



Global Climate Change and Its Effects on Nature and Human Life; Evaluation of Vulnerability and Contributors to Climate Change

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Abstract

Climate change occurs as a result of the consistent alterations of the normal atmospheric weather conditions that result in an imbalance of the earth's climate, caused by the radiations from chemical, biological, or natural sources, leading to an increased surface temperature that is capable of causing an intense threat to human's life, plants, animals, and the planet ecosystem. The purpose of this study is to alert the world about the dangers associated with climate change and the factors capable of causing climate change. This study also reveals the top 10 countries that contribute the most to climate change through the emission of greenhouse gases and other factors. Finally, this study will help to inform the world about the most vulnerable countries to climate change in a ranking format from the most affected to the least. We used an MCDM technique called fuzzy preference ranking organization method for enrichment evaluation (F-PROMETHEE) to rank the most vulnerable countries to climate change. We considered 14 countries that have been severely affected by climate change, and we evaluated them based on seven criteria. Results indicated that China is the highest contributor to climate change as they emit (9,300 million tons) of greenhouse gases, followed by the USA (4,800 Mt), and Saudi Arabia (532.2 Mt) occupies the tenth position as the countries that make this planet a risk zone for humans, plants, and animals. Results from the PROMETHEE approach show that Mozambique is the most vulnerable country to climate change, followed by India, and then Japan.

Keywords: Climate change, global warming, fuzzy-PROMETHEE, greenhouse gas

1. Introduction

The word climate is derived from the Greek word "Klima" which means "inclination" or "slope" [1]. Climate as a word has been in use for over 100 years in the English vocabulary before it was used in the 16th century to refer to weather conditions over a long period, averaging 30 years [1]. From the middle of the 17th century, the word "climate" was used synonymously with "atmosphere" by most people, soon it became globally paired with "change" in modern usage [4]. The compound word Climate Change, therefore, means a periodic alteration of the atmosphere that causes an imbalance to the earth's climate, caused by the radiations from natural sources like the Earth's rotation around its axis, moving continents, chemical, and biological factors, especially from human activities [1,2,3,4,5]. Over the years, climatic changes have been occurring with steady periodic alterations, but it's more alarming now as the collective weight of damage to the atmospheric weather is on the

increase due to increased human activities leading to global warming [1,2,3,4,5]. Global warming is often used interchangeably with climate change, but distinct values. While climate change refers to the side effects of the earth's warming, Global warming is the periodic increasing average surface temperature [1]. Both terms, "Global warming" and "Climate Change", pose an intense threat to human life and the ecosystem as the global mean temperature is expected to rise to 5.4°C by 2100 due to the overwhelming human activities that are constantly on the rise to degrade climatic stability (such as the burning of fossil fuels causing increased accumulation of carbon dioxide in the atmosphere, and biodiversity) with a little contribution from solar activities and volcanic eruptions [1,2,3,4,5].

2. Causes of Climate Change

Climate change occurs as a result of the consistent alterations of the normal atmospheric weather condition that results in an imbalance of the earth's climate, caused by the radiations from chemical and biological natural sources leading to an increased surface temperature [1,2,4,5]. Greenhouse heat-trapping gases like nitrous oxide, methane, and CO₂ are on the increase due to the evaporation of water from oceans and other water bodies into the atmosphere leading to the increasing mean of the surface temperature [4]. One of the most common greenhouse gases is Carbon dioxide (CO₂), which is also naturally obtained from the exhale of animals and humans as a waste metabolic product. Another known source of CO₂ is traced to human chemical and biological activities of burning fossil fuels like (gases, coal, and oil), deforestation, and agricultural factors that emit CO₂ causing climate change [1,2,4]. China is the world's leading carbon dioxide emitter followed by the United States of America (USA), Russia, India, and Japan [1,4]. Energy-related CO₂ emissions in the United States dropped to 4.58 billion metric tons in 2020, from 5.1 billion metric tons recorded in 2017, totaling 31.5 billion metric tons of energy-related CO₂ emitted globally in 2020, which is also a drop from 32.5 billion metric tons of global records in 2017 [1]. This reduction is still on the high side as damages this could cause to the climate are still very enormous [4]. Deforestation is another significant factor that contributes to global climate change [1,2,4,5].

3. Effects of Climate Change

The effects of climate change on human life, animals, and plants are notably intense and adverse [6,7]. Some cold regions may have some health benefits due to warmer temperatures but habitable human coastal communities, coral reefs, and forests have more vulnerability to climate change [6,7,8].

3.1. Effects of Climate Change on the Environment

Our environment has suffered severe negative impacts due to the current climatic conditions [4,5]. Climatic changes have for decades been the primary cause of increased temperature, the rise of sea levels, dangerous hurricanes and rainstorms, melting of mountain glaciers and loss of ice, drought, wildfire, ocean acidity, and other natural disasters [1,2,3,4,5,6,7,8].

3.1.1. Increased Temperature

The measurement of the degree of hotness and coldness of the environment started in the early 18th century through what is known as systematic observations of the weather and the use of a thermometer [1,4]. Only since the early 19th century have temperature records from modern thermometers (with temperature scales) been available. Scientists can deduce past temperatures by investigating indirect characteristics (chemical and structural fingerprints). The temperature of the universe at 10 to 35 seconds old was around 1 octillion degrees Celsius [4]. The universe's temperature dropped to roughly 1 billion °C in less than 2 minutes. Planet Earth has changed between ice ages with protracted cold periods (glacial) and mild times (interglacial) on 100,000-year cycles over at least the last several million years [4]. The balance between energy input from the sun and energy

loss back into space determines the Earth's temperature [9,10]. Nearly a third of the sun's incoming short-wave radiation (ultraviolet and visible spectrum) is reflected into space. The remaining heat is absorbed by the land and oceans, which then emit it as long-wave infrared radiation. The current climate change is linked to rising global temperatures (land surfaces and upper layers of the ocean). Land surfaces heat more quickly than water surfaces [9]. A warmer atmosphere can store more water vapor, resulting in greater precipitation on average. The temperature of the Earth has risen by about 0.7°C in the last 70 years. The number of cold days and nights has dropped since 1950, while the number of warm days and nights has risen. The rate of warming since 1976 has been faster than at any other period in the prior 1,000 years. There are extreme temperatures at any given time. The lowest air temperature on Earth was -94.7°C (measured in Antarctica in 2010) and the highest air temperature was 70.7°C (recorded in Iran's Lut Desert in 2005) [4]. The world's mean temperature is currently approximately 15.0°C. Surface temperatures are currently rising at a rate of about 0.2°C every decade. Global mean temperatures would rise by 0.9 to 5.4°C by 2100, according to the Intergovernmental Panel on Climate Change (IPCC), based on various emission scenarios. The rise in world average temperature is not uniform. The temperature of the Earth varies by place. In the short run, some locations will not even become warmer and may even get colder. At higher latitudes, the warming is more pronounced [4,9,10].

3.1.2. Rise of Sea Levels

Sea levels rise as a result of climate change either due to an increase in ocean water volume as it warms and expands, or an increase in the mass of ocean water primarily due to melting glaciers [1]. The worldwide mean sea level has risen by about 0.20 meters since 1900. i.e. The worldwide mean sea level has risen by 0.003 meters every year on average during the last 25 years. Sea levels are expected to rise between 0.40 and 1.50 meters by 2100, depending on emissions forecasts. Sea-level rise will cause the extinction of some islands, as well as flooding that would result in homelessness and population migration [1,4,6].

3.1.3. Dangerous Hurricanes and Rainstorms

Due to the increasing temperature of ocean water, climate change promotes more destructive hurricanes and heavier rainstorms [1,4,11]. Per 1.0°C of global warming, the proportion of Category 4 and 5 storms has grown by 25–30%. Hurricane Katrina (Category 5, 2005, New Orleans, USA) was one of the deadliest hurricanes in recent US history. There were 1,833 people killed directly or indirectly as a result of Hurricane Katrina (reports from state and local officials in five states) [11]. There were six storms in the North Atlantic hurricane season of 2019. (including three major hurricanes, e.g., Category 3 or higher) [1,4,11].

3.1.4 Melting of Mountain Glaciers and Loss of Ice

Climate change melts mountain glaciers and increases the rate of ice loss in Greenland and Antarctica [1]. Some glaciers hold significant sacred and symbolic meanings for countryside localities and religious communities. Observable changes in glaciers bring changes to cultures and human subjectivity for those who locate their deities on or within mountain glaciers (e.g., in the Peruvian Andes, the Nepalese Himalayas, and the Chinese Meili Snow Mountains). Lakes all over the world are freezing less and for a shorter period. Thousands of lakes may lose their winter ice cover in the coming decades [1,12].

3.1.5 Drought

Drought is a multifaceted concept affected by a combination of physical and biological processes. Drought is one of the most complicated and expensive natural disasters. Climate change is fully accountable for more frequent and intense droughts (especially in subtropical regions), promoting the emergence of deserts. This will result in misery, hunger, starvation, and population Emigration [1,13].

3.1.6 Wildfire

Wildfires are becoming increasingly common as a result of climate change. In various nations, the dry, hot weather has enhanced the intensity and destructive nature of forest fires (e.g., Brazil, USA, Australia, and some parts of Africa) [1,14]. Deforestation, major property damage, protracted exposure of large populations to

contaminated and poisonous air with potential health effects (e.g., respiratory disorders), and mortality can all result from wildfires. During recent droughts, the Amazon (Brazil) has become more flammable and subject to wildfires. In recent years, California (USA) has seen severe autumn wildfires, with over 100 people killed directly as a result of the most destructive and deadly wildfires, which occurred in 2017 and 2018 [1,14,15].

3.1.7 Ocean Acidity

The ocean provides the majority of the planet's life-supporting environment. As some carbon dioxide dissolves in ocean water, generating carbonic acid, the abundance of carbon dioxide in the atmosphere causes the surface waters of the oceans to become more acidic [1,16]. Ocean acidification has the potential to disrupt marine ecosystems, including harm to coral reefs (which provide numerous benefits to humans), fish, and other aquatic animals [1,4,16,17].

3.2. Effects of Climate Change on Plants

Plant phenology is affected by climate change. Carbon dioxide levels in the atmosphere, abnormally increased temperatures, the rise of sea level, rainfall, weeds, and pests or bacteria are all negative impacts of climate change [1,7,8,18]. Climate change affects plant growth and survival. Increased mean temperature and mild winters encourage insect proliferation (e.g., allowing more pine beetles to live), as well as the invasion of farmlands by salty water, wildfires, and droughts, which endanger plant survival and cause forest loss and damage to plants. Agriculture, according to some assessments, is the most vulnerable activity to climate change. Food insecurity will result from reduced agricultural production [1,7,8,18].

3.3. Effects of Climate Change on Animals

Climate change subjects animals to several factors that affect metabolic and endocrine activities, potentially jeopardizing species' survival [8,20]. Every year, more animal species become extinct as a result of climate change [8]. A total of 700 mammalian species are affected. The degree of susceptibility varies by species and is impacted differently [1,8,20,21]. Species having a low tolerance for abnormally increased temperatures are at high risk of extinction. e.g. Polar bears, koalas, elephants, sea turtles, cheetahs, panda bears, and penguins are among the vulnerable/endangered animals. Climate-change-affected species will either need to relocate to more suitable habitats (e.g., higher altitudes and latitudes) or adapt to changes in their current ecosystems. They may perish and become extinct if they are unable to change their environments. Several habitats for animals may be degraded or lost as a result of climate change (e.g., polar bears, koalas, and birds). Polar bears rely on sea ice to survive. The melting of arctic sea ice is threatening the habitat of polar bears due to rising temperatures [25]. The eucalyptus tree is essential to koalas' survival. Increased temperatures and drought are producing wildfires, which are harming the habitat of koalas. Polar bears would have difficulty locating food due to the melting of arctic sea ice which is the habitat of polar bears, this would leave polar bears relying and feeding on their fat reserves which would eventually lead to starvation. They must have to swim larger lengths in the water in search of food and suitable habitat, and many young cubs perish as a result of their inability to do so. Eucalyptus leaves are the primary food source for koalas [22]. Each koala consumes about 1 kilogram of eucalyptus leaves every day. The amount of water in the eucalyptus tree is decreasing as a result of climate change. Increased carbon dioxide levels cause a drop, in protein levels in the trees, lowering the nutritional quality of the plant. Dehydration, malnutrition, and famine are all consequences of these alterations. Koalas put their lives in danger by descending from their trees in quest of water and food, this exposes them to predators and puts them at risk of being hit by motorists. Over the previous three generations, the population of koalas has decreased by more than 30% [22]. In addition to the amount needed for bathing and playing, elephants require 150–300 liters of water per day for drinking [23]. Droughts can lead to population loss. Also, because most turtles lay their eggs on beaches, rising sea levels pose a hazard to sea turtle eggs [24]. Climate

change has the potential to alter sex determination in a variety of animals. The temperature of the nest determines the sex of sea turtles. Males are produced in greater numbers in colder temperatures, whereas females are produced in greater numbers in warmer temperatures. The gender population of sea turtles is changing as a result of climate change, with females outnumbering males. Certain locations may wind up producing exclusively female turtles, putting local species at risk of extinction due to a lack of mating partners for female turtles [1,8,20,21,22,23,24,25].

3.4. Effects of Climate Change on Humans

Climate change poses a serious threat to humanity's survival [1]. It has several negative health repercussions, including an increase in morbidity and mortality. Some of the adverse impacts of climate change on humans include; abnormal increases in temperature, infection, impact on hygiene and nutrition, population movement, etc. [1,4]

3.4.1. Increased Temperature

To achieve optimal physiological performance, the human core temperature averages 37.0°C and is closely controlled within a range of 33.2°C and 38.2°C. Extreme departures from the usual core temperature, such as hypothermia (below 27.0°C) or hyperthermia (over 42.0°C), can be fatal [1,2]. Many places of the world are seeing increased exposure to extreme heat as a result of climate change. Reduced performance and work productivity, behavioral changes, heat exhaustion, heatstroke, respiratory failure, myocardial infarction, stroke, and death are some of the physiological reactions that occur in humans as the temperature rises, putting some organs at risk and exposing people to increased morbidity and mortality [1,2,19]. Reduced work efficiency (up to 10% in some hot places) has significant economic implications. Reduced work productivity might cost the economy more than 20% of the gross domestic product by 2100 if we don't adjust. When exposed to heat stress, children, the elderly, the impoverished, outdoor laborers, individuals who are forced to wear protective clothing and personal protection equipment, and persons with chronic health conditions are at greater risk of severe impact. Heat-related deaths are estimated to be around 1,500 per year in the United States. 70,000 people died in Europe during the summer of 2003 due to a heatwave [1,2,19,25,26].

3.4.2. Infection

Climate change influences the prevalence of several infectious illnesses by increasing the viability, reproduction, and dispersion of disease pathogens and vectors and creating an enabling transmission environment through changes in temperature, precipitation/humidity, wind, and solar radiation. Malaria, dengue fever, and Lyme disease are among the infectious disorders involved [1,27,28].

3.4.3. Hygiene and Nutrition

In numerous nations, climate change is causing water and food shortages, which substantially influences hygiene and nutrition [1,6,9]. The significant exposure to salt through drinking water, food, and bathing can lead to a variety of health concerns in the absence of effective desalination of drinking water impacted by increased salinity due to sea-level rise (particularly in low-income nations like Bangladesh) (e.g., hypertension and skin diseases). Climate change harms food production systems in many regions. Rice yields might be reduced by 10% if nighttime temperatures rise by 1.0°C, according to the International Rice Research Institute in the Philippines. As ocean temperatures rise, various fish populations may migrate to higher latitudes, posing a threat to millions of people's dietary protein supplies [1,6,9,27].

3.4.4. population movement

Many people will be displaced as a result of climate change [1], which will create unsuitable living conditions such as desertification, sea-level rise, loss of freshwater supply, food shortages, deforestation, and health difficulties [1]. Humans would be forced to migrate from one place to another in search of a better weather-favorable environment [1,4]. Human mobility has an especially negative influence on poor societies. Up to

several hundred million people are expected to be relocated by 2050. Countries will face a variety of issues as a result of population movement (e.g., social, health, and financial consequences and violent conflicts) [1,9,29].

4. Evaluation of the Top 10 Countries That Contribute to Climate Change the Most

Several criteria can be considered to compare countries' contributions to climate change. Greenhouse Gas emissions can be seen as an absolute criterion. Absolute emissions or per capita terms could be considered as well as historical emissions and the carbon footprint of consumption, including imported items, are evaluated. There's also the inclusion of deforestation, waste, power plants, oil drilling, transport, vehicles even fossil fuel production are all included [1,4,30,31]. Each method provides a unique perspective, and none of them can explain the entire tale on its own. In this study, more focus was aimed at the greenhouse gas emission rate for our ranking.

4.1. Greenhouse Gas Emission

A greenhouse gas (GHG) is an atmospheric gas that traps heat [31]. The greenhouse effect is caused by greenhouse gases that allow sunlight to travel through the atmosphere but prevent heat from exiting [31]. Greenhouse gases are necessary for keeping the Planet warm; without them, the mean temperature would be around 0°F. Water vapor, carbon dioxide, methane, nitrous oxide, and ozone are the principal greenhouse gases in the Earth's atmosphere [31]. Carbon dioxide is released into the atmosphere as a result of the combustion of fossil fuels (coal, natural gas, and oil), solid waste, biological materials, and chemical reactions [1,4,31]. Methane is released into the atmosphere as a result of livestock and agricultural practices, as well as the production and transportation of coal, natural gas, and oil. Nitrous oxide is released through industrial and agricultural processes, as well as the combustion of fossil fuels and wastewater treatment. The most abundant greenhouse gas is carbon dioxide (CO₂) [1,4,31]. Global carbon dioxide emissions have increased by 90% since 1970, with fossil fuel burning and industrial processes accounting for roughly 78 percent of the entire increase. the economic sectors that emit the most greenhouse gas emissions are Electricity and heat-generating machines (25 percent), agriculture, forestry, and other land use (24 percent), industry (21 percent), and transportation (14 percent) according to the Environmental Protection Agency (EPA) [1,4,30,31]. The amount of greenhouse gases released into the atmosphere varies by country. The size of a country's population, GDP, energy mix, and other factors all contribute to its overall emissions level. According to the International Energy Agency, worldwide carbon dioxide emissions from fuel burning reached 32.8 billion tons in 2017. China was the largest contributor, accounting for 28% of all emissions, followed by the United States (14%), the European Union as a whole (10%), India (7%), Russia (5%), Japan (3%), Korea (2%), Canada (2%), Indonesia (2%), and Iran (2%). The rest of the world contributed around a quarter of the emissions. The simplest and most frequent method of comparing country emissions is to add up all of the fossil fuels burned and cement produced in each country and convert that to CO₂. The top-10 countries according to the Greenhouse gas emission data in 2022 [31] with the highest carbon dioxide emissions (in million tons (Mt)) are China (9,300 Mt), The United States (4,800 Mt), India (2,200 Mt), Russia (1,500 Mt), Japan (1,100 Mt), Germany (718.8 Mt), Korea (600 Mt), Iran (567.1 Mt), Canada (547.8 Mt), Saudi Arabia (532.2 Mt) [1,4,30,31].

5.1. Using Fuzzy-PROMETHEE to Evaluate the Top 10 Countries Most Vulnerable to Climate Change

Climate change is accelerating, affecting the lives of many people, disrupting national economies, and altering our ecosystems [30,31,32,34]. Climate change is having an impact all across the planet [1,2,3,4,5,6,7,8,9,10]. Climate change is often known as the "climate problem" or "global warming". We constantly hear about ice caps melting, hungry polar bears, and dead dolphins with trash bags in their guts. Climate change and the health of our planets are intertwined, and changes in one will have an impact on the other. Governments are becoming increasingly burdened as a result of climate change, particularly in countries with limited resources.

Drought and shorter but more intense rainfall, for example, can have a detrimental influence on health and contribute to issues like flooding, food insecurity, and migration. Indigenous peoples, the poor, women, and people with disabilities are often the ones who suffer the most. Wildfires rage uncontrollably in hot weather, consuming vast forests. The oceans are becoming more acidic as they warm. All of our lives, including our food security, health, and quality of life, are at risk. The annual temperature on Earth has risen over the last century, the oceans have warmed, the snow and ice caps have shrunk, and sea levels have risen [1,2,3,4,5,6,7,8,9,10,11,12,13,15,34].

5.2 Methodology

This section of this study aimed to evaluate the countries most affected by climate change from 2018 to 2021 according to the IPCC's sixth assessment report on climate change 2022 [32] and numerous reviewed articles. The evaluation was done considering certain criteria which include natural disasters like earthquakes, flooding, hurricanes, wildfire, increased temperature, deforestation, etc., that have affected the country's economy, led to food insecurity, Emigration, fatality rate, cost of living, losses per unit GDP in %, and standard of living. The tool we have chosen for our evaluation is a Multi-Criteria Decision-Making (MCDM) tool called FUZZY-PROMETHEE which has been used by many researchers e.g. (Ozsahin et al) [33] to evaluate conflicting alternatives in instances of uncertainty. More information about FUZZY-PROMETHEE and its applications can be seen in [33].

5.2.1. Germany

Germany is a cultural and artistic hotspot, with the fourth-biggest economy in the world and the largest in Europe. Due to the storms, droughts, and heatwaves that occurred in 2018, Germany is one of the most climate-affected countries. In 2018, Germany experienced the warmest year in its history, with damages to the agriculture sector totaling more than 3,500 million dollars. The weather events in Germany resulted in 1,246 deaths (1.5 per 100,000 people), losses of \$1.18 billion dollars, and a 0.12% drop in per capita GDP [30,31,32,34].

5.2.2. Japan

Japan is a country steeped in heritage while still embracing constant change. Japan has been hit by a slew of extreme weather occurrences in the last decade. The shortened snow seasons and fewer snowfalls are the most significant environmental changes in Japan. This had a significant impact on the Japanese skill industry. Geographical and climatic factors have long made Japan vulnerable to severe natural disasters. Heavy rains, heatwaves, the Osaka earthquake, and the Jebi typhoon in Japan in 2018 and 2019 resulted in 1,282 deaths on the island — 1.01 per 100,000 people — as well as 25 billion dollars in economic damages and a 0.64 percent drop in per capita GDP [30,32,34].

5.2.3. India

Climate change, according to scientists, will put a strain on India's ecology, agriculture, and other resources. India's average temperature has already risen as a result of greenhouse gas emissions. Several Indian locations are hotspots, and climate change is accelerating. The annual monsoon season in 2018 and 2019 resulted in over 2,000 deaths (0.16 per 100,000 people), losses of 8.1 billion dollars, and a 0.36 percent drop in per capita GDP [30,31,32,34].

5.2.4. Fiji

Fiji is a Pacific island nation with a population of about 200,000 people. Climate change is wreaking havoc on the people and the ecology in that area. Fiji is made up of over 300 islands, many of which are small and low-lying, with people living close to the water. Rising sea levels and rising temperatures are wreaking havoc on residents, with more frequent cyclones, floods, and droughts. Between February and April 2018, Fiji was hit by three cyclones. Cyclone Gita, Cyclone Josie, cyclone Keni, and the severe flooding that followed took 8 lives —

0.9 per 100,000 people — and caused about \$120 million in losses and a 1.14 percent drop in per capita GDP [30,32,34].

5.2.5. The Philippines

The Philippines' geographic location is one of the key reasons for the country's vulnerability to the effects of the climate catastrophe. Every year, the Philippines is struck by an average of 20 typhoons. The Philippines is an archipelago of islands where many people live along the coast. Sealife is suffering as a result of global warming. The Philippines' coral reefs are being decimated by rising sea temperatures and pollution. As the number of fish in the ocean decreases, prices rise, leaving tens of thousands of people hungry. Typhoon Mangkhut struck the Philippines in 2018, affecting more than 250,000 people and resulting in 455 deaths (0.43 per 100,000 people), as well as more than \$4.540 million in economic losses and a drop of 0.48% per capita GDP [30,31,32,34].

5.2.6. Madagascar

Madagascar is a big island in the Indian Ocean's southwest corner. Moreover, 80% of Madagascar's population lives in rural areas and is impoverished. Madagascar has the greatest biodiversity priority on the globe, with a large number of unique plant and animal species. Cyclones, droughts, and flooding are all typical phenomena in Madagascar. Food security, drinking water supply, irrigation, public health systems, environmental management, and lifestyle are all being impacted more frequently. Cyclone Ava and Eliakim struck the country in 2018, causing 72 deaths (0.27 per 100,000 people), \$568 million in economic losses, and a 1.32 percent decline in per capita GDP [30,32,34].

5.2.7. Kenya

Kenya is a country that is extremely sensitive to climate change. According to studies, the average yearly temperature is expected to rise. Kenya's economy is based on tourism and agriculture, both of which are highly impacted by significant weather changes. Droughts are becoming more common, and the heat is contributing to agricultural losses. More than a million people were on the verge of starvation as a result of the 2018 droughts and floods. The harsh environment of that year claimed the lives of 296 people in Kenya, or 0.48 per 100,000 people, resulting in losses of more than 708 million dollars and a 0.4 percent decline in per capita GDP [30,32,34].

5.2.8. Rwanda

A huge portion of Rwanda's population is impoverished and lives in rural areas. They are all reliant on natural resources in their daily lives. They also have to deal with waterborne infections like Malaria, which is the country's leading cause of death. Because Rwanda's economy is based on agriculture, it is extremely sensitive to climate change. Heavy rains in March 2018 caused a devastating flood, killing 88 people (0.73 per 100,000), causing 93.2 million dollars in economic losses, and a 0.34 percent drop in per capita GDP [30,32,34].

5.2.9. Canada

According to scientists, Canada is warming twice as quickly as the rest of the world. It's due to several variables, including a lack of snow and sea ice. These include rising sea levels and increasingly frequent and severe extreme weather, such as previously unheard-of heat waves. Oceans are also anticipated to grow more acidic and oxygen-depleted, posing a threat to marine life. In 2018, river overflows resulted in 103 deaths (0.28 per 100,000 residents), \$2,282 million in losses, and a 0.12 percent drop in per capita GDP [30,31,32,34].

5.2.10. Sri Lanka

The effects of climate change are being felt on Earth as a result of increased greenhouse gas levels in the atmosphere. Sri Lanka is very vulnerable to the effects of climate change. Sri Lanka is a tropical island, with a land area of 65,610 square kilometers and a coastline of 1,340 kilometers. Climate change is having a significant impact on Sri Lanka, with rising sea levels, shifting temperatures, fading trees, and natural calamities. In 2018, the monsoon rains in Sri Lanka resulted in 38 deaths (0.18 per 100,000 people), \$3,625 million in losses, a 1.24 percent drop in per capita GDP, and a significant rate of migration owing to weather conditions.

5.2.11. Zimbabwe

Zimbabwe in 2019 was affected by a cyclone that displaced about 280000 people leading to 340 deaths and causing damages that are worth \$622 million. This led to a 4.2% drop in per capita GDP [30,32,34].

5.2.12. Malawi

Malawi’s economy is heavily dependent on agriculture and this makes them vulnerable to climate change. In 2019, Malawi experienced heavy rainfall that claimed 60 lives and affected about 975000 people, leaving 86000 people homeless. The damages caused were worth \$290 million and this led to a 2% drop in per capita GDP [30,32,34].

5.2.13. Mozambique

Mozambique was hit by a devastating cyclone of category 4 in 2019. Cyclone Kenneth claimed 600 lives and caused total damage of \$3.2 billion which led to a 13% drop in the per capita GDP of Mozambique’s economy [30,32,34].

5.2.14. Bahamas

The Bahamas was greatly affected in 2019 by a category 5 hurricane which is known as the greatest hurricane in history. This disastrous hurricane led to heavy rainfall of about 914mm in a few hours. This led to the death of 74 people and total damage of \$3.4 billion resulting in a decrease in per capita GDP to 14.5% [30,32,34].

Table 1: Visual Fuzzy-PROMETHEE Application showing Countries most vulnerable to climate change and their evaluating criteria [30,31,32,34].

| | Criteria and Alternatives | Fatality Rate | Drop per capita GDP | Worth of damages | Decrease of standard of living | Effect on people’s health | Food Insecurity | Emigration rate |
|--|---------------------------|---|---------------------|------------------|--------------------------------|---------------------------|-----------------|-----------------|
| TABLE 2. Linguistic Fuzzy Scale | MIN/MAX Evaluations | MAX | MAX | MAX | MAX | MAX | MAX | MAX |
| | Rwanda | 88 | 0.34 | 93200000 | VH | H | VH | VH |
| | Japan | 1282 | 0.64 | 2500000000 | H | VH | H | H |
| | Kenya | 296 | 0.4 | 708000000 | VH | H | VH | VH |
| | Bahamas | 74 | 14.5 | 3400000000 | VH | H | H | H |
| | Sri Lanka | 38 | 1.24 | 3625000 | H | H | H | VH |
| | Canada | 103 | 0.12 | 2282000 | M | H | M | M |
| | Zimbabwe | 340 | 4.2 | 622000000 | VH | H | H | VH |
| | Malawi | 60 | 2.0 | 290000000 | VH | VH | VH | VH |
| | Mozambique | 600 | 13.0 | 3200000000 | VH | H | VH | VH |
| | Germany | 1246 | 0.12 | 1180000000 | H | H | H | H |
| | Madagascar | 72 | 1.32 | 568000000 | VH | H | VH | VH |
| | Philippines | 455 | 0.48 | 4540000 | VH | VH | VH | H |
| | India | 2000 | 0.36 | 8100000000 | VH | H | VH | VH |
| Fiji | 8 | 1.14 | 120000000 | VH | VH | VH | H | |
| Fuzzy Scale | Triangular Scale | Fuzz Importance ratings of criteria | | | | | | |
| Very High (VH) | (0.75, 1, 1) | Fatality rate, drop-per capita GDP, Worth of damages, food insecurity | | | | | | |
| Important (H) | (0.50, 0.75, 1) | decreased standard of living, effect on people’s health | | | | | | |
| Medium (M) | (0.25, 0.50, 0.75) | emigration rate | | | | | | |
| Low (L) | (0, 0.25, 0.50) | | | | | | | |
| Very Low (VL) | (0, 0, 0.25) | | | | | | | |

6. RESULTS

Fuzzy-PROMETHEE is a reliable MCDM tool for decision-making. This is evident from the evaluation of countries most vulnerable to climate change as shown in Table 1 above. Table 2 shows the defuzzification of

importance weight of criteria using the linguistic fuzzy scale of very high, High, Moderate, Low, and Very Low. The implementation of the fuzzy scale data in the visual Fuzzy-PROMETHEE lab software as shown in Table 1 above proved that Japan has encountered more damages worth \$25 billion which is higher than every other country impacted by climate change must have incurred followed by the Bahamas (\$3.4 billion) and then Mozambique (\$3.2 billion). However, India has the highest fatality rate of 2000 deaths followed by Japan and then Germany. Bahamas has the highest drop in per capita GDP of approximately 15% which shows how climate change grossly affected their economy followed by Mozambique with a drop in per capita GDP of 13%. The Philippines, Malawi, and Fiji have the highest negative effects as regards a decrease in the mean standard of living, and the highest effects on health and food insecurity. India has been observed to be one of the countries that have the highest number of emigrants due to its low standard of living, food insecurity, and highest fatality rate as a result of its vulnerability to climate change.

Table 3: PROMETHEE Flow Table

| Rank | Alternatives | NetFlow | Positive Outranking NetFlow | Negative Outranking NetFlow |
|------|--------------|---------|-----------------------------------|-----------------------------------|
| 1 | Mozambique | 0,4226 | 0,5187 | 0,0962 |
| 2 | India | 0,3644 | 0,4321 | 0,0678 |
| 3 | Japan | 0,1800 | 0,3810 | 0,2009 |
| 4 | Kenya | 0,1164 | 0,3080 | 0,1916 |
| 5 | Bahamas | 0,0389 | 0,3512 | 0,3123 |
| 6 | Zimbabwe | 0,0311 | 0,3118 | 0,2808 |
| 7 | Malawi | 0,0090 | 0,2727 | 0,2636 |
| 8 | Philippines | -0,0026 | 0,2740 | 0,2765 |
| 9 | Madagascar | -0,0131 | 0,2380 | 0,2511 |
| 10 | Germany | -0,0199 | 0,2677 | 0,2876 |
| 11 | Rwanda | -0,0580 | 0,2211 | 0,2790 |
| 12 | Fiji | -0,1698 | 0,1899 | 0,3597 |
| 13 | Sri Lanka | -0,3643 | 0,0832 | 0,4476 |
| 14 | Canada | -0,5347 | 0,0745 | 0,6092 |

The PROMETHEE Flow Table 3 above shows that Mozambique ranks first as the most vulnerable country to climate change with a fatality rate of 600 deaths, damages that cost 3.2 billion dollars, a rapid drop of 13% in per capita GDP, a Very high decrease in standard of living, very high food insecurity rate and very high number of emigrants due to the effects of climate changes. Canada ranks last on the list because it can manage and mitigate the effects of climate change.

7. CONCLUSION

This study has demonstrated how FUZZY-PROMETHEE which is a decision-making tool in MCDM can be applied to solving real-life problems associated with decision-making in the presence of uncertainty. Furthermore, this study will help to alert the world on the dangers associated with climate change and the factors capable of causing climate change. This study also reveals the top-10 countries that contribute the most to climate change through the emission of greenhouse gases and other factors like deforestation, waste, oil drilling, power plants, transport, and vehicles thereby making this planet a risk zone for humans, plants, animals, and the environment. Finally, this study will help to resolve the argument on which country is the most vulnerable to climate change. Through the help of the FUZZY-PROMETHEE technique, we have been able to circumvent the hurdles associated with the argument and concluded from the evaluation as seen above,

that Mozambique is the most vulnerable country to climate change, based on the considered criteria above and the countries of choice we evaluated. More countries and criteria could be evaluated when available to improve this study.

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