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Drivers and Impacts of Climate Change: Comprehensive Review of Natural and Anthropogenic Forcing with GCM-Based Projections

Abstract: Climate change constitutes an escalating global crisis that features significant implications for ecosystems, water resources, agriculture, and industry. Understanding its causes and potential impacts is crucial for formulating effective mitigation and adaptation strategies. This study systematically reviews recent scientific findings and scenario-based climate models to assess both the natural and anthropogenic (human-induced) factors that are driving climate change. It highlights the rising levels of atmospheric carbon, the increasing global temperatures, and the resulting environmental challenges (including extreme weather events, rising sea levels, and biodiversity losses). By drawing on more than 40 regional and global studies, this paper synthesizes results from various GCMs – particularly those that are applied in arid and semi-arid regions (where climate vulnerabilities are most pronounced). The findings revealed disparities in regional vulnerability and highlighted the necessity of selecting accurate GCMs for effective adaptation planning. By synthesizing the existing literature and climate models, this paper aims to establish a comprehensive reference for researchers and policymakers, thus facilitating informed decision-making that is geared toward a sustainable future.

Keywords: climate change, GCMs, possible consequences; sustainable future

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1. Introduction

The impacts of global climate change are growing to be more extensive, directly endangering the lives of all living things [1, 2]. The globe has currently warmed by 1.1°C since 1850, with 1.5°C considered to be the acceptable climatic limit [3–5]. In other words, the global average surface temperature can increase to no more than 1.5°C above pre-industrial levels (1850–1900) by 2100 [6, 7]. The world is predicted to warm 1.2–1.3°C by 2050 [8]. The carbon in the atmosphere has increased by approximately 1.3 times due to global climate change [9]. It is estimated that, if the current negative effect continues, the amount of carbon in the atmosphere will be nearly 1.4 times higher [10]. For all of these causes, climate change will continue to significantly impact life in the environment, water supplies, and agricultural and industrial operations (with pressure on them increasing). It is critical to research, examine, and define climate change, which directly affects life and has a high potential to affect it in the future; this study is addressed to this point.

Once the current and future impacts of climate change are considered, it is clear that it poses a significant threat to our planet. Natural disasters such as floods, droughts, and fires will become more frequent, threatening all living things (including people). Several regions are now being affected. Numerous studies in the literature have investigated the alterations that have occurred and may occur in the future. The authors of [11] conducted a flood-risk analysis for the Tajan basin in the context of climate change; representative concentration paths (RCP2.6 and RCP8.5) were used to achieve this. The authors of [12] examined the impact of climate change on fires in the United States as an example. The authors of [13] investigated the potential consequences of climate change on Canada's snow and groundwater droughts. According to [14], the invasive Acacia nilotica will become more prevalent in Australia due to global climate change. The authors of [15] found that climate change is hurting avocado output in the Mediterranean basin. The study that was conducted in [16] determined that coffee (arabica and robusta coffee) was sensitive to climate change and that Brazil and Vietnam (which are currently the two countries that produce the most coffee) would be negatively affected by this change. In another study that was conducted by [17] on arabica coffee, it was stated that climate change would negatively affect existing production areas and that their yields and quality would decrease. Table 1 shows some of the research in the literature that has examined the effects of climate change.

According to the literature, climate change affects many activities and is estimated to gradually increase its impact; therefore, the changes that will occur in the climate should be determined, and a roadmap should be drawn accordingly. For this purpose, different climate scenarios and models have been used (Table 2).

Table 1. Climate change studies in literature

Reference	Issue	Location
[18]	Fire	World
[19]		California/USA
[20]		World
[21]		USA
[22]		Quebec/Canada
[23]	Flood	UK
[24]		World
[25]		Tena River/Ecuador
[26]		Phnom Penh/Cambodia
[27]		New York/USA
[28]	Drought	China
[29]		Jirisan National Park/South Korea
[30]		World
[31]	Groundwater	Central Italy
[32]	Water	Spain
[33]	Avocado	Michoacán/Mexico
[34]	Kiwi	Kastamonu/Türkiye
[35]	Coffee	Mexico
[36]	Sugar cane	Brazil
[37]	Pitaya	Vietnam

Table 2. Models and data that were utilized in studies on climate change in literature

Reference	Model	Scenario
[38]	CCSM4	RCP4.5, RCP8.5
[39]	CCSM4	RCP4.5, RCP8.5
[40]	MIROC-ESM & CCSM4	RCP2.6, RCP4.5, RCP8.5
[41]	BCC-CSM1-1	RCP2.6, RCP4.5, RCP6.0, RCP8.5
[42]	ACCESS-ESM1, BCC-CSM-MR	SSP2-4.5, SSP5-8.5
[43]	MIROC-ES2L, BCC-CSM2-MR	SSP1-2.6, 2, SSP2-4.5, SSP5-8.5
[44]	GISS-E2.1	SSP1-2.6, SSP2-4.5, SSP4-6.0, SSP5-8.5
[45]	Access-CM2, HadGEM, UKESM1	SSP1-2.6, SSP2-4.5, SSP5-8.5
[46]	BBC-CSM1-1, CCSM4, CNRM-CM5, GFDL-CM3, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, MIROC-ESM, MIROC5, MPI-ESM-LR, MRI-CGCM3, NorESM1-M	RCP2.6, RCP4.5, RCP8.5
[47]	CC-CSM1.1, CESM1-CAM5, GFDL-CM3, GISS-EL-R, HadGEM2-ES, NorESM1-M	RCP2.6, RCP8.5
[48]	EC-EARTH, HadGEM2-ES, MIROC5, MPI-ESM	RCP4.5, RCP8.5
[49]	Multiple regression	–
[50]	GISS-E2-R	RCP2.6, RCP4.5, RCP6.0, RCP8.5
[51]	HadGEM2-ES&MIROC5	RCP4.5, RCP8.5
[52]	HadGEM2-ES&RegCM4.3.4	RCP4.5, RCP8.5
[53]	HadGEM3	RCP8.5
[54]	CanESM2	RCP2.6, RCP4.5, RCP8.5
[55]	CanESM2	RCP2.6, RCP4.5, RCP8.5
[56]	CanESM5, MPI-ESM1-2-HR, EC-Earth3, NorESM2-LM	SSP2-4.5, SSP5-8.5
[57]	CESM2, GFDL-ESM4, IPSL-CM6A-LR, MIROC6, MRI-ESM2-0	SSP2-4.5, SSP5-8.5

Identifying any potential changes and outcomes from climate change in the future is critical. In this context, more than 40 studies were analyzed (as is detailed in Tables 1 and 2). The reviewed studies were sourced from the Google Scholar and Web of Science (WOS) platforms. The selected period ranged from 2012 through 2025, with the following keywords being employed in the search: "climate change"; "global climate models (GCMs)"; and "climate scenario." Furthermore, those studies that were classified as non-indexed (SCI, SCI-Expanded, and SSCI) were excluded from the analysis. Only those studies that met these criteria were included in the examination.

1.1. Problem Statement

Global climate change is a complex and escalating crisis that is affecting not only environmental systems but also socio-economic and political structures. Changes in land use and deforestation have significantly altered our atmosphere's composition and disrupted Earth's energy balance. Additionally, natural processes such as volcanic eruptions, solar cycles, and tectonic shifts are contributing to long-term climate fluctuations. Given this context, it is fair to assert that climate change poses a severe threat to our planet. Various climate scenarios and models have been employed to develop projections for the future; however, disparities in their results have often arisen due to factors such as regional model sensitivity, data quality, and differences in scenarios. This variability presents a significant challenge for policymakers who are striving to implement effective strategies – especially those in arid and semi-arid regions. Consequently, this issue forms the primary focus of the study. There is a pressing need for comprehensive research that addresses both the natural and human factors that are related to climate change while systematically reviewing the existing literature.

1.2. Aim of Study

The primary objective of this study was to thoroughly investigate both the natural and anthropogenic (human-induced) drivers of climate change while evaluating the anticipated environmental and socio-economic impacts based on recent scientific evidence. In this context, the study did the following:

- reviewed key natural factors (such as volcanic activity, solar variations, and orbital changes) alongside anthropogenic contributors (including fossil fuel emissions, industrialization, and land-use changes);
- assessed the effects of climate change across critical impact areas (including agriculture, rising sea levels, drought, and ocean acidification);
- synthesized findings from more than 40 regional and global studies that employed global climate models (GCMs) and various emission scenarios (RCP and shared socio-economic pathways – SSP), with particular emphasis on their relevance in vulnerable regions.

This study aims to combine existing knowledge with scientific data, thus providing a reliable reference for decision-makers and researchers regarding climate change adaptation and mitigation.

1.3. Organization

This study is organized around three key aspects: (a) climate change; (b) its causes; and (c) its potential outcomes. Figure 1 illustrates the workflow of the study.

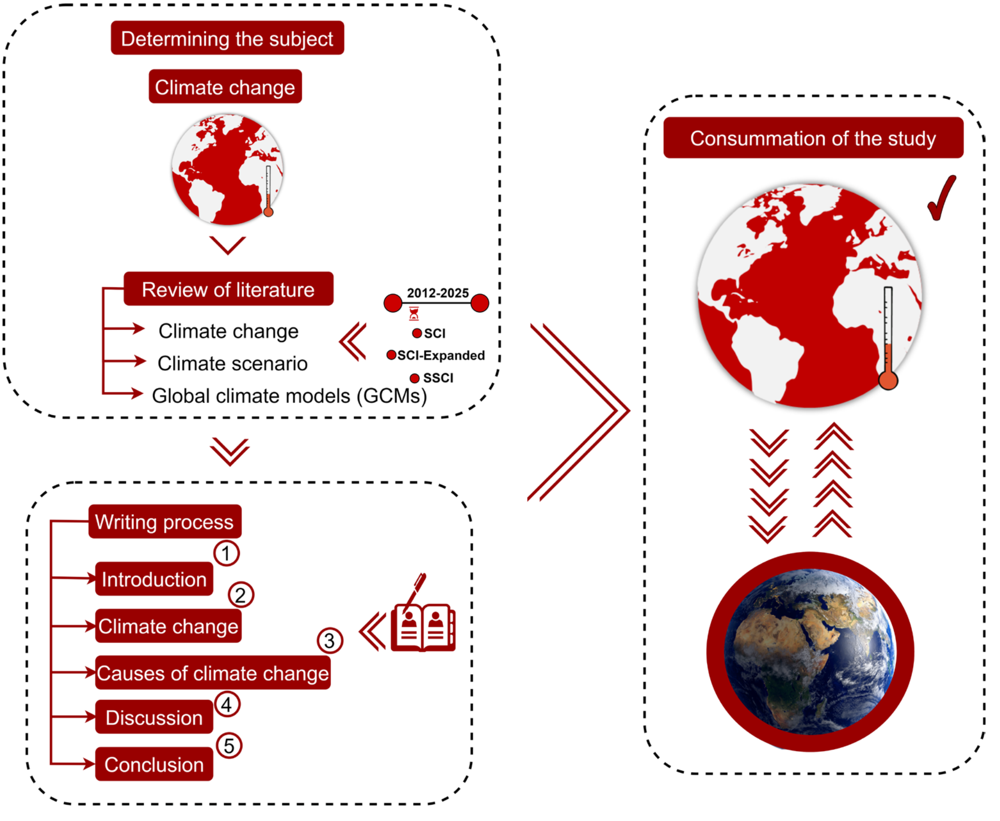

Fig. 1. Flowchart of study

2. Global Climate Change (Global Warming)

Half of the solar radiation that hits the upper atmosphere arrives at the Earth's surface [58]; approximately 20% of this is absorbed, and 30% is reflected back into the atmosphere. The radiation that is reflected by the Earth is possessed by carbon dioxide (CO_2), methane gas (CH_4), water vapor, and other gases in the atmosphere. The absorption of this radiation in the atmosphere causes increases in temperature on Earth and the greenhouse effect [58, 59]; in other words, it causes global climate change (global warming) (Fig. 2). Especially toward the end of the 20th century, the Earth began to warm up due to the industrialization and increased use of fossil fuels that were the result of the Industrial Revolution. With the warming, these gases retain much more radiation, which triggers global warming. The increased concentrations of these gases in the atmosphere causes the ozone layer to thin and eventually become perforated; this situation causes the planet to warm up even more. This cycle gradually increases global climate change and its adverse effects.

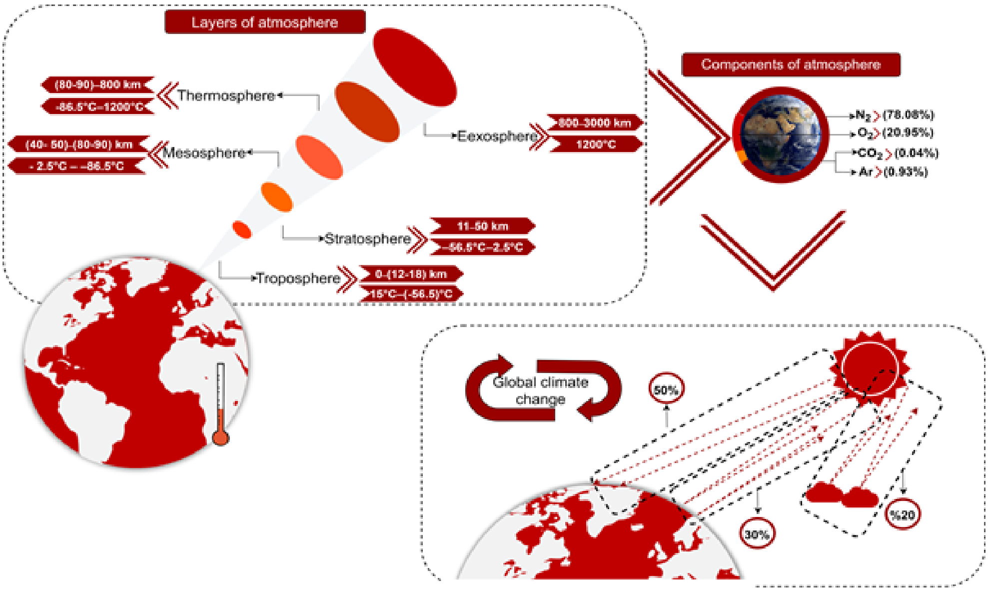

Fig. 2. Flowchart of climate change

The global climate models (GCMs) that have been developed also predict that global warming will continue to increase [44, 60]. When the current and future effects of global climate change are considered, they will seriously threaten the world and all living things (via drought, flood, fire, glacial melting, loss of biodiversity, etc.). At this point, it is essential to determine our global climate change and its effects so that the world can remain livable.

Global climate change is a significant matter for life on Earth. It is impossible to explain the change that has ensued with a single reason, as atmospheric processes are complex, interconnected, and highly large-scale [58]. Therefore, the factors that are causing climate change are classified in two ways: (a) natural effects; and (b) anthropic effects.

3. Natural Factors Causing Global Climate Change

The changes in climate that are due to natural factors are included in this scope. The adequate long-term modeling of atmospheric changes would enable more-reliable predictions of natural influences on climate change. Several hypotheses have been proposed for this, but none have sufficiently explained climate change over all of the periods. For this reason, several GCMs have been developed for the different locations and periods.

3.1. Plate Movements and Orbital Changes

Lithospheric plate movements shift continents closer to and further away from the equator. Although this movement in the plates is very slow, it is fair to claim that it has had a significant and critical impact on climate change over millions of years [58]. Moving plates can alter ocean circulations, thus resulting in heat transfer. Climate change has happened as a result of this movement (which causes an increase in temperature in one location while decreasing it in another – Fig. 3).

Fig. 3. Impacts of plate movements on global climate change

Another natural factor that triggers climate change is orbital movements. Changes in the Earth's orbit (eccentricity), changes in the angles that the Earth's axis make with the orbital plane (obliquity), and changes in the axis (precession) all produce seasonal and latitudinal variations in solar radiation. As a result, changes have appeared in the climate (Fig. 4). This has been effective in the creation of shifts – particularly during the glacial-interglacial phases of the Ice Age.

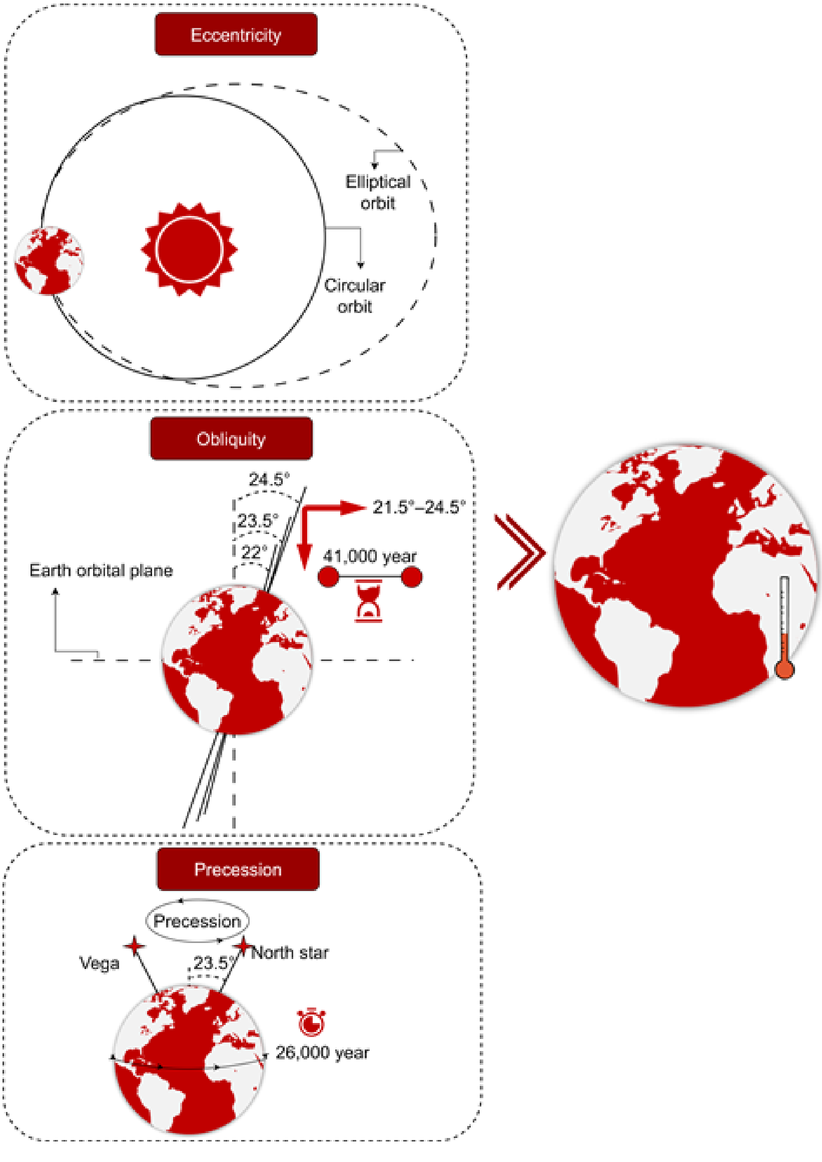

Fig. 4. Impacts of orbital movements on global climate change

3.2. Volcanic Movements

Volcanic eruptions send gases and fine particles into the atmosphere; it is widely understood that this condition causes and influences climate change [58]. Several hypotheses have been proposed to explain the relationship between volcanic movements and climate change. Among the assumptions that have been advanced, it is possible to state that the hypothesis that some of the materials (gas + matter) that are released into the atmosphere as a result of volcanic eruptions are filtered by solar radiation and prevented from reaching the Earth, thus reducing the temperature of Earth's troposphere is scientifically accepted (Fig. 5). Furthermore, new research has supported this claim [61–63].

Benjamin Franklin asserted that a volcanic eruption caused a change in the climate in Iceland. According to Franklin, the Laki volcano in Iceland (which erupted for about eight months between June 8, 1783, and February 7, 1784) was the cause of the frigid winters of 1783–1784 and 1784–1785. Investigations have indicated that the volcanic eruption put pressure on the climate during the mentioned period and had an extremely negative effect on life [64–66]. As a result of the eruptions, approximately $8 \cdot 10^6$ tons of hydrogen fluoride (HF) and $120 \cdot 10^6$ tons of sulfur dioxide (SO_2) were released into the atmosphere [67]. This situation caused the air pollution that was known as the "Laki smog" throughout continental Europe. As a result of all of these negative situations, the winter of 1784 was the coldest winter period for 225 years; meanwhile, the summer of 1783 was the hottest in Europe [67]. However, almost 20% of the population, 80% of the small cattle, and 50% of the large cattle and horses were poisoned by substances that were released into the atmosphere [67]. Furthermore, agricultural yields decreased, a seven-year famine occurred, and 9350 people died [67, 68]. The eruption of the Laki volcano has provided a clear understanding of the effects of volcanic activity on climate change; this has been determined to have a significant impact on climate change.

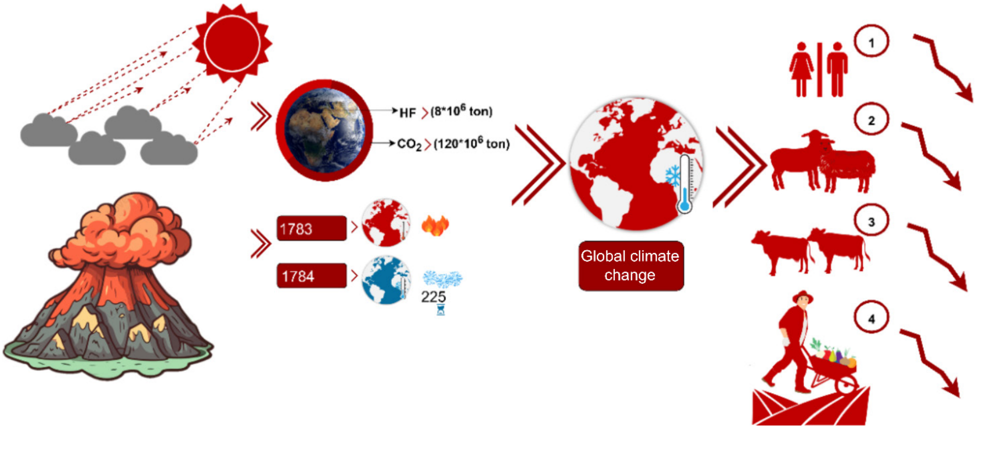

Fig. 5. Impacts of volcanic movements on global climate change

3.3. Variations in Solar Energy

There are differences in solar energy over time; an increase in energy output causes the atmosphere to warm up, while a decrease causes it to cool down (Fig. 6).

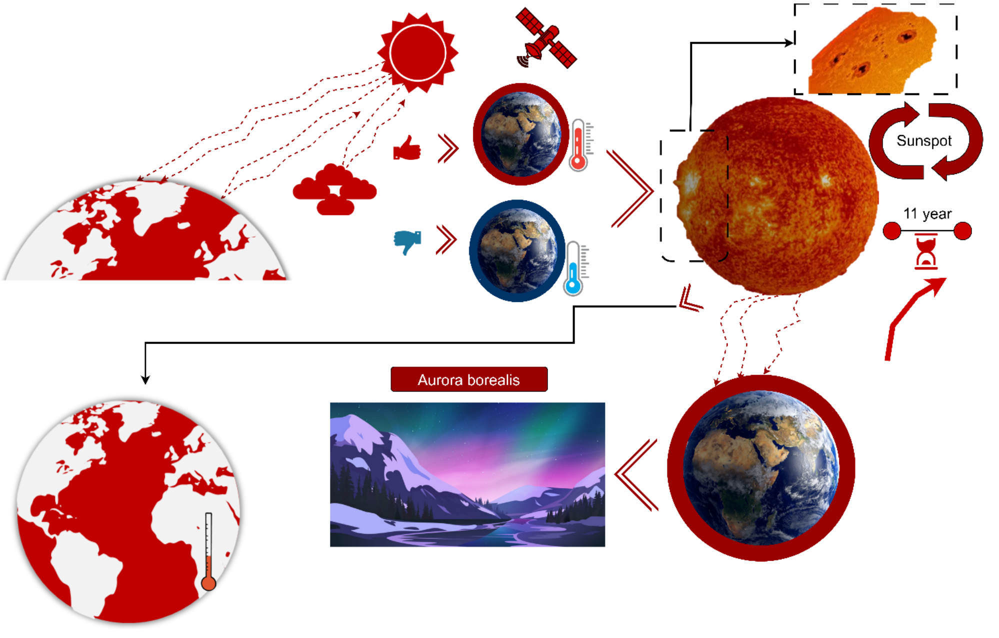

Fig. 6. Impact of changes in solar activity on global climate change

This change in solar energy directly influences climate change [58]. Although variations in solar energy can be measured by satellites, long-term records are still required to assess the extents of these fluctuations. For this reason, climate change has been attempted to be expressed with sunspot cycles. Dark-colored sunspots are the most straightforward and most noticeable features on the sun's surface [69]. Sunspots are large magnetic storms that extend from the sun's surface to the center [58]. When these storms reach the Earth's atmosphere, they interact with gases and cause the formations of aurorae boreales. Sunspots emerge cyclically; hence, their changes can be analyzed, and their effects on climate change can be determined. Sunspots peak approximately every 11 years [70]. During periods when sunspots increase, more energy is emitted from the sun; this triggers climate change [58]. During the period 1645–1715, for instance, sunspots were scarce; this period is known as the Little Ice Age. Although the correlation between sunspots and climate has been attempted to be explained in this way, it is accepted by many scientists that this was not the only (nor most important) factor that was responsible for the occurrence of the Little Ice Age.

4. Anthropic Factors Causing Global Climate Change

Humans have lived on Earth for centuries. Initially, the Earth was used for fire, the grazing of domesticated animals, and meeting our basic needs for agricultural activities. These essential activities led to decreased forests and vegetation and, consequently, such changes in climate factors as surface albedo (reflectance), evaporation rate, and surface winds [58]. The impact of anthropic activities on Earth continued in this way for many years. Later, industrialization and fossil fuel use (coal, oil, natural gas, etc.) increased significantly toward the end of the 20th century (the effect of the Industrial Revolution). Nonetheless, the Earth began to be utilized for many purposes: from large-scale conventional agricultural activities to industrial facilities, and from meeting our sheltering needs to extracting minerals and fossil fuels. Compared to the pre-industrial period (1850–1900), activities were carried out much faster, and the Earth was consumed wildly. As a result, natural elements (primarily, soil, surface, and groundwater resources) have been recklessly destroyed over the years. Various human activities (both pre-industrial and post-industrial) have increased the CO_2, CH_4, water vapor, and other gases in the atmosphere. This has driven the atmosphere (and the Earth) to warm up (Fig. 7). Thus, global climate change was triggered by human practices. Although CO_2 and other gases (0.04%) are found in small amounts in the atmosphere, CO_2 plays a primary role in global climate change due to its ability to absorb solar radiation.

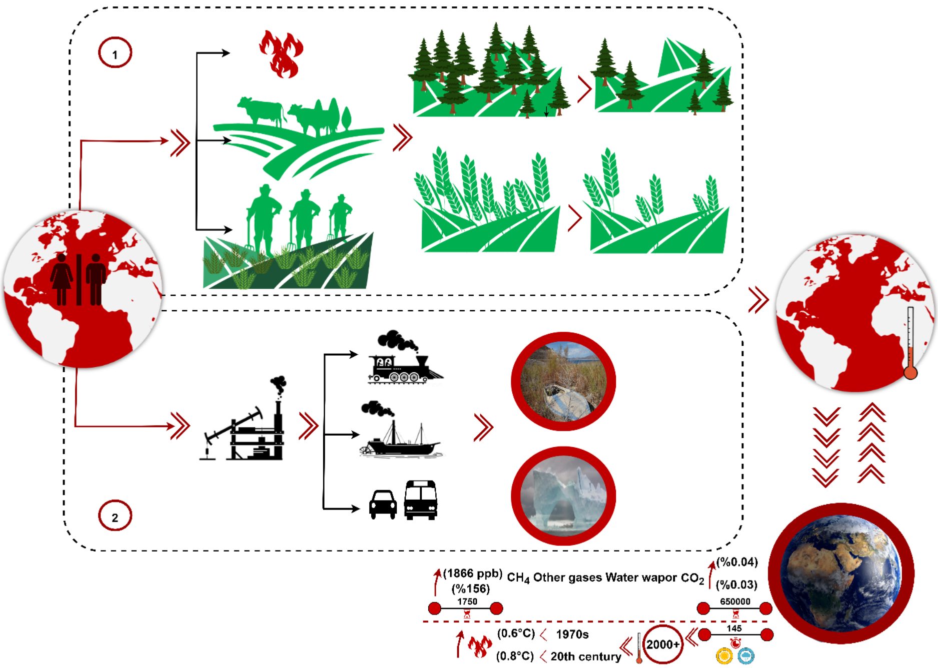

Fig. 7. Impacts of anthropic factors that are causing global climate change

Thirty percent of the radiation that reaches the Earth is reflected and absorbed by the gases in the atmosphere (mainly, the CO_2). As a result, the Earth warms up, and the greenhouse effect occurs. An examination of the 145-year climate record reveals that the warmest decade (excluding 1998) occurred after the year 2000. While the CO_2 in the atmosphere did not exceed 0.03% for 650,000 years, this rate has additionally increased to 0.04% today as a result of the Industrial Revolution [58]. The amount of CH_4 has grown by 156% as compared to the pre-industrial period, reaching 1866 ppb (parts per billion) [71]. As a result of human activities, the Earth has warmed by approximately 0.6°C since the mid-1970s and 0.8°C over the last century [58].

5. Potential Consequences of Climate Change

Natural and human factors are expected to exacerbate the effects of global climate change throughout time. The temperature increase will be more minor in certain parts of the world (tropical regions), while it will be more prominent in others (as one moves closer to the poles) [58]. However, the precipitation in tropical and sub-tropical regions will likely decrease due to rising temperatures and evaporation. In some areas (monsoon regions and the higher latitudes), precipitation is expected to increase the global climate change that is being caused by natural and human sources, thus resulting in differences on Earth.

5.1. Increasing Sea Levels

Human activities are estimated to have caused more-significant sea-level changes than natural factors have. It is thought that coastal cities, low-altitude settlements, and wetlands will be exposed to frequent flooding with rising sea levels (Fig. 8).

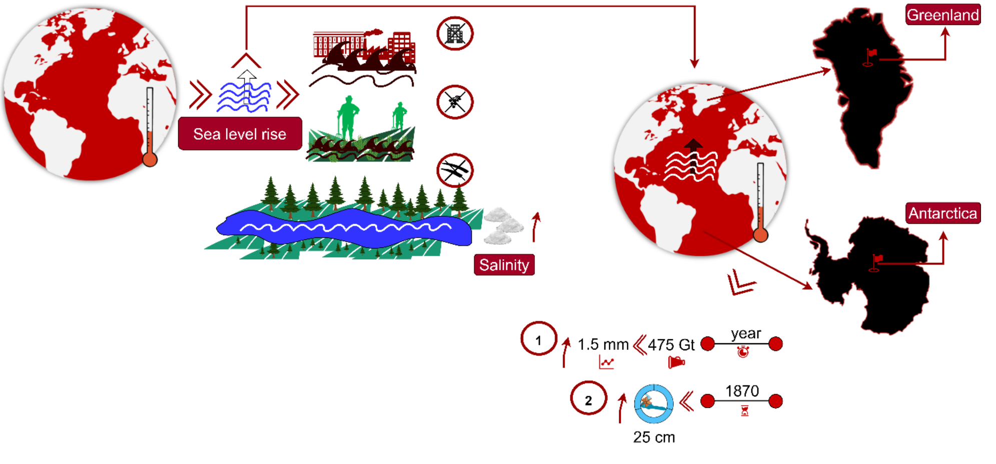

Fig. 8. Impacts of rising sea levels on global climate change

In addition, it is estimated that the coastlines will be destroyed and eroded, and the amounts of salt in rivers and groundwater resources will increase. Another important reason for the rise in sea level is the melting of the glaciers [72]. The loss of mass in the ice sheets in Antarctica and Greenland has been measured to be 475 gigatons (Gt) per year on average [58]. This situation is accepted as the amount that will cause sea levels to rise by approximately 1.5 mm per year [58]. With the increasing effect of global climate change, recent studies have revealed that there has been a rise of approximately 25 cm in sea levels since 1870 (McInnes, 2024; [58]; Vestergaard, 1991). Also, their rate of increase has accelerated in recent years, and sea levels are expected to rise further in the future [73, 74].

5.2. Increasing in Ocean Acidity

The increase in the CO_2 level in the atmosphere (mainly due to human factors) will have adverse effects on the chemical properties of the ocean and, accordingly, on life. CO_2 pushes the oceans' pH levels to decrease, thus increasing the acidity of the water. CO_2 in the atmosphere dissolves in the ocean and causes the formation of carbonic acid (H_2CO_3); this also reduces the pH level of the water and disrupts its chemical balance (Fig. 9).

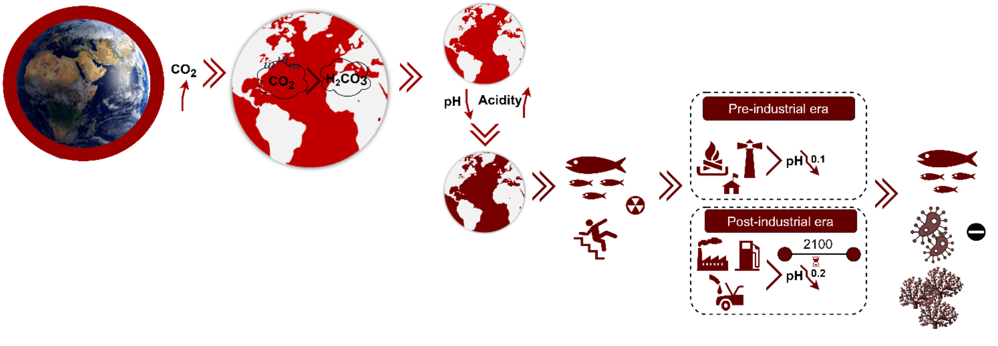

Fig. 9. Impacts of rising ocean acidity on global climate change

During the pre-industrial period, CO_2 accumulated in the oceans at an amount that would cause the pH levels to decrease by 0.1 units; this was due to natural and human factors. Nevertheless, much more CO_2 began to be released into the atmosphere with the introduction of the Industrial Revolution. If the current situation continues, it is assessed that the oceans will experience pH-level decreases of 0.2 units by 2100; thus, there will be modifications in the chemical properties of the oceans that has not occurred for millions of years. With this increase in acidity, it will not be possible for some marine organisms to form their hard shells or parts from calcium carbonate (calcite-$CaCO_3$). Additionally, it will endanger the lives of calcite-secreting microbes and corals.

5.3. Global Climate Change's Impact on Agriculture

Drought is the most significant detrimental consequence of global climate change on agricultural activities [75]. When it is considered that agriculture is one of the areas that are most deeply affected by this change in climate, it is understood that drought is a grave threat. With droughts, effects such as changes in agricultural product patterns, differentiations in existing production areas, and decreases in yields occur, and these are expected to increase in the future (Fig. 10). At this stage, a thorough examination of drought is required to better understand the effects of climate change.

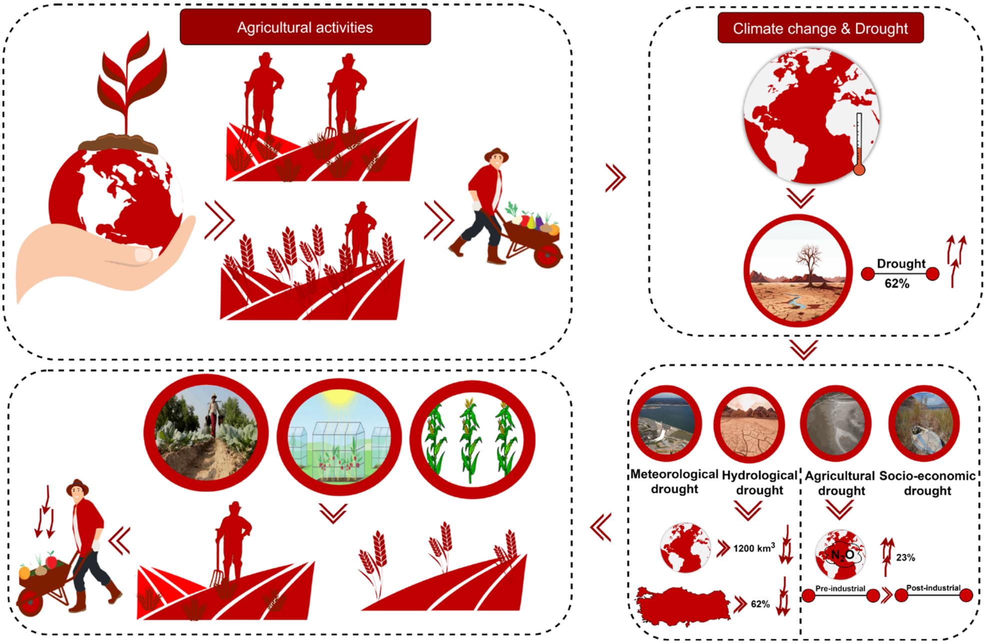

Fig. 10. Impacts of global climate change on agriculture

Drought is a natural event that causes negative effects on soil, surface, and groundwater resources and disrupts the hydrological balance due to rainfall amounts being considerably below the expected levels [71]. Drought is generally divided into four types:

1) meteorological,
2) agricultural,
3) hydrological,
4) socio-economic [71, 76].

Meteorological drought is described as a period that lasts for months to years with below-normal rainfall levels.

Agricultural drought is characterized as dry soil that results from lower-than-average rainfall amounts, heavy but less-frequent rain events, or more evaporation than usual. However, it is not feasible to directly associate agricultural drought with low rainfall. Even during periods of low rainfall, it is not correct to talk about agricultural drought if there is enough water in the plant root zone and soil to support plant development [71].

Hydrological drought surrounds those periods when water levels and stream flows are lower than the long-term average. To speak of hydrological drought, a long period must ensue. Decreases in water levels due to short-term or seasonal differences cannot be communicated as hydrological droughts. If there is still a decrease in water levels and quantities after a meteorological drought is over, then we then can speak of hydrological drought.

Socio-economic drought can be defined as a type of drought that causes problems in meeting the demands for producing products with economic value; this type is related to the other types of drought.

Drought is mostly caused by rising temperatures and lower precipitation. Current and potential consequences of drought on agriculture are as follows:

– Drought will probably increase throughout approximately 62% of the world [77]. As a result, there will be decreases in surface and groundwater resources, in water levels and flows, or complete drying. In the current situation (especially due to El Niño), nearly 1200 km^3 of freshwater has been lost worldwide [78, 79]. It is estimated that roughly 25% of the current water resources in basins will be lost due to drought in Türkiye alone [80]. The agricultural sector will be most affected by this negative situation in water resources. Approximately 77% (44 billion m^3) of the 57 billion m^3 of water that is currently being used in the different sectors in Türkiye is used in agricultural activities [71, 80]. With global climate change, this rate will likely decrease to 64% in the future [81].
– Dry farming areas are likely to be adversely affected by decreasing rainfall levels. It is known that an area that is larger than India has shifted from humid climate characteristics to arid climate zones in the last 30 years. As a result, water resources and, therefore, agriculture have been negatively affected [82]. Agricultural lands in Turkey account for 23.97 million hectares, and approximately 18.50 million hectares (77%) of this are for dry farming [71, 81, 83]. In this case, drought is emerging as a formidable foe for agriculture, thus challenging farmers and threatening the very foundations of our food supply.
– Increases in temperatures and the resulting decreases in the amounts of moisture in the atmosphere cause water stress in plants. Global climate change triggers this situation. With drought, the water in the soil evaporates, and the transpiration increases in the plants; thus, plant growth may slow down and dry out in the ongoing process.

– In addition to the loss of moisture in the atmosphere, there are losses in the amounts of moisture in the soil due to the increases in temperature, decreases in precipitation, and drought. For the soil to continue its biological vitality and for the plants to be nourished by the soil, there should be a liquid phase in the pores of the soil at a rate of 25% [71]; the moisture in the soil provides this. However, a decrease in the soil moisture affects the soil and, therefore, the life in it. Ultimately, effects such as salinization in the soil, a lack of organic matter, deformations in the soil structures, low yields in agricultural products, and changes in product patterns may occur. As a result of agricultural practices, the widespread use of nitrogenous fertilizers, the destruction of vegetation by burning, and the use of nylon (which is frequently preferred in greenhouse farming) have caused the nitrous oxide (nitrogen protoxide – N_2O) in the atmosphere to increase by 23% as compared to pre-industrial times (reaching a value of 332 ppb) [71]. Once all of these issues are considered, it is predicted that agricultural drought will pose a grave threat.

5.4. Potential Contingencies

The future status, speed, and level of the impact of climate change will be related to the amounts of gases that are emitted into the atmosphere. Most of the changes will be gradual over the years (which is also supported by the GCMs). Since the climate and the world are complex and dynamic, however, many different factors that cannot be modeled or fully explained are also effective in addition to the climate characteristics that have been determined today (temperature, precipitation, humidity, etc.); as a result, unexpected, sudden, and effective changes in the climate may occur (Fig. 11).

While the potential economic, social, cultural, and political effects of the expected changes in the climate can be predicted, the magnitudes and impact capacities of sudden changes are unknown, and any possible results cannot be anticipated; hence, there will be insufficient time and capacity to take precautions or intervene.

Other changes that may occur due to global climate change can be listed as follows:

– cold days will be less frequent;
– hot days will be more frequent;
– amount of frozen ground will decrease;
– re-glaciation will not start before year 3000 due to melting of glaciers in northern hemisphere;
– if amount of CO_2 in atmosphere doubles, temperatures will increase by 1.5–4.5°C by end of 21st century (according to GCMs).

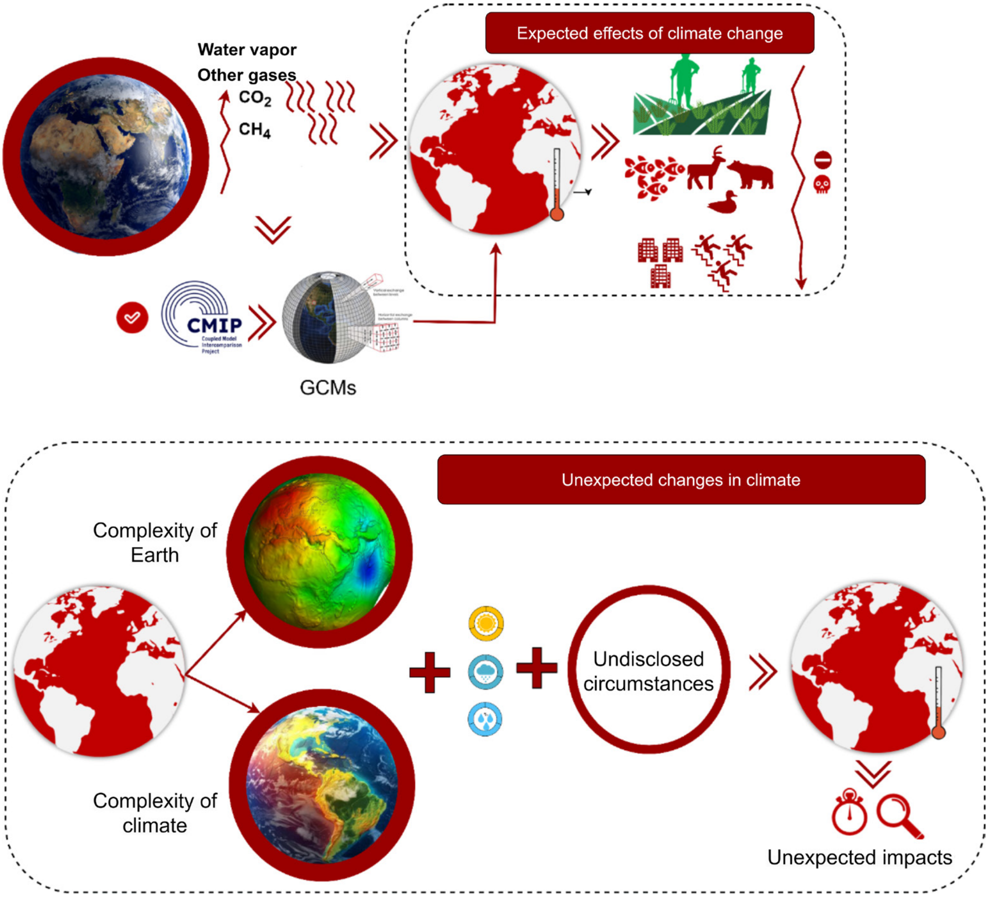

Fig. 11. Expected and unexpected impacts of climate change

6. Discussion

Our research examined many studies that were performed in different regions (Fig. 12); notably, these studies were mainly conducted in arid or semi-arid areas. In light of the information that was obtained from the investigated studies and the research that was conducted throughout the study, it was determined that the mentioned regions were highly vulnerable to the effects of climate change. The studies that were conducted by Avand et al. [11], Cárceles Rodríguez et al. [15], and Estrela et al. [32] also supported this observation.

This study identified both of those natural and anthropogenic factors that have caused climate change. While these factors have been explained in detail in the previous sections, this part aims to critically analyze their interrelationships, compare the findings across the reviewed studies, and highlight any implications for future research and policy-making.

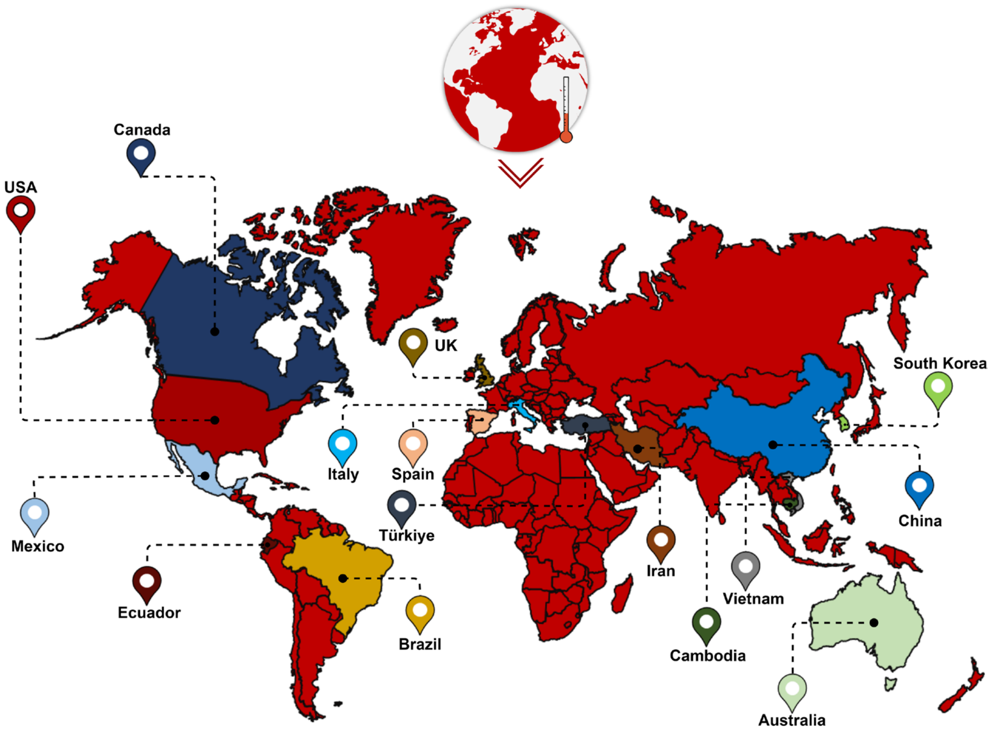

Fig. 12. Regions where examined studies were conducted in research

6.1. Comparative Analysis of Natural and Anthropogenic Drivers

Natural factors such as volcanic activities, variations in solar radiation, and changes in Earth's orbit have historically impacted the planet's climate. For instance, fluctuations in solar activity were associated with climate variations during the pre-industrial era. However, a robust body of evidence has indicated that the significant rise in global temperatures over the past 50 years has been predominantly attributable to anthropogenic activities [84, 85]. The U.S. Environmental Protection Agency (EPA) asserts that there has been no net increase in solar activity in recent decades, thus emphasizing that the observed warming has primarily been the result of greenhouse gas emissions [86].

In contrast, human-induced activities – especially the burning of fossil fuels, deforestation, and industrial emissions – are recognized as the primary causes of our recent climate change. Reports from the IPCC have attributed the majority of the warming that has been observed since the mid-20st century to these anthropogenic influences. This conclusion has been further supported by research that has employed the appropriate detection techniques; these have indicated that most of the increases in near-surface temperatures can be linked to human activity.

6.2. Regional Disparities and Model Sensitivities

It is understood that modeling is required to determine the future effects of climate change as well as to draw any projection; for this purpose, different GCMs were used under various climate scenarios. The location of a region is of utmost importance when choosing GCMs; those that can accurately model the regions' current climate (temperature and precipitation) characteristics should be preferred. Otherwise, it is likely that any predictions that have been made for the future will not be consistent. As a result of selecting inappropriate models, any decisions that are meant to reduce the adverse macro effects of climate change (agriculture, industry, water, etc.) may be erroneous; this will cause both economic and time losses. Therefore, the selections of appropriate GCMs is crucial (as has been emphasized in the studies that were conducted in [38], [46], and [41]).

6.3. Integration of Results and Policy Implications

The synthesis of the literature highlights the intricate relationship between natural and anthropogenic factors in driving climate change. While natural influences contribute to climate variability, the predominant evidence indicates that human activities are the main drivers behind the recent warming trends. This distinction is crucial for effective policy-making, as it underscores the necessity for mitigation strategies that concentrate on reducing anthropogenic emissions.

Furthermore, the regional disparities in climate impacts call for tailored adaptation measures. Policymakers should regard region-specific susceptibilities and predictive models in order to develop effective adaptation plans. The incorporation of high-resolution regional models can support this effort by providing more-precise assessments that inform the decision-making.

6.4. Limitations and Future Research Directions

While this review is comprehensive, several limitations discussed below must be acknowledged to contextualize its findings and inform future research.

Dependence on existing literature. This study relies entirely on secondary data that was drawn from peer-reviewed publications, climate model outputs, and institutional reports. Although these sources are generally reliable, they inherently reflect the assumptions, methodologies, and scopes of the original authors; consequently, the current analysis is constrained by the quality, geographical focus, and temporal coverage of the reviewed literature. For instance, most of the cited GCM-based studies tended to emphasize global or regional scales and often lacked high-resolution location-specific assessments – especially in underrepresented areas such as parts of Africa, Central Asia, and the Middle East.

Model uncertainties and scenario assumptions. The review incorporated various climate models across different RCP and SSP scenarios; however, each model possessed distinct sensitivities, assumptions, and parameterizations that may have led to inconsistent or divergent results when applied to the same region or variable (e.g., temperature and precipitation). Furthermore, many climate projections are based on idealized socio-economic pathways that do not fully capture real-world political, economic, or technological developments, thereby introducing uncertainties into long-term planning.

Limited integration of socio-economic dimensions. While the environmental impacts of climate change (such as drought, rising sea levels, and ocean acidification) have been examined in depth, this review offered a limited discussion on socio-economic consequences (including migration, food security, and public health) [87, 88]. These factors are crucial for formulating comprehensive adaptation strategies and should be incorporated into future multidisciplinary studies.

Absence of empirical validation. This review does not incorporate ground-truthing or empirical validation through observational data sets (e.g., meteorological station data, satellite-derived variables, and crop-yield records). As a result, a gap exists between the model-based projections and the real-world evidence – particularly regarding the pace and scale of the observed climate impacts [89, 90].

7. Conclusion

The study focused on global climate change, which has touched the entire planet and is predicted to have an even more significant impact in the future. The research that was added to the literature on this issue was examined (Tables 1 and 2). Although numerous studies have been added to the literature on this topic, an attempt has been made to cover recent research. Second, climate change has been explained in depth; after this, the natural and human elements that have caused global warming were investigated. The following stage offered a comprehensive overview of the existing effects of climate change and its potential future effects.

The conclusions that were derived from this study are as follows:

- The environmental impacts of climate change are apparent, manifesting as increased drought frequency, rising sea levels, ocean acidification, and fluctuations in agricultural yields (particularly in arid and semi-arid regions).
- One of the significant insights from this study is the considerable variability in climate-impact forecasts across different regions. This variability is closely linked to the choices of GCMs that are used in conjunction with various scenarios (such as RCP and SSP). Understanding this regional inconsistency is crucial, as it highlights how different models and scenarios can yield divergent predictions about the effects of climate change in specific areas.
- Inappropriate model-selection can lead to misleading conclusions – particularly in high-risk regions such as the Mediterranean Basin, Central Asia, and Sub-Saharan Africa. Therefore, it is crucial to carefully evaluate any model's sensitivity and regional applicability.

This review provides a comprehensive and comparative overview of existing studies, thereby enhancing our scientific understanding of climate change and establishing a foundation for evidence-based climate policy.

Based on the findings, the following recommendations are proposed:

- **Region-specific climate modeling.** Policymakers and planners should prioritize the utilizations of regionally validated GCMs in order to develop precise and actionable climate-adaptation strategies – particularly in the sectors of agriculture and water management.
- **Integrated climate adaptation planning.** Adaptation frameworks must consider both anticipated and sudden impacts (such as extreme weather events) by integrating scientific modeling with local knowledge systems – particularly in vulnerable regions.
- **Sustainable emission reduction strategies.** Governments must strengthen their commitments to reducing carbon emissions through energy-transition policies, reforestation initiatives, and sustainable land-management practices.
- **Support for climate-sensitive agriculture.** There should be significant investments in drought-resistant crops, efficient irrigation technologies, and soil-conservation practices in order to mitigate the effects of climate variability on food production.
- **Further Interdisciplinary Research.** There is an urgent need for interdisciplinary studies that integrate climate science with socio-economic analysis in order to fully understand the range of the risks and devise equitable adaptation mechanisms.

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CRediT Author Contribution

M. Ö. Ç.: conceptualization, methodology, investigation, resources, data curation, writing – original draft preparation, writing – review and editing, visualization.

O. O.: conceptualization, supervision, writing – review and editing.

M. A. K.: conceptualization, supervision, writing – review and editing.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data.

Use of Generative AI and AI-Assisted Technologies

No generative AI or AI-assisted technologies were employed in the preparation of this manuscript.

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