Colombo Geographer

Journal of Colombo Geographer

Geographies of Global Climate Tipping Points (CTPs) and Their Implications for the Planet Earth: A Bibliometric Review

Ananda Y. Karunarathne[1]

[1]*Department of Geography, Faculty of Arts, University of Colombo, Colombo 07.*

Abstract

The burgeoning global phenomenon of climate change, coupled with the potential breach of critical climate tipping points (CTPs), has emerged as a paramount concern for the inhabitants of planet Earth. The deleterious impacts of global warming are increasingly manifesting across both the Northern and Southern hemispheres. The cardinal objective of this scholarship is to investigate the geographies of CTPs and their implications for planet Earth. In this scholarly examination, a bibliometric review endeavors to elucidate the verifiable/ample evidence surrounding global warming and the hazardous state of CTPs. The methodology employed in this scholarship adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model, ensuring a systematic filtration and selection process for pertinent literature. Through a thorough sequence of identification, screening, and inclusion, materials such as manuscripts, news articles, and reports, all disseminated in the English language, were subjected to analysis. Stricter adherence to the study's predefined criteria led to the exclusion of inappropriate or tangentially related literature. The resultant dataset comprised 53 selected sources, distilled from an initial pool of 115 pieces. The outcomes of this comprehensive systematic literature review serve to underscore the incontrovertible evidence pertaining to the dangerous/risky status of CTPs. This examination bridges the gaps in the existing knowledge discourse of CTPs within the Sri Lankan context and its disaster risk reduction policy reforms (the author consider this as a pressing urgency), as an island country in the midst of the current global climate change crisis.

Key words: Global Warming; Global Climate Change crisis; Global Climate Tipping points (CTPs)**;** Extreme climatic events; Collapse of AMOC/Gulf Stream

1. Introduction and Background

The rapid increase in world population has been considered as one of the cardinal reasons not only to accelerate a range of unhealthy anthropogenic activities on the planet Earth but also to exacerbate Hydrometeorological disasters in both Northern and Southern hemispheres (IPCC, 2021; Karunarathne and Lee, 2019; Karunarathne, 2021). Basically, torrential rains, mass flooding events, landslides (wet), tropical cyclones, different kinds of other storms, prolong droughts, extreme winter conditions plus cold waves, wild/forest fires and heat waves etc. can be identified as serious

Corresponding author.
E-mail address: ananda@geo.cmb.ac.lk (Ananda Y. Karunarathne)

Hydrometeorological disasters and events. In particular, abovementioned events have closely been intertwined with the global warming and global climate change scenarios (Bonneuil, Choquet and Franta, 2021; Marlon et al., 2021; Jones and Lucas, 2023; Zhang et al., 2021; Osberghaus and Fugger, 2022). According to the latest IPCC's (which is one of the leading international bodies for assessing climate change), AR6 synthesis report has provided extensive evidence that human activities, particularly the burning of fossil fuels and deforestation, have significantly contributed to the warming of the planet (IPCC, 2022). This is because many countries around the world has adversely been experienced torrential rains, mass flooding events, cyclones, and prolong droughts (Osberghaus and Fugger, 2022; Cannon, 2022; Baloch, 2022; Manawadu and Wijeratne, 2021; Cuddy, 2021; Karunarathne and Lee, 2019; Mirza, 2002).

On the other hand, Climate Tipping Points (CTPs) of the globe, have been reaching very serious situation as the planet Earth has adversely been impacted by the global warming and global climate change. The scholarship and discussion about CTPs has come to the fore, since the scientists throughout the world have long been issued serious warnings on collapsing situation of world natural systems (Carrington, 2022; IPCC, 2021; Harvey, 2018). For example, Carrington (2022) has reported that there are five CTPs which are immensely dangerous for the planet Earth and its human population. They include the collapsing of Greenland's ice caps; sea level rise; the collapse of a key current which is in the North Atlantic; disrupting rains amid prolong droughts; and unexpected melting of carbon-rich permafrost in polar regions. These CTPs will adversely impact on the natural atmospheric systems. As a consequence, a range of extreme events which are mostly related to the Hydrometeorological disasters can be expected throughout the globe. This is because, in particular, the areas situated in low lying altitudes are vulnerable to be impacted amid almost all the coastal cities which are vulnerable at the highest level. On the other hand, both developing and developed countries are at risk in the face of future climatic breakdowns. Especially in the case of developing countries, a plethora of natural and human system failures are possible due to the lack of adaptive capacities and poor resiliency levels. More importantly, the accelerating risk is intertwined with the informal settlement areas such as slums and shanties situated in the cities of developing counties. For instance, Sri Lanka, as a developing island country, has adversely been experiencing torrential rains, mass flooding events and related disaster events for decades (Karunaraathne, 2021; Churchill and Hutchinson, 1984). More importantly, this situation has adversely been accelerated due to the ongoing climate change impasses. The monsoon patterns and raining regimes have already been changed and shifted, in accordance with the personal

observations. We can expect quite similar narratives from the rest of developing countries as well. On this context, this review work will shed some light on the examining of ongoing global climate change impasses, Climate Tipping Points and related Hydrometeorological disasters. Further, this work also fills some gaps in the extant body of literature on the discourse of global geographies of disaster risk reduction (DRR). In particular, this study seeks to address the following research questions; what are the Climate Tipping points (CTPs) related to global climate change? What are their implications on the planet Earth? The next section explains the methodological approach which was occupied, and the 3rd section presents the results revealed and discussion of this study. Finally, the 4th section draws the concluding remarks of the study with future research foci.

2. Methodological approach

This systematic literature review done on the global climate change related impasses and related consequences was occupied with the PRISMA model (Moher et al., 2009). The study conducted a systematic literature review using various search engines and databases such as Google Scholar, Elsevier, Scopus, Pubmed, as well as reports like those from the Intergovernmental Panel on Climate Change (IPCC) and news articles. The study also used specific search terms and fuzzy search rules to identify relevant articles on environmental change, global climate change, climate crisis, global warming, vulnerability, adaptation. Figure 1 presumably provides an illustration of the article search and filtering process, demonstrating the steps of identification, screening, and inclusion in the study.

The searching mechanism started with the selection of an initial pool of articles and applying of certain exclusion criteria. The exclusion criteria included articles written in non-English languages, articles published before the year 2005, and articles for which full texts were not accessible. After applying these exclusion criteria, the study ended up with 68 articles that were selected for further analysis. In particular, the author read the abstracts of these articles to determine their relevance to the research topic. The study also considered the aspect of global climate change or related facts in the selected articles. Out of the initial selection, the study further narrowed down their choices and considered 53 manuscripts that were selected as the most appropriate for this work. These manuscripts and news articles were published in peer-reviewed, scholarly, indexed journals and reputed international news agencies. Additionally, the study included some reports, as indicated in Figure 1. To ensure transparency and adherence to research standards, the study employed the PRISMA (2020) checklist tool developed by Moher et al. (2009) to finalize the compilation of the manuscript. In particular, some news articles

and manuscripts have considered for having the background information which are also listed in the reference list. This is because the reference list repots more than 53 cited works.

The study performed the systematic literature review on the resilience based studies, particularly by using the following search terminologies and fussy search rules; such as, “Global warming”; OR “Climate Change”; AND OR “CTPs”; OR “Climate Tipping Points”; OR “Extreme Climate Events”; AND OR “Climate Change-Adaptation”; OR “Climate Resilience”. Figure 1 clearly exemplifies the article search and filtering process following the identification, screening and inclusion processes.

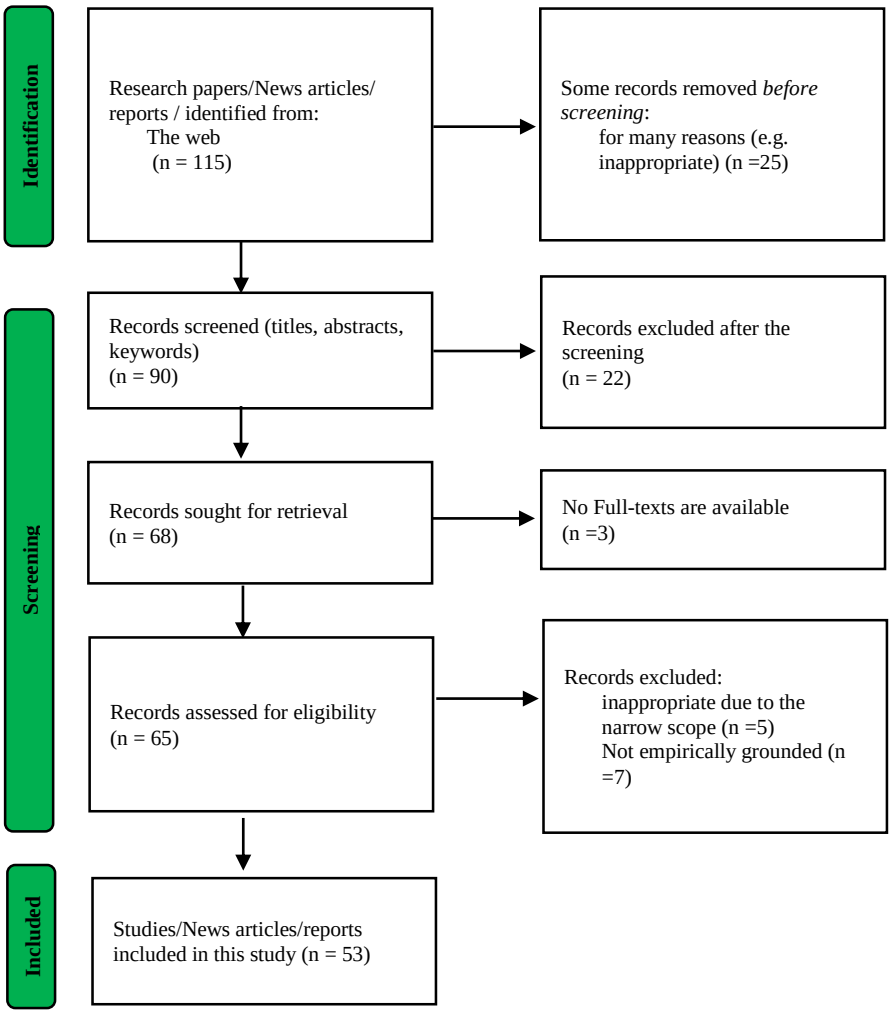

Figure 1: Web Searching mechanism of the study
Source: Designed by the author based on the PRISMA model (Moher et al., 2009)

3. Results and Discussion

This section examines the results revealed by the systematic literature review on global climate change impasses, the CTPs and their cumulative influence on the extreme Hydrometeorological events/disasters. Demonstration of the global status of CTPs and related extreme events will be more important to the Sri Lankan context, as a developing island country and of course will bridge the significant gap/s of the climate change discourse.

3.1 Dramatic nature of global climate change related CTPs

In accordance with the extant body of literature, the cardinal causative factor for worsening the CTPs is climate change. More importantly, climate change has adversely been imposing stressors on the human population and their adaptations (see, Owen, 2020), on the ecological resilience and biodiversity (Clement, Standish, and Kennedy, 2023), on the peoples' climate depression and anxiety (see, Marczak et al., 2023; Perga et al., 2023), on the peoples' resilience (e.g. Frijters et al., 2023), natural resources and gender (Karunarathne and Gress, 2023; Fonjong and Zama, 2023) etc. In particular, the impacts of global climate change impasses on human and ecological systems in different dimensions is represented in the figure 2 below, in accordance with the extant body of reviewed literature.

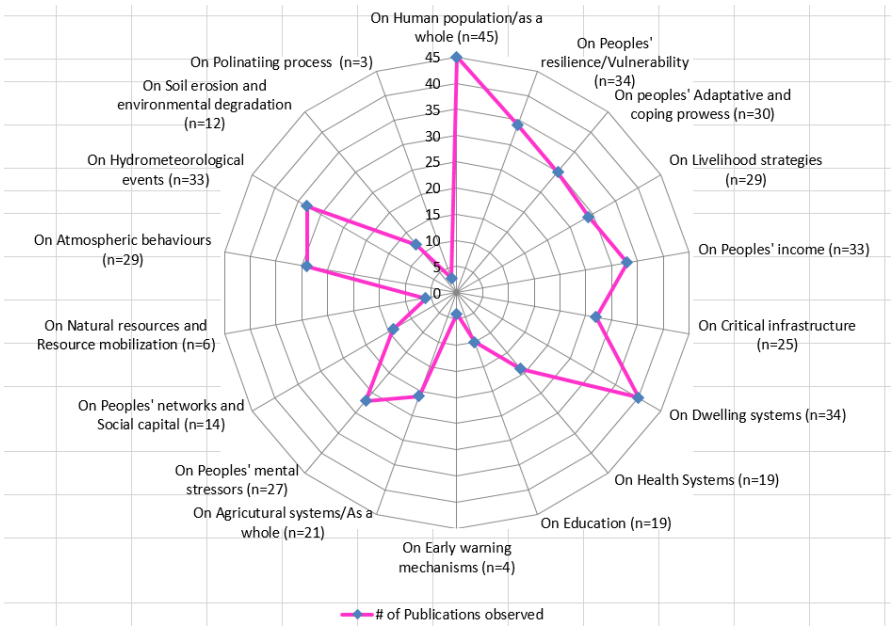

Figure 2: Impacts of global climate change impasses on human and ecological systems

Source: Prepared by the author based upon the reviewed literature, 2023

Note: Some publications were concerned/researched more than one of the above aspects

Figure 2 depicts how the consequences of global climate change impacting in a range of ways on human and ecological systems. It is worthwhile to understand that the human adaptation to climate change has been becoming a perilous issue at the modern age (Robert, Quercy, and Schleyer-Lindenmann, 2023; Castro and Sen, 2022; Nalau and Cobb, 2022; Owen, 2020).

The results indicated that the consequences have seriously been woven into the life of both the Northern and Southern hemispheres. Another aspect is that the number of publications pertaining to the impacting areas of pollinating process and global food supply, early warning mechanisms, natural resource and resource mobilizations, soil erosion and environmental degradation, are lacking. Conducting more and more researches on these areas are very important to safeguard the wild pollinating process and the global food supply. On the other hand, more research have been conducted on the vulnerability, resilience, Hydrometeorological disasters, extreme climatic events and related issues on human population. Of course, these figures/values are totally defending upon the number of selected publications and search algorithms. However, it is very clear that the global climate change related issues is a sharp peak in human and ecological systems (Frijters et al., 2023). These findings are hugely exiting and will be very important for the climate policy reforms and establishments.

The cardinal causative factor/reason behind the escalated global climate change impasses is the global warming (Bonneuil, Choquet, and Franta, 2021; Marlon et al., 2021; Jang and Hart, 2015; Smith and Leiserowitz, 2013; Freudenburg and Muselli, 2010). As can be seen from the Figure 3, the global surface temperature has dramatically been increased for decades and in particular, July 2023 was the world's hottest month on record (Watts et al., 2023).

According to the figure 3, we can observe warmer average temperature during past two decades compared to the previous decades which were indicated the surface temperature with cooler than the average. This is because the globe is facing seemingly an imminent global warming related climate crisis. Since the 22nd hottest month on record in July, 1998 1st and 2nd recorded in the year 2023. Due to this serious situation many related CTPs are reaching their dangerous limits amid many records heat-deaths are surging (Watts et al., 2023). This situation seriously been impacted on the global water availability (Fonjong and Zama, 2023). This is because the need of understanding the real/actual situation of CTPs has been come to the fore. The 4th figure implies a great sense on the CTPS.

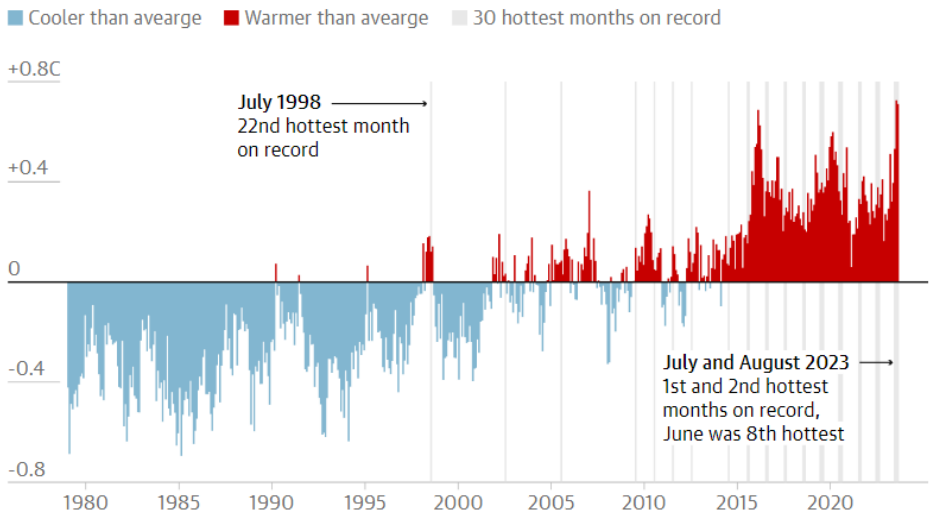

Figure 3: Global surface temperature irregularities relative to a 1991-2020 baseline (Monthly average)
Source: Watts et al., 2023 (Data: Copernicus/ERA5).

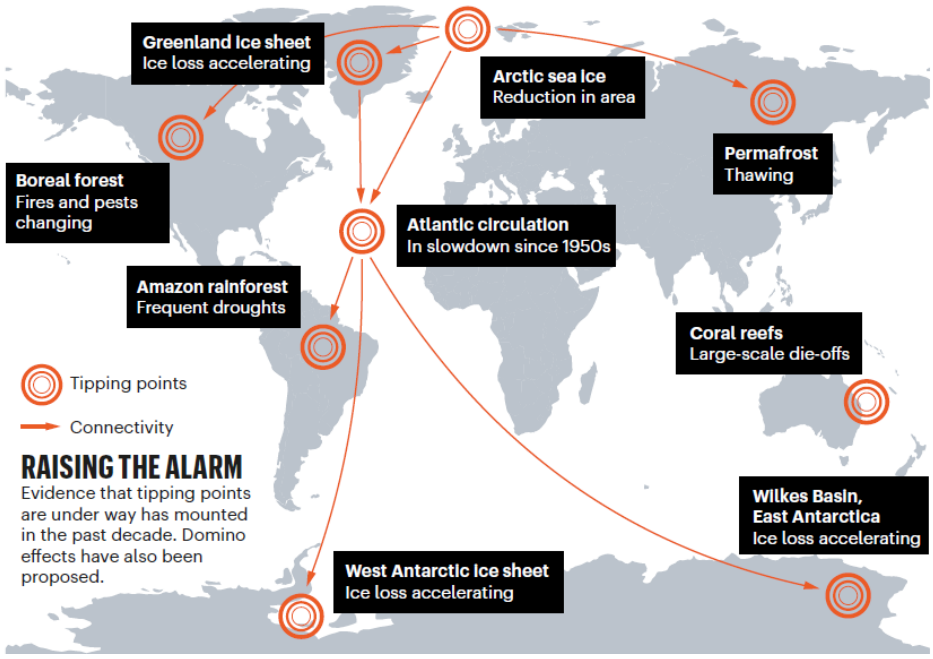

Figure 4: Connectivity among global CTPs
Source: Lenton et al., 2019 (based upon Lenton et al., 2008)

CTPs were originally researched by Lenton and colleagues (2008) and they emphasized the danger of triggering and cascading them. They named these CTPs as "Tipping Elements" of global climate systems. In accordance with Tim Lenton's words, *"Climate tipping points are a game-changing risk—an existential threat and we need to do everything within our power to avoid them".* Nevertheless, Lenton and his colleagues mentioned that the Intergovernmental Panel on Climate Change (IPCC) had introduced the notion of CTPs two decades ago (Lenton et al., 2019). By their second seminal work, Lenton and colleagues (2019) urged the need of controlling greenhouse gas emissions in case of controlling the triggering nature of CTPs. At present, five seriously dangerous CTPs are much more concerned (Carrington, 2022b; Hood, 2021). In particular, *"approaching a global cascade of tipping points*" could generate a range of disastrous events in the nearby future (Lenton et al., 2019). In the following section five serious CTPs are discussed.

3.1.1 Collapse of Greenland Ice Cap

A range of anthropogenic activities have adversely affected the natural processes of the planet Earth, resulting in a serious impacts on the ecological and human systems. This is because the decay of the Greenland Ice Sheet (GIS) has been identified as one of the crucial climatic tipping points (elements) (Lenton et al., 2008). The main causative factor behind more rapid sea-ice decline than expected, is the amplification of warming over the area of Greenland. According to the simulated models, the GIS is possible to be doomed at 1.5°C of warming and this could happen as soon as 2030 (Lenton et al., 2019). This may happen because the Cop 26 and Cop 27 summits hugely occupied on the policy reforms and re-establishment activities aiming at of reducing ongoing global warming as much as possible although some countries like India and Australia disagreed to do so. This precarious situation has been further urged by Armstrong McKay and colleagues as "*Exceeding 1.5°C global warming could trigger multiple climate tipping points"* (Armstrong McKay et al., 2022). According to the sixth assessment report of the IPCC (see, IPCC, 2022), during the years 2010-2016, the rate of mass loss from both the Antarctic ice sheet, whether linked to marine ice sheet instability or not, and the Greenland ice sheet was over seven times greater than that observed from 1992 to 1999, specifically for Greenland. This is because the accelerated melting nature has dramatically become inevitable for years (Rounce et al., 2023; Carrington, 2022a; Carrington, 2021a). The melting down of Greenland's ice sheets will also affect the sea currents seriously (Harvey, 2020).

A very recent study, conducted by Box and colleagues, revealed that the ice budget deficit in Greenland became apparent in the post-1980s period due

to rising surface meltwater runoff and increased ice flow discharge from its tidewater sectors (Box et al., 2022). The study further demonstrated that the milder western regions of Greenland's ice sheet tend to be more vulnerable to contemporary surface warming, resulting in greater volumes of melting, which are exacerbated by their flatter elevation profile, reduced seasonal snow cover, and a darker ablation area. More importantly, this study utilized satellite measurements to track ice losses from Greenland and monitor changes in the ice cap's shape from 2000 to 2019 covering almost two decades. This dataset provided the scientists with the means to determine the extent to which global warming, up to the present, has disrupted the equilibrium where snowfall equals ice loss. This, in turn, allowed them to calculate the additional amount of ice that must be lost to restore stability. On the other hand, mountain glaciers in the Himalayas and the Alps are currently on track to lose one-third and half of their ice, respectively. Additionally, some scientists believe that the west Antarctic ice sheet may have already crossed the threshold where significant ice loss is unavoidable (Carrington, 2022a). A recent study, published by Boers and Rypdal (2021), employed temperature records, ice core data, and modeling techniques to reconstruct the elevation and melting rates of the ice sheet dating back to 1880. A thorough analysis of the magnitude and duration of variations over this time span unveiled unmistakable indications of an impending tipping point. These findings demonstrated that the Greenland's ice sheet's capacity to rebound from melting is rapidly diminishing. The revealed results further emphasized that the process of melting leads to a reduction in ice sheet height, which in turn exposes the ice sheet surface to warmer temperatures, further accelerating the melting. The authors of the study have identified early-warning signals for an impending critical transition by examining height reconstructions derived from ice cores. They conclude that the western Greenland ice sheet has been losing stability in response to increasing temperatures. The study indicates that the feedback loop between melting and elevation is likely to be responsible for this observed destabilization. Their findings suggest a significant increase in melting in the near future. Moreover, Weston (2023) reported that a large glacier melt-hole has been observed on top of an iceberg in Disko bay, Ilulissat, situated in western Greenland. Jason P. Briner and colleagues also have proved that the rate of mass loss from the Greenland ice sheet is projected to surpass the values seen during the Holocene era within this century (Briner et al., 2020). Harvey reported this situation as 'Greenland's ice is melting at a pace faster than at any point in the past 12,000 years' (Harvey, 2020). It is very clear that, according to this in-depth review, the melting down impasses have been rapidly and steeply developing.

3.1.2 Huge sea level rise

The serious situation of huge sea level rise is totally intertwined with the melting-down crisis of ice caps and polar glaciers. In other words, the rapid global warming and melting down of major glaciers can be identified as the cardinal reasons behind the accelerating issue of sea-level rise (Boers and Rypdal, 2021). Many studies have proved that the future sea-level rise will be much more serious than ever before (Rounce et al., 2023; Box et al 2022; Carrington, 2021a; Briner et al., 2020; Harvey, 2020). According to the current analysis, the sea level rise has become an inevitable truth and mass challenge (Carrington, 2022a). Based upon these challenges, many dimensions of sea level rise have been of great to concern to researchers (for examples, Nepal et al., 2022; Smart et al., 2021; Hindsley and Yoskowitz, 2020; Treuer, Broad, and Meyer, 2018; Pycroft, Vergano, and Hope, 2014). In particular, the coastal communities can be identified as one of the mostly affected human population by the future sea level rise (Pia Vantaggiato et al., 2023). I can highlight specific geographical settings such as archipelagos and island countries, and low lying countries like The Netherlands, The Philippines, Indonesia etc. which are mostly exposed and vulnerable for impacts by sea level rise. Basically, melting down of Greenland ice sheet will be one of the largest causative factors of sea-level-rise (SLV) (Box et al., 2022; Harvey, 2020). According to Carrington (2022a), 110tn tonnes of ice have been melted from Greenland alone. In the face of ongoing carbon emissions, the combination of ice cap retreat and oceanic thermal expansion present a significant likelihood of a substantial sea-level increase, potentially extending into multiple meters. Given the substantial population inhabiting coastal areas, the inundation resulting from ascending sea levels stands as one of the most enduring repercussions of the climate crisis. Different groups of people, indigenous communities in particular, are potential to be impacted much by sea level rise if the proper mitigation and adaptation practices will not be worked (Marino, 2018; Graham et al., 2014; Martı´nez et al., 2014; Haer et al., 2013; Gibbons and Nicholls, 2006). There also can be cumulative impacts of climate change and sea-level rise on the heightening of extreme Hydrometeorological disasters (Karim and Mimura, 2008).

This is because human population plus flora and fauna will be impacted adversely, if the current rate of the global warming continues to be escalated. This is because the social and ecological adaptation needs have come to the fore (see, Pia Vantaggiato et al., 2023). The authors have emphasized the sea level rise as one of the most pressing climate adaptation issues around the world. In this sense, regional actors/organizations and NGOs have to play a cardinal role in terms of establishing and understanding the adaptation mechanisms. All in all, the economic cost of the consequences of sea level rise

will be very brutal (Lincke and Hinkel, 2018; Pycroft, Vergano, and Hope, 2014; Haer et al., 2013). In particular, the cost of the impacts possible to be experienced in the densely populated coastal areas will be very serious. This is because mitigating of these risks has often come to the fore. More importantly the cost of losses will be aligned with the most vulnerable countries for the Hydrometeorological disasters like USA. On this context, the policy reconsiderations and reforms are pivotally important (see, Moser, 2005), since the existing DRR policies are not pretty enough to safeguard the future world from the augmented extreme events. It is certain that the variegated geographical settings of Southern and Northern hemispheres can differently be impacted.

3.1.3 Collapse of Atlantic Meridional Overturning Circulation (AMOC)/ Gulf Stream Systems

More importantly, the Atlantic Meridional Overturning Circulation (AMOC), often referred to academically as the "conveyor belt" due to its role in transporting warm water from the equator, is primarily governed by the Gulf Stream. As articulated by L. Caesar and her colleagues, the AMOC serves as one of Earth's major ocean circulation systems responsible for heat redistribution and exerting a significant influence on our planet's climate. They emphasize that the AMOC is a delicate nonlinear system, intricately dependent on subtle thermohaline density variations within the ocean. Major transitions in the AMOC have been associated with millennial climate events during the last glacial period (Caesar et al., 2021; Rahmstorf, 2002).

The Gulf Stream, originating in the Gulf of Mexico, plays a pivotal role in the Atlantic Ocean's circulation system. It has been recognized as a critical tipping point for the Earth's climate balance. It is indeed concerning that scientists have conducted extensive investigations over the years, revealing credible indications of the potential collapse of the Gulf Stream system due to the impasses created by global warming (Harvey, 2021). Furthermore, it's crucial to highlight the Gulf Stream's profound influence on the weather systems of Europe, particularly in delivering warm and mild weather conditions. In the words of Harvey (2021), "*The AMOC is one of the world's most extensive ocean circulation systems, transporting warm surface water from the Gulf of Mexico northward into the North Atlantic. As it progresses, this warm water cools and becomes saltier, ultimately sinking north of Iceland. This process, in turn, draws more warm water from the Caribbean. Concurrently, accompanying winds contribute to the delivery of mild and moist weather to regions such as Ireland, the UK, and other parts of Western Europe*."

The collapse of this system will be impacted adversely on the west and north European region. More importantly, this situation could result in more and severe storms impacting much on the UK, severe winter conditions, prolong droughts and intense heat-waves impacting the Europe. Furthermore, the Atlantic coast of the US will also be experiencing huge impacts by raising sea levels due to the weakened Gulf stream. Scientists have further stressed that *"If we continue to drive global warming, the Gulf Stream System will weaken further – by 34 to 45 percent by 2100 according to the latest generation of climate models…this could bring us dangerously close to the tipping point at which the flow becomes unstable.*", (Caesar et al., 2021). The fastest way of melting down the Greenland's ice sheet can be identified as one of credible signs of shutting down the AMOC (Carrington, 2021). According to Niklas Boers, they have identified distressing indicators of a potential collapse of the Gulf Stream, a vital component within the Earth's list of critical tipping points. The research has unveiled a concerning trend of "an almost complete loss of stability over the last century" in the currents constituting the AMOC, which is often referred to as the Gulf Stream. Notably, these currents are currently operating at their most sluggish pace in at least 1,600 years, and the latest analysis suggests they may be approaching a state of cessation (Boers, 2021). The ramifications of such an occurrence would be catastrophic on a global scale. It would profoundly disrupt rainfall patterns relied upon by billions of people for sustenance in regions such as India, South America, and West Africa. Additionally, it would escalate the frequency of storms and reduce temperatures in Europe while leading to a rise in sea levels along the eastern coast of North America. Furthermore, it would exacerbate the vulnerability of the Amazon rainforest and the stability of the Antarctic ice sheets. Boers emphasized the importance of utilizing eight distinct datasets that independently measure temperature and salinity, with historical records spanning up to a century and a half. The study demonstrated that global warming is undeniably amplifying the instability of ocean currents. This effect extends beyond merely altering their flow patterns. The worrying situation is that the recent decline in the AMOC may be indicative of a nearly complete loss of stability throughout the past century (Boers, 2021; Carrington, 2023a). A new study revealed that AMOC could be approaching a critical tipping point, potentially leading to its complete collapse within the time frame spanning from 2025 to 2095 (see, Turner, 2023). If this were to occur, the consequences would be profound, including a significant drop in temperatures, the collapse of ocean ecosystems, and a surge in global storm activity. This is because Gulf Stream collapse can be identified as a key danger for our earth planet forever.

3.1.4 The loss of the Amazon rainforest

The reducing rhythm of world's natural forest covers have dramatically been accelerated mainly due to a range of androgenic activities. On the other hand, the global warming has also contributed a lot to the reduction of rain forests escalating devastating forest/wild fires throughout the globe. According to Damian Carrington's report, new data reveals that the Amazon rainforest is approaching a critical tipping point, beyond which its loss would have profound consequences for global climate and biodiversity. This analysis relies on real-world satellite observations spanning three decades, in contrast to previous computer models. The findings from novel statistical analysis indicate that over 75% of the undisturbed Amazon forest has become less resilient since the early 2000s (Carrington, 2022c). This reduced stability translates to a longer recovery period following droughts and wildfires. The areas most affected by this loss of stability are those in proximity to farms, roads, urban development, and regions experiencing increased aridity. The evidence strongly suggests that deforestation and global warming are the driving forces behind this concerning trend. In essence, the Amazon may already be on the brink of a critical threshold, beyond which rainforest dieback becomes a dire reality, as concluded by the scientists.

According to Fiona Harvey, the data highlights that tree loss from fires is most severe in far northern latitudes. Russian forests are particularly impacted, raising concerns about the release of significant amounts of previously stored carbon dioxide (Harvey, 2022). In accordance with Heacox (2021), the Amazon rainforest is shrinking at a rate of approximately 10,000 acres per day. Since 1988, human activities have led to the destruction of a rainforest area roughly equivalent in size to the state of California. On the other hand, the worrying news in the last decade is that the boreal forests in the far north have experienced the most extensive tree cover loss from fires worldwide. Clearing and burning of trees occur in the Amazon rainforest, primarily driven by deforestation and agricultural expansion. This contributes to heightened fire activity in tropical regions, where deliberate burns can unintentionally trigger forest fires. According to Williams, cook, and Smerdon (2022), soil moisture deficits have doubled in the past 22 years compared to levels in the 1900s, with 42% of the increase in severity attributing to human-caused warming. The same researchers urged that this prevailing situation will be very rapid and steep. Williams and his colleagues further expressed that, *"We are watching our bank account of water decline,"*…"*and we know that eventually we need to slow our expenditures before the account runs out".*

In this context, regional warming has dramatically been increased for decades and the Amazon deforestation seems difficult be stopped (Butt et al.,

2023). This study indicates that forest conservation would primarily be beneficial to agricultural enterprises. The research carries political implications, as farmers in Amazonian states have historically been at the forefront of forest clearance, driven by the belief that clearing more land would yield financial gains. For Watts (2023), it underscores the advantages of forests in terms of cooling local temperatures and enhancing rainfall. The Brazilian Amazon reveals that deforestation exerts a significantly larger influence on regional temperatures than previously understood. On the other hand, the California region has lost many hundreds of acres of historic forests due to the climate change related wildfires, compared to the wildfires without climate change. Record say that, California has lost around 23,000 acres of forests, including fired 15 buildings, and 5 homes (Cannon, 2021). Due to large-scale wildfires, the USA has experienced significant losses in wildlife habitats, niches, biodiversity, and a decline in ecosystem services, resulting in a substantial economic cost. Not only in the western United States but also in Algeria, Siberia, Turkey, numerous European countries and Australia, thousands of acres of natural forests have been lost over the years due to wildfires, which have been exacerbated by severe heatwaves. All in all, many of the developing countries including Sri Lanka have also been experiencing a huge loss of natural forest covers, especially due to a range of lopsided political influences.

3.1.5 An unexpected melting of carbon-rich permafrost

According to L.M. Farquharson and colleagues, the permafrost refers to the ground that maintains a temperature at or below 0°C for a period of two years or more, and it is found beneath a substantial portion of the Arctic region. In Arctic lowland areas, permafrost often contains significant amounts of ground ice. When this ice thaws, it leads to the collapse of the ground surface. With the ongoing warming of the Arctic, the widespread degradation of ice-rich permafrost is anticipated (Farquharson et al., 2019). Regarding the melting down impasses, Damian Carrington has reported that there is an escalating consensus regarding the potential for multi-meter sea-level elevation occurring within the upcoming century to two. Specifically, the catastrophic disintegration of the immense east Antarctic ice sheet, which, if fully liquefied, could result in an astonishing 52-meter surge in sea levels over millennia, remains averted through the implementation of expeditious and decisive climate mitigation measures (Batchelor et al., 2023; Carrington, 2023b; Carrington, 2022a). According to the recent findings, the frozen ice blocks which are thousands of years of old, have been started to diestablish (figure 5). When compared to the 5,000 years of climate, the current climate is warmer than at any time in the past (Farquharson et al., 2019). These authors seriously warned about the climate emergency which has been growing for

decades. Moreover, they emphasize on the cutting down emissions and decarbonizing the economies.

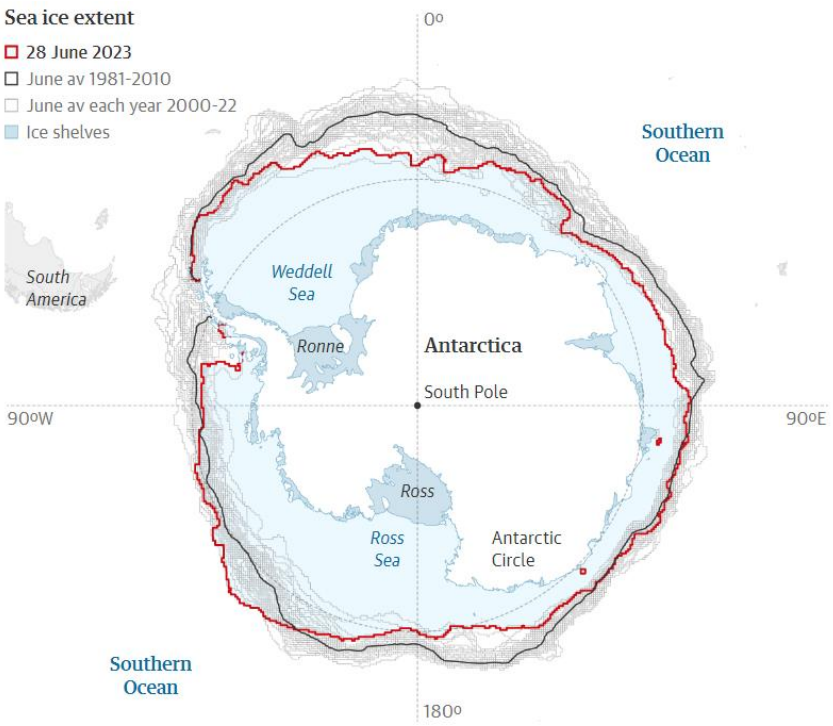

Figure 5: Antarctic sea ice extent, 28 June 2023
Source: Watts et al., 2023 (Data credit: Sea Ice Index, National Snow and Ice Data Center).

John Vidal reported that two decades ago, an expanse of ice believed to be nearly 500 billion tonnes in weight dramatically fractured from the Antarctic continent, splintering into thousands of icebergs within the Weddell Sea. The Larsen B ice shelf, spanning 1,255 square miles (3,250 square kilometers), was recognized for its rapid melt, yet no one had foreseen that it would completely disintegrate in just a single month, despite being 200 meters thick (Vidal, 2021). On the other hand, Lisa Cox reports that the Denman ice shelf in East Antarctica is experiencing an annual melt rate of 70.8 billion tonnes due to the intrusion of warmer seawater (see, Cox, 2022). Until quite recently, there was a prevailing belief that East Antarctica would not undergo the same accelerated ice loss as observed in the western region. However, recent research indicates that warm water is indeed making its way to this part of the continent.

In accordance with the IPCC report (IPCC, 2022), collapsing ice sheets (high confidence) is identified as one of the crucial adaptation challenges which is aligned with the sea-level-rise. The report further illustrates that rural areas across the globe are home to around 3.4 billion people, and a significant portion of them face high levels of susceptibility to the impacts of climate change. The crucial reason behind this gloomy situation is that by 2,100 a half of Earth's glaciers have the potential to be melted according to the current investigations (see, Weston, 2023). According to D. Carrington, a recent study revealed that, ice sheets have the potential to rapidly crumble into the ocean, retreating at rates of up to 600 meters (2,000 feet) per day, significantly faster than previous observations (Carrington, 2023b). In particular, deglaciation process is potential to be accelerated and will be severe in the mid-latitude regions (Rounce et al., 2023). Another aspect of melting glaciers is a substantial quantity of microorganisms is being unleashed as glaciers melt on a massive scale (Carrington, 2022d; (see, Niranjan, 2023; Milman, 2023). This is because extremely dangerous pathogens are possible to be released by the mass amount of disintegrating and melting glaciers. In this context, the greater concern of the resilience of people who are living in coastal, low lying and archipelagos areas has come to the fore.

4. Challenges in the Sri Lankan Context

Sri Lanka, as a developing country, has been facing a range of living and economic hardships since the country's economic and political landscapes began to meltdown. Since early 2021, Sri Lanka has grappled with immense economic shocks and challenges, with the tourism industry being one of the hardest-hit sectors. The industry was already facing difficulties following the impact of the Easter Sunday attack in 2019, and the COVID-19 pandemic further exacerbated the situation, leading to a near-collapse of tourism. Amid this precarious state, the Sri Lankan economy has begun to experience a meltdown, manifesting in various crises. In July 2022, the inflation rate soared to 60%, while foreign debts escalated sharply. On the other hand, Sri Lanka, as an island country, has been facing a plethora of Hydrometeorological disasters such as torrential rains, mass flooding events, landslides, storms, and droughts, in addition to biological disasters like the Covid-19 pandemic and other rain-fed diseases.

As consequences, hundreds of thousands of people are experiencing adverse impacts amid living in disaster-prone areas. This is because their situation is very vulnerable. We can anticipate many unexpected calamities in the future due to the above-discussed ongoing global climate change impasses. According to personal observations, the country's rainfall seasons and respective rainfall intensities have dramatically changed. In the middle of

December 2022, Sri Lanka also experienced huge impacts due to the slowdown of daily temperatures. The main causative factor for this situation was a massive depression generated in the Bay of Bengal. As the Global Assessment Report on Disaster Risk Reduction emphasized (UNDRR, 2022), the planet Earth can be affected by several resiliency challenges. In the case of Sri Lanka, the future challenges may include access to effective early-warning systems, drought risks and food insecurity, increased water stress and population growth, soil erosion and degradation, heat stresses, pollution, torrential rains and flood risks, livelihood challenges and poverty, coastal flooding, etc. This is because preparing for future cascading disaster challenges has come to the fore. In particular, more research on Disaster Risk Reduction (DRR), educating people, resource mobilization, safeguarding livelihood strategies, and overall improving community resilience are urgent needs.

5. Concluding Remarks

This systematic literature review analyzed numerous research papers, reports, and news articles to assess the credible evidence of the global CTPs and their impacts on the planet earth. It revealed that climate change-induced CTPs are reaching their safe limits. The cardinal causative factor behind this gloomy nature is the global warming. This is because the situation of CTPS has adversely been worsening, resulting a range of bad consequences to the human population and also to the nature. Several research findings have brought to light the imminent dangers and severe future consequences of CTPs, adversely affecting both human and ecological systems. All in all, events such as the mass flooding in Germany and the EU region in 2021, the historic devastating flooding event in Pakistan in 2022, and the flood catastrophe in Libya in 2023 and all other extreme climatic events serve as clear examples exemplifying the gravity of the current situation on planet Earth.

More importantly, Sri Lanka, as an island nation, has faced numerous climate-related challenges, which should be addressed due to the need for global and country-level policy reforms. Efforts to mitigate climate change induced impasses include reducing greenhouse gas emissions through renewable energy adoption and enhancing resilience through infrastructure improvements and early warning systems. While progress has been made, global cooperation, emission reductions, and enhanced adaptation measures remain essential to be addressed in the climate crisis. International agreements like the Paris Agreement aim to limit global warming and provide support to developing countries, but there's a need for sustained and accelerated efforts from all sectors of society. Moreover, as the world's largest climate meeting,

the 28th Conference of the Parties (COP28) which took place in Dubai in December 2023, developed countries such as the USA, UK, and Australia must reconsider phasing out fossil fuel production and allocate more funds to assist developing nations in recovering from losses and damages. In particular, a considerable portion of people in Sri Lanka is living under serious economic hardships and vulnerability. On the other hand, Sri Lanka, as an island developing country, with potential to experience a range of climate change impasses, will be triggered by the global climate change scenarios. Basically, the resilience to torrential rains and mass flooding events have not been improved so far, covering all geographically variegated settings. This is because in the face of global climate change impasses, the sophisticated/innovative adaptive needs and resiliency improvements have come to the fore. On this context, one potential research foci is the role of social capital and social support networks in terms of enhancing the resiliency of human population in the face of climate change challenges due to the worsening of CTPS. In addition to that, research works should place greater emphasis on the impacts of CTPs across variegated geographical settings and sectors in Sri Lanka.

References

Armstrong McKay, D.I., (2022). Exceeding 1.5°C global warming could trigger multiple climate tipping points. *Science*, 377, pp. 1171 and eabn7950.

Batchelor, C.L., et al., (2023). Rapid, buoyancy-driven ice-sheet retreat of hundreds of metres per day. *Nature*, 617, pp.105-110.

Baloch, S. M., (2022). Pakistan declares emergency as floods hit over 30million people. Theguardian, Available from: https://www.theguardian.com/world/2022/aug/26/pakistan-declares-emergency -floods-monsoon-rains, (Accessed: 01/10/2023).

Boers, N., (2021). Observation-based early-warning signals for a collapse of the Atlantic Meridional Overturning Circulation. *Nature Climate Change*,11, pp. 680–688.

Boers, N., and Rypdal, M., (2021). Critical slowing down suggests that the western Greenland Ice Sheet is close to a tipping point. *PNAS*, 118 (21), pp. 1-7.

Bonneuil, C., Choquet, P., and Franta, B.,(2021). Early warnings and emerging accountability: Total's responses to global warming, 1971–2021. *Global Environmental Change*, 71,102386.

Box, J.E., et al., (2022). Greenland ice sheet climate disequilibrium and committed sea-level rise. *Nature Climate Change*, 12, pp. 808–813.

Briner, J.P., et al., (2020). Rate of mass loss from the Greenland Ice Sheet will exceed Holocene values this century. *Nature*, 586, pp. 70-86.

Butt, E.W., et al., (2023). Amazon deforestation causes strong regional warming. *PNAS*, 120 (45), e2309123120.

Caesar, L. et al., (2021). Current Atlantic Meridional Overturning Circulation weakest in last millennium. Nature Geoscience, 14, pp. 118–120.

Cannon, G., (2021). California couple whose gender-reveal party sparked a wildfire charged with 30 crimes. Theguardian, Available from: https://www.theguardian.com/us-news/2021/jul/21 /co u ple-gender-reveal-party-wildfire-charged, (Accessed: 29/10/2023).

Cannon, G., (2022). US west 'megadrought' is worst in at least 1,200 years, new study says. Theguardian, Available from: https://www.theguardian.com/environment/2022/feb/15/us-west-megadrought-worst-1200-years-study, (Accessed: 07/10/2023).

Carrington, D., (2021a). Greenland ice sheet on brink of major tipping point, says study. Theguardian, Available from: https://www.theguardian. com/environment/ 2021/may /17 /gre enland-ice-sheet -on- brink-of-major-tipping-point-says-study (Accessed: 17/10/2023).

Carrington, D., (2021b). Climate crisis: Scientists spot warning signs of Gulf Stream collapse. Theguardian, Available from: https://www.theguardian.com/environment/2021/ aug/05/ climate-crisis-scientists-spot-warning-signs-of-gulf-stream-collapse (Accessed: 19/10/2023).

Carrington, D., (2022a). Major sea-level rise caused by melting of Greenland ice cap is 'now inevitable'. Theguardian, Available from: https://www.theguardian.com/ environment /2022 / aug/29/major-sea-level-rise-caused-by-melting-of-greenland-ice-cap-is-now-inevitable-27cm-climate (Accessed: 23/10/2023).

Carrington, D., (2022b). World on brink of five 'disastrous' climate tipping points, study finds. Theguardian, Available from: https://www.theguardian.com/environment/2022 /sep/08/ world -on-brink-five-climate-tipping-points-study-finds, (Accessed: 05/10/2023).

Carrington, D., (2022c). Climate crisis: Amazon rainforest tipping point is looming, data shows. Theguardian, Available from: https://www.theguardian.com/environment/2022/mar/07 /c l im ate-crisis-amazon-rainforest-tipping-point (Accessed: 05/10/2023).

Carrington, D., (2022d). 'Vast' mass of microbes being released by melting glaciers. Theguardian, Available from: https://www.theguardian.com /environment/ 2022/nov /17/ mic robes-melting-glaciers-bacteria-ecosystems (Accessed: 25/10/2023).

Carrington, D., (2023a). Gulf Stream could collapse as early as 2025, study suggests. Theguardian, Available from: https://www.theguardian.com/environment/2023/jul/25/gulf-stream-could-collapse-as-early-as-2025-study-suggests (Accessed: 21/10/2023).

Carrington, D., (2023b). Ice sheets can collapse at 600 metres a day, far faster than feared, study finds.

Castro, B., and Sen, R., (2022). Everyday Adaptation: Theorizing climate change adaptation in daily life. *Global Environmental Change*, 75, 102555.

Churchill, R.R., and Hutchinson, D.M. (1984). Flood hazard in Ratnapura, Sri Lanka: Individual attitudes vs collective action. *Geofonm*, 15(4), 517-524.

Clement, S., Standish, R.J. and Kennedy, P.L., (2023). Expert preferences on options for biodiversity conservation under climate change. *Global Environmental Change*, 83, 102759.

Cuddy, A., (2021). Germany floods: How a country was taken by surprise. BBC, Available from: https://www.bbc.com/news/world-europe-57867773, (Accessed: 01/06/2023).

Cox, L., (2022). East Antarctic glacier melting at 70.8bn tonnes a year due to warm sea water. Theguardian, Available from: https://www.theguardian.com/world/2022/oct/14/east-antarctic-glacier-melting-at-708bn-tonnes-a-year-due-to-warm-sea-water (Accessed: 01/11/2023).

Farquharson, L.M., et al., (2019). Climate Change Drives Widespread and Rapid Thermokarst Development in Very Cold Permafrost in the Canadian High Arctic. *Geophysical Research Letters*, 46, pp. 6681–6689.

Freudenburg, W.R., and Muselli, V., (2010). Global warming estimates, media expectations, and the asymmetry of scientific challenge. *Global Environmental Change*, 20, pp. 483–491.

Frijters, P., et al., (2023). Resilience to disaster: Evidence from American wellbeing data. *Global Environmental Change*, 79, 102639.

Fonjong, L. and Zama, R.N., (2023). Climate change, water availability, and the burden of rural women's triple role in Muyuka, Cameroon. *Global Environmental Change*, 82, 102709.

Gibbons, S. J., and Nicholls, R. J., (2006). Island abandonment and sea-level rise: An historical analog from the Chesapeake Bay, USA. *Global Environmental Change*, 16, pp. 40–47.

Graham, S., et al., (2014). Local values for fairer adaptation to sea-level rise: A typology of residents and their lived values in Lakes Entrance, Australia. *Global Environmental Change*, 29, pp. 41–52.

Haer, T., et al., (2013). Relative sea-level rise and the conterminous United States: Consequences of potential land inundation in terms of population at risk and GDP loss. *Global Environmental Change*, 23, pp. 1627–1636.

Harvey, F., (2018). 'Tipping points' could exacerbate climate crisis, scientists fear. Theguardian. Available from**:** https://www.theguardian.com/enviro nment/2018/ oc t/09 / tipping-points-could -exacerbat e-climate-crisis-scientists-fear, (Accessed: 05/10/2023).

Harvey, F., (2020). Greenland's ice melting faster than at any time in past 12,000 years. Theguardian. Available from: https://www.theguardian.com/world/2020/sep/30/greenlands-ice-melting-fas ter-sea-level-rise (Accessed: 25/10/2023).

Harvey, F., (2021). Atlantic Ocean circulation at weakest in a millennium, say scientists. Theguardian. Available from: https://www.theguardian.com/environment/2021/feb/25/atlantic-ocean-circ ul ation-at-weakest-in-a-millennium-say-scientists, (Accessed: 15/10/2023).

Harvey, F., (2022). Tree loss due to fire is worst in far northern latitudes, data shows. Theguardian. Available from: https://www.theguardian.com/environment/2022/aug/17/tree-loss-due-to-fire-is-worst-in-far-northern-latitudes-data-shows (Accessed: 25/10/2023).

Heacox, K., (2021). The Amazon rainforest is losing about 10,000 acres a day. Soon it will be too late. Theguardian. Available from: https://www.theguardian.com /commentisfree /2021 /oc t/07/the-amazon-rain-forest-is-losing-200000-acres-a-day-soon-it-will-be-too-late (Accessed: 23/10 / 2 023).

Hood, M., (2021). Climate scientists fear tipping points (maybe you should too). PHYSORG. Available from: https://phys.org/news/2021-10-climate-scientists.html (accessed:25/10/2023)

Hindsley, P., and Yoskowitz, D., (2020). Global change—Local values: Assessing tradeoffs for coastal ecosystem services in the face of sea level rise. *Global Environmental Change*, 61, 102039.

Intergovernmental Panel on Climate Change (IPCC) (2021). Climate Change 2021: The Physical Science Basis. Available from: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/ (Accessed: 02/05/2023).

Intergovernmental Panel on Climate Change (IPCC) (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Working Group II Contribution to the Sixth Assessment Report of the IPCC, Cambridge University Press, Cambridge, UK.

Jang, S.M., and Hart, P.S., (2015. Polarized frames on ‘‘climate change’’ and ‘‘global warming’’ across countries and states: Evidence from Twitter big data. *Global Environmental Change*, 32, pp. 11–17.

Jones, C.A. and Lucas, C., (2023). ‘Listen to me!’: Young people’s experiences of talking about emotional impacts of climate change. *Global Environmental Change*, 83,102744.

Karim, M. and Mimura, F.M., (2008). Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. *Global Environmental Change*, 18, pp. 490– 500.

Karunarathne, A.Y. and Lee, Gunhak (2019). Traditional social capital and socioeconomic networks in response to flood disaster: A case study of rural areas in Sri Lank, *International Journal of Disaster Risk Reduction*, 41, pp. 101279.

Karunarathne, A. Y., (2021). Geographies of the evolution of social capital legacies in response to flood disasters in rural and urban areas in Sri Lanka. *International Journal of Disaster Risk Reduction*, 62, 102359.

Lenton, T. M., et al., (2008). Tipping elements in the Earth's climate system. *Proc. Natl. Acad. Sci. U.S.A.* 105, pp. 1786–1793.

Lenton, T. M., et al., (2019). Climate tipping points - too risky to bet against. *Nature,* 575, pp. 592–595.

Lincke, D., and Hinkel, J., (2018). Economically robust protection against 21st century sea-level rise. *Global Environmental Change,* 51, 67.

Manawadu, L., and Wijeratne, V.P.I.S., (2021). Anthropogenic drivers and impacts of urban flooding-A case study in Lower Kelani River Basin, Colombo Sri Lanka**.** *International Journal of Disaster Risk Reduction*, 57, 102076.

Marczak, M., et al., (2023). Beyond climate anxiety: Development and validation of the inventory of climate emotions (ICE): A measure of multiple emotions experienced in relation to climate change. *Global Environmental Change*, 83, 102764.

Marino, E., (2018). Adaptation privilege and Voluntary Buyouts: Perspectives on ethnocentrism in sea level rise relocation and retreat policies in the US. *Global Environmental Change*, 49, pp. 10–13.

Marlon, J.R., et al., (2021). Hot dry days increase perceived experience with global warming. *Global Environmental Change*, 68,102247.

Martı´nez, M.L., et al., (2014). Land use changes and sea level rise may induce a ''coastal squeeze'' on the coasts of Veracruz, Mexico. *Global Environmental Change*, 29, pp.180–188.

Milman, O., (2023). Global heating is accelerating, warns scientist who sounded climate alarm in the 80s. Thegurdian. Available from: https://www.theguardian .com/environment /2023 /nov /02/heating-faster-climate-change-greenhouse-james-hansen (Accessed: 06/11/2023).

Mirza, M. M. Q., (2002). Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. *Global Environmental Change*, 12, 127–138.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., (2009). The PRISMA Group, Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med. 6* (7), pp. 1–6. https://doi.org/10.1371/journal.pmed.1000097.

Nalau, J., and Cobb, G., (2022). The strengths and weaknesses of future visioning approaches for climate change adaptation: A review. *Global Environmental Change*, 74, 102527.

Nepal, P., et al., (2022). Global forest products markets and forest sector carbon impacts of projected sea level rise. *Global Environmental Change*, 77, 102611.

Osberghaus, D., and Fugger, C., (2022). Natural disasters and climate change beliefs: The role of distance and prior beliefs. *Global Environmental Change*, 74,102515.

Owen, G., (2020). What makes climate change adaptation effective? A systematic review of the literature. *Global Environmental Change*, 62, 102071.

Perga, M., et al., (2023). The climate change research that makes the front page: Is it fit to engage societal action?. *Global Environmental Change*, 80, 102675.

Pia Vantaggiato, F., et al., (2023). Creating adaptive social-ecological fit: The role of regional actors in the governance of Sea-level rise adaptation in San Francisco bay. *Global Environmental Change*, 80,102654.

Pycroft, J., Vergano, L., and Hope, C., (2014). The economic impact of extreme sea-level rise: Ice sheet vulnerability and the social cost of carbon dioxide. *Global Environmental Change*, 24, pp. 99–107.

Rahmstorf, S., (2002). Ocean circulation and climate during the past 120,000 years. *Nature*, 419, pp. 207-214.

Robert, A., Quercy, A., and Schleyer-Lindenmann, A., (2023). Territorial inertia versus adaptation to climate change. When local authorities discuss coastal management in a French Mediterranean region. *Global Environmental Change*, 81, 102702.

Rounce, D.R., et al., (2023). Global glacier change in the 21st century: Every increase in temperature matters. *Science*, 379, 78.

Smart, L.S., et al., (2021). Cultural ecosystem services caught in a 'coastal squeeze' between sea level rise and urban expansion. *Global Environmental Change*, 66, 102209.

Smith, N., and Leiserowitz, A., (2013). American evangelicals and global warming. *Global Environmental Change*, 23, pp. 1009–1017.

Treuer, G., Broad, K., and Meyer, R., (2018). Using simulations to forecast homeowner response to sea level rise in South Florida: Will they stay or will they go?. *Global Environmental Change*, 48, pp. 108–118.

Turner, B., (2023). Gulf Stream current could collapse in 2025, plunging Earth into climate chaos: 'We were actually bewildered'. Available from: https://www.livescience.com/planet-earth/climate-change/gulf-stream-current-could-collapse-in-2025-plunging-earth-into-climate-chaos-we-were-actually-bewildered (Accessed: 25/1o/2023).

United Nations Office for Disaster Risk Reduction (UNDRR), (2022). *Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk: Transforming Governance for a Resilient Future*. Geneva.

Vidal, J., (2021). Scientists watch giant 'doomsday' glacier in Antarctica with concern. Thegurdian. Available from: https://www.theguardian.com/world/2021/dec/18/scientists-watch-giant-doo msday -glacier-in-antarctica-with-concern (Accessed: 24/10/2023).

Watts, J., (2023). Deforestation has big impact on regional temperatures, study of Brazilian Amazon shows. Thegurdian. Available from: https://www.theguardian.com/environment /2023/ oct /30/deforestation-has-big-impact-on-regional-temperatures-study-of-brazilian-amazon-shows (Accessed: 26/10/2023).

Watts, J., et al., (2023). The hottest summer in human history – a visual timeline. Thegurdian. Available at: https://www.theguardian.com/environment/ng-interactive/2023/sep/29/the-hott est-summer- in-human-history-a-visual-timeline (Accessed: 28/10/2023).

Weston, P., (2023). Half of glaciers will be gone by 2100 even under Paris 1.5C accord, study finds. Thegurdian. Available at: https://www.theguardian.com/environment/2023/jan/05/half-planets -glaciers-gone-2100- even-under-paris-15c-accord-data-finds (Accessed: 25/10/2023).

Williams, A. P., cook, B. I., and Smerdon, J.E., (2022). Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. *Nature Climate Change*, 12, pp. 232–234.

Zhang, W., et al., (2021). Socio-economic and climatic changes lead to contrasting global urban vegetation trends. *Global Environmental Change*, 71,102385.