased or extreme temperatures, which can be directly or indirectly attributed to the increased NCDs prevalence. Furthermore, inhalation and or exposure to acute ozone exposure leads to oxidative stress, inflammation, ultimately leading to diabetes mellitus I & II, CVDs and cancers. Oxidative stress is also associated with DNA damage, endothelium dysfunction, damage to blood cells leading to high blood pressure, arteriosclerosis, myocardial infarction among other cardiovascular conditions. However, further research is required to strengthen this hypothesis. This information will help in attainment of sustainable development goal (SDG) number 3 on ensuring health for all, promotion of wellbeing for all at all ages and number 13 on combating climate

KEYWORDS: Climate change, Health, Non-communicable diseases (NCDs), Diabetes, Cancers, Cardiovascular diseases (CVDs)

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1. INTRODUCTION

Climate change has been identified as the biggest 21st century threat to population health by Costello *et al.* (2009) [1]. Climate change, which has been defined as change in global or regional climate patterns occurs in various forms such as droughts, increase in atmospheric temperatures or heat waves, change in weather patterns, depletion of stratospheric ozone, global warming, increase in air pollutants, increase in greenhouse gases (Carbon monoxide, Sulphur dioxide, nitric oxide)[2]. The atmospheric temperatures have been increasing by 0.6ºC annually due to climate change [3]. This has led to negative impacts in health in general and in particular NCDs. The burden of NCDs has become so large that it has warranted global attention [4]. Increased atmospheric temperatures and Ozone (O_3) have been associated with increased imbalance in antioxidant defence systems, free radicals otherwise referred to as oxidative stress and reactive oxygen species (ROS). This has been linked with chronic inflammatory conditions, cancers, diabetes mellitus, artherosclerosis and several neurogenerative diseases [5]. O_3, a pale blue gas, offers an important protection against solar radiation. However disruption or depletion of the layer has leads to an increase in the atmospheric O_3, where it is regarded as an oxidant and most toxic air pollutant. Importantly, O_3 is cable of causing directly oxidization or peroxidation of biomolecules such as deoxynucleic acid (DNA), proteins and lipids or indirectly by free radical mechanisms [6,7]. Therefore, urgent measures to mitigate climatic changes such as greenhouse emissions are required [8].

Climate change and diabetes mellitus

An estimated 422 million adults were living with diabetes in the world by 2014[9]. Climate change such as increased atmospheric temperatures or heat waves, droughts may indirectly increase the risk of diabetes by promoting physical inactivity, disrupting traditional food supplies and increasing food insecurity [10]. Directly, acute exposure to O_3 is associated with various mechanisms in oxidative stress, inflammation and tissue injury. A close association between obesity and greenhouse emissions from transport and food production has been reported [11]. Diabetes mellitus especially type II has been on the increase globally recently particularly in the middle age bracket. Erosion and depletion of the stratospheric O_3 layer due to increased greenhouse effects (increased carbon emissions from industries and use of fossil fuels), has led to global warming, which is characterized by increased atmospheric temperatures. As mentioned earlier, world temperatures have been increasing annually by 0.6ºC since 1950's [12]. Furthermore, O_3 being a potent oxidant, is capable of oxidizing biological

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molecules generating free radicals and other reactive intermediates. Hence, it plays an important role in inflammation [13]. Consequently, it causes lipid peroxidation [14], oxidation of proteins, nucleic acids as well as chromosomal aberrations [15,16,17]. In addition, increased exposure to O_3 has been linked to increased incidences of diabetes mellitus type I [18]. Moreover, inflammation induced by exposure to O_3 in humans has been reported [19]. Although most of the damage by O_3 occurs in the lungs due to inhalation, it has been shown to cause oxidation or peroxidation of biomolecules such as DNA, proteins, lipids, leading to a vicious cycle of chronic inflammation and oxidative stress commonly seen in diabetes [13]. This can lead to damage or functional defects in organs such as the beta cells of the liver [20]. Dandona, (1996) [21] and Pan, (2007) [22], noted that diabetes was a case of DNA damage. Accordingly, if the oxidative damage occurs in the liver, cellular functions of β cells of the islets of langerhans, responsible for production of insulin, the hormone that facilitates absorption of glucose into the cells is affected. Consequently, low insulin leads to increased blood glucose a characteristic of diabetes mellitus type II. Significantly, increased temperature is capable of causing cellular metabolic alteration, leading to glucose influx [23], which in association with damaged islets of langerhans, decreased or absence of insulin leads to hyperglycemia, a characteristic of diabetes mellitus disease. Increased temperatures also encourages people to stay indoors with little activity (sedentary lifestyles), leading to obesity, which in association with low fiber diets are risk factors for the condition.

Climate change and cardiovascular diseases (CVDs)

Global warming has led to increased or extreme atmospheric temperatures as discussed earlier leading to high blood pressures [24]. The increased atmospheric temperatures and O_3, a potent non-radical oxidant, are capable of causing acute exposure-induced oxidative stress and metabolic alterations. In addition, O_3 is capable of inducing base changes in DNA, causing DNA damage to cells [13]. This causes focal lesions, which initiates inflammatory rsponses by recruiting inflammatory cells such as macrophages, fat cells, fibroblasts, Neutrophils, which produce more free radicals such as ROS, pro-inflammatory and other cytokines [25]. As a consequence, this leads to a vicious cycle of chronic inflammation and oxidative stress, which is common in CVDs. If this happens in the endothelium of blood vessels, it leads to lipid peroxidation, endothelial damage, its dysfunction, leading to further recruitment and deposition of more inflammatory cells on the endothelium as plaque. Deposition of the plaque and the ensuing endothelial dysfunction leads to arteriosclerosis, blockage of the blood vessels, high blood pressure, which can lead to strokes. If this happens in arteries close or in the heart, it leads to arteriosclerosis, myocardial infarctions and heart attacks [26]. Diets high in cholesterol, coupled by obesity, sedentary or inactive lifestyle due to increased atmospheric temperatures, oxidation of the fatty acids producing cholesterol, leads to deposition of

the cholesterol in the inside of blood vessels, which can lead to high blood pressure, strokes, arteriosclerosis, myocardial infarction and other cardiovascular conditions[27].

Climate change and cancers

Disruption and depletion of the stratospheric O_3 has led to an increase in atmospheric O_3 and temperatures (global warming). Similarly, inhalation of atmospheric O_3 is associated with acute exposure-induced oxidative stress and inflammation with serious health consequences especially in the lungs [28]. As mentioned earlier, O_3 is a powerful non-radical oxidant capable of directly or indirectly via oxidative stress mechanisms causing changes in DNA bases, inducing DNA damage, "survival mutations" in proto-oncogenes (Ras & c-MYC), tumour suppressor genes (p53 & RB), metabolic reprogramming and ultimately induction of the seven cancer hallmarks. Acute O_3 exposure-induced oxidative stress is thought to cause DNA damage, which forms the primary focal tumour lesions [29,30]. The focal tumour lesions initiates an inflammatory response by recruiting inflammatory cells, which react by generating increased amounts of ROS and pro-inflammatory cytokines such as tumour necrosis factor alpha (TNF-α), Interleukin I & 6 (IL-I & 6) and Interferons[25]. This leads to a vicious cycle of chronic inflammation, immune activation, oxidative stress, metabolic reprogramming, induction of the seven cancer hall marks, strongly linked with initiation, maintenance and progression of cancer. According to Colotta*et al*. (2009) [31], Candido&Hagemann (2013) [32], Ataie-Kachoie *et al.* (2014) [33], cancer is described as a failed resolution of the inflammatory process or tissue remodeling, which develops in a setting of chronic oxidative stress, inflammation and immune activation. Directly, increased exposure to ultraviolet B (UVB) radiation resulting from depletion of stratospheric O_3 has been reported to cause basal and squamous cell skin cancer. Furthermore, increased temperatures due to climate change may lead to skin cancers [34]. Indirectly, high temperatures encourage inactive lifestyle, which leads to obesity, important risk factors for cancer. Changes in climate may also contribute to cancers via increased air pollutants, changes in distribution patterns of infectious agents, increased aflatoxin poisoning during dry seasons, wet seasons (post-harvest storage), increase in pests, weeds thus demand for increased use of pesticides and herbicides [35]. Importantly, climate change has led to the currently experienced droughts especially in Africa, which contributes to increased hunger and poverty. Subsequently, increased poverty leads to stress, which is now a recognized risk factor for cancers. Specifically, stress acts on the hypothalamic-pituitary-adrenal axis (HPA), causing increased secretion of cortisol, a hormone which reacts with migration inhibitory factor (MIF), a potent pro-inflammatory cytokine, other cytokines, chemokines such as interleukin-I (IL-I), interleukin 6 (IL-6), tumour necrosis factor alpha (TNF-α) and interferons (IFNs) initiating inflammatory response, oxidative stress requisite for carcinogenesis[36,37].

Need for mitigating effects climate change on health

The international community on realization of the negative impacts of climate change has responded by developing policies, passing and implementing several legislations relating to standards, regulation of carbon emissions air pollution and environmental conservation. Such regulations include regulating greenhouse emission, air pollution by automobiles and control of the use of non-biodegradable products such as plastic bags. In 2005, 195 states ratified the Kyoto protocol under which they committed to reduce their greenhouse gases emissions by 5% [38]. However, despite all the efforts, there is in exhaustive evidence on the extent and impact of climate change and the increased prevalence of NCDs. To explore the hypothesis that climate change might be associated with the increased prevalence of NCDs, the author conducted a descriptive systematic review of existing literature. Currently, very little studies on climate change and NCDs have been done; therefore evidence is lacking to strengthen the hypothesis. The aim was to investigate the association between climate change and the increased prevalence in NCDs. The author was trying to answer the following research questions:

1. Does climate change impact on health in general?
2. Is climate change associated with the increased prevalence of NCDs?
3. Are there measures put in place by the government and other stakeholders to mitigate the impact of climate change on health (specifically NCDs).

Methods and Design

This was a descriptive systematic review in which PubMed, ScienceDirect and Google scholar databases were searched using different combinations of the keywords; climate change, mitigation, health, on-communicable diseases, diabetes, cancers and cardiovascular diseases (CVDs). The inclusion criteria was all studies involving climate change and health, non-communicable diseases, in English and with the search words. The exclusion criteria were studies not linking directly climate change, health and NCDs, not in English. The downloaded articles were critically appraised. PubMed, ScienceDirect and Google scholar databases were searched using different combinations of the previously identified keywords. The identified relevant articles were downloaded at Kirinyaga University from 20th February 2017- 10th April, 2017. A total of 3,204,565 hits were obtained and after critical appraisal to assess the relevance, bias, validity and quality of the existing literature, 35 articles were selected for the survey. Pearling by referring to other essential references from the downloaded ones was also used.

3.RESULTS AND DISCUSSIONS

Climate change and health

Table I: Climate change and Health or NCDs

Databases/Studies on climate change	Health	[1]NCDs	Diabetes	Cancers	[2]CVDs
PubMed	5,910	105	35	34	89
Google Scholar	3,060,000	57,900	85,000	80,000	82,000
ScienceDirect	138,655	2002	9700	22,910	10,139
Total	**3,204,565**	**60,007**	**94,735**	**102,944**	**92,228**

Table 1 show the number of existing studies linking climate change with health and NCDs. A lot of studies on impacts of climate change on health have been done although not relevant to NCDs. NCDs in general are not widely studied. Among the NCDs, climate change and cancers is the most studied. 1=Non communicable disease, 2= Cardiovascular diseases.

DISCUSSION

The aim of the current study was to review existing literature on studies associating climate change, health and specifically with NCDs. Based on the objectives, research questions of the descriptive survey, search words climate change, health, non-communicable diseases, diabetes, cancers, cardiovascular diseases, a total of 3,204,565 hits were obtained, critically appraised to assess their quality, methodology, what was analyzed in the studies, results and relevance to the survey, 35 articles were selected. The search was conducted at Kirinyaga University from 20th February 2017-10th April, 2017. The results of the selected studies were reviewed, analyzed, compared and presented in form of summary tables as shown above. The area of climate change and health globally is well studied, although studies specific to non-communicable diseases are not adequate. However, majority of the studies obtained were on association between climate change and diabetes. The strong link, directly or indirectly between climate change and health is well delineated, though inexhaustively from the previous studies. Significantly, a direct and an indirect association between climate change and health is documented [1,4,5]. Specifically, climate change is directly linked to diabetes mellitus type I through inhalation of O_3, interaction with its reactive metabolites, which leads to chronic oxidative stress and inflammation, DNA damage characteristic of the disease [4,29,30]. Indirectly, heat waves or increased atmospheric temperatures leading to inactive or sedentary lifestyles, obesity, which are risk factors for the disease, urbanization in addition to change in diets as a result of droughts is associated with diabetes mellitus type II[24]. Furthermore, climate change has been directly linked to increased CVDs via inhalation of atmospheric O_3, leading to acute ozone exposure-induced oxidative stress and inflammation [28]. This occurs mainly in the endothelium of

blood vessels, which leads to generation of free radicals, specifically the ROS, endothelial damage and its dysfunction. Ultimately, the oxidative stress causes lipid peroxidation, deposition of peroxidation products, fat cells, foam cells and macrophages onto the endothelium as plaque, damaged endothelium, arteriosclerosis and clogging of blood vessels. This if untreated, may lead to high blood pressures, strokes and myocardial infarctions. Indirectly, climate change can also cause CVDs via urbanization, change in diets, too high in lipids (Cholesterol) as a result of droughts, which if deposited on endothelium causes high blood pressure. Similarly, heat waves lead to inactive lifestyles or physical inactivity, obesity risk factors for NCDs. Importantly, climate change is directly associated with cancer via acute O_3 exposure-induced oxidative stress, inflammation, DNA damage, induction of "survival mutations "in the proto-oncogenes (Ras & c-MYC) and tumour suppressor genes (p53 & RB), metabolic reprogramming and induction of the seven cancer hallmarks [25,31,32,33]. Indirectly, climate change is associated with cancers through increased atmospheric temperatures (heat waves) leading to inactive (sedentary) lifestyles, obesity, which are risk factors for the disease and chronic diseases [36].Although several studies have been done on climate change and health globally in general, specific studies relating directly to the current increase in prevalence of NCDs are in exhaustive, hence evidence to support or strengthen the hypothesis associating the current increase in prevalence of NCDs is lacking. The author therefore strongly recommends further studies such as retrospective case-control studies or longitudinal studies on the association or causal relationship between climate change and specific NCDs such as diabetes, CVDs and cancers. Despite several studies indicating an association with climate change and health, very few specific studies have been done on NCDs such as cancer, diabetes, cardiovascular diseases such as high blood pressure, arteriosclerosis and myocardial infarctions. This means data to support policy development relating to mitigating climate change and control of NCDs lacking. Lack of such studies indicates that prevention, control treatment and management of NCDs policies do not incorporate this critical aspect of their cause. Therefore, this makes the current policies largely ineffective. It also indicates that few studies or little research effort is directed to this type of studies, making this area of climate change and its association with increased prevalence of non-communicable diseases a fertile ground for future research. Although most of the generation and emissions of greenhouse gases happens in highly industrialized and developed nations of the world, it is in least developed nations where their impact is highest. As a result, international treaties such as the Kyoto protocol of 2005, Doha amendment to the protocol in 2012, has committed developed countries to reduce greenhouse gases emission by 5% [38]. In addition, the use of clean energy such as wind, geothermal is strongly encouraged as opposed to the highly pollutant coal and fossil fuels. Furthermore, use of unleaded fuels to reduce amount of carbon emission by automobiles, increasing forest cover by planting of more trees, protection of water catchment areas, discouraging encroachment of water catchment areas

and forests, use of biodegradable products to protect the environment are encouraged. From previous studies, inhalation and or exposure to acute ozone exposure leads to oxidative stress, inflammation, ultimately leading to diabetes mellitus I & II, CVDs and cancers [30]. Consequently, current management strategies of these diseases most of which do not consider these factors require review. Integration of modulators of oxidative stress, inflammation from inhalation of atmospheric O_3 into the current and future practices will be a promising therapeutic approach. Active participation by healthcare stakeholders in climate change and its mitigation measures is recommended. Importantly, review of healthcare providers curricula to include climate change and its impact on health and specifically on NCDs need to be considered. Involvement in evidence based research by healthcare workers in direct association with patients of NCDs to guide their decisions in management of NCDs will also be important. That climate change is closely associated with health is not in doubt, therefore it can be implicated in the increased prevalence of NCDs. This makes urgent climate change mitigation strategies such as reducing greenhouse gases critical. However, to support and strengthen this hypothesis, more research on the causal effect of climate change on NCDs, specifically the role of climate change and development of cancers, diabetes and cardiovascular diseases are required. This could be in form of retrospective case-control studies, longitudinal studies or experimental design using *in vivo* laboratory experiments, mouse and primate models. Such studies will not only be important in helping the country's attainment of SDG number 13 on combatting climate change, its impacts but also number 3 on ensuring health for all, promotion of will being for all at all ages and realization of the vision 2030.

CONFLICT OF INTEREST

The authors have no conflict of interest.

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