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A COMPREHENSIVE REVIEW ON IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES AND ITS POSSIBLE SOLUTIONS

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ABSTRACT

The balance between water and climate is very delicate. Changes in weather drive the key components of water cycle through evaporation and precipitation. But rapid Climate change has been disturbing the water cycle for decades. As accessible water resources accounts for only 2.5% of the total earth's water, so these are already limited but climate change has further created complications by degrading and diminishing these resources. Rapid climate change has triggered intense droughts, floods, glacier melting, sea-level rise, and storms that have drastic consequences. Some parts of the world are receiving more than average rainfall causing floods and some parts of the world receive little to no precipitation resulting in droughts. Sea-level is rising annually due to rapid melting of glaciers. Either of the extremity is not good because both are resulting in water and food insecurity. The quality of drinking water resources is getting worse. The demand for water is increasing with the increase in global population. But Climate change has built an imbalance between water demand and water availability. Climate change has a direct impact on water security and global conflicts. Although, Climate change cannot be ceased but its pace can be lower down by slow adoption of mitigatory measures at global level. By strengthening adaptive policies to improve built and natural infrastructure, waste water management, increasing water storage capacity, and adopting water efficient practices in agriculture and industry can ensure water conservation. Therefore, there is a need to adopt both mitigatory and adaptive policies worldwide to curb climate change and its impacts on water resources.

1. INTRODUCTION

The water is one of our most precious resources, but our water supplies are limited. 97.5% of the earth's water is salty and only 2.5% is freshwater but over 2/3 of this fresh water is locked in the polar ice caps and glaciers. This leaves only 0.5% in our lakes, rivers, and groundwater for agricultural industrial and personal use but due to pollution the quality of this water is under threat (McGraw-Hill International Edition, 2008). According to the World Health Organization only 0.007% of the world's total water supply is safe for consumption and this miniscule amount needs to be shared by the more than 9.4 billion people on the planet and this water is not distributed evenly throughout the world. 1.2 billion people live in areas of water scarcity in places such as southwestern United States, India, Spain, North Africa,

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Australia, and northern China. One out of four health care facilities worldwide lack basic drinking water services. 7 million people could be displaced by intense water scarcity by 2030. Two out of five people worldwide do not even have basic hand washing facility with soap and water at home and still 673 million people which makes about 9% of the global population practices open defecation (WHO, 2017).

At the same time demand for water is intensifying over the last 100 years global population has tripled, and water consumption has increased sixfold, but our total water supply has remained unchanged. More people are now using a lot more of the same limited amount of water but what has driven this exponential increase in water consumption? A growing middle class in the emerging markets has been one key contributor as disposable incomes rise eating habits change and people tend to eat more meat. It takes 1300 liters of water to produce 1K of wheat and 3400 liters for 1K of rice, but 15,500 liters of water are required to produce 1K of beef and with continued population growth and prosperity meat consumption is expected to double by 2050. At this rate by 2030 social demand for water will exceed the available global supply by 40% (Schiermeier, 2019).

Climate change based on an article in the New York times the average temperature on the surface of the planet has already increased 1.7 degrees Fahrenheit since 1880 which may not seem like much but think about it this way the heat from human emissions is roughly equal to 400,000 Hiroshima atomic bombs exploding across the planet every single day. Future generations are in big trouble but for now it will gradually continue to get warmer and storms will grow more intense with longer periods of drought in between but longer term if emissions continue to rise unchecked the climate disasters will be so severe; they will destabilize entire nations send millions of refugees across borders caused widespread extinction of most species on earth and melt the polar ice caps leaving most of the world's coastal cities several feet underwater (Hansen et al, 2013).

All this could take centuries but something like the collapse of agriculture would trigger immediate chaos in society. Best case is we get to act together and begin to rapidly bring emission levels down. Meanwhile earth turns out to be less sensitive to greenhouse gases than we currently believe plants and animals adapt quickly and major technological breakthroughs help society limit emissions and adjust to climate change, but these are all the opposite of what we are seeing. So, the only thing in our control is to limit emissions using all available tools and best behaviors. Currently, at our disposal worst case the collapse food production causes spiraling prices then, as utopia breaks down, billions starve as our world gets violent and messy real quick kind of like a zombie apocalypse, but, with extreme hunger spreading chaos instead still just like a zombie apocalypse (Dalfes et al, 2013).

This would be coupled with the melting of the Antarctic ice sheet leading to rapidly rising seas that would force us to abandon many of our greatest cities and all the social and scientific progress that we were making within them adding insult to injury is the fact that many of the emissions were emitted while building these now

abandoned underwater metropolises (Oppenheimer et al., 2019). If emissions continue unchecked, we are looking at a total rise of between 82160 feet which would occur if all the ice in the poles melted so the oceans will rise. The real question is how fast? Scientists only have earth's history to base their predictions on which suggests that the rate has occasionally had one foot per decade so, will have to adapt to an altered coastline sooner or later but probably much sooner than later because computer forecasts only give us a range of future possibilities (Kwadijk et al, 2010).

The most important evidence comes from the study of past climate conditions which clearly show that every time the amount of carbon dioxide in the air rises the earth warms up, ice melts and the ocean rises. We are in uncharted territory; humans are pumping carbon dioxide into the air far faster than nature ever has before us (O'Neill et al., 2017).

Scientists have been publishing strong evidence that warming is making drought and heat waves more frequent causing heavier rainstorms and more severe coastal flooding. Conservatives do not like the policies proposed to fight climate change and have chosen to try and block them by actively undermining the science. This effort has been funded by the oil and coal industry who favor making money above all else as more resources are devoted to solving the problem. Our chances at big technological breakthroughs are improving but we still should be spending about three times as much money as we currently are on these efforts (Bates, 2008).

According to several in depth reports you can reduce your carbon footprint by doing things like plugging leaks in your home insulation, installing a smart thermostat, taking public transit, taking less airplane trips, buying an electric car and putting solar panels on your roof and big one is eating less meat which really needed is for you to speak up and exercise your rights as a citizen because strong collective action through state national policies is how will make the most impact (Mehran et al, 2017).

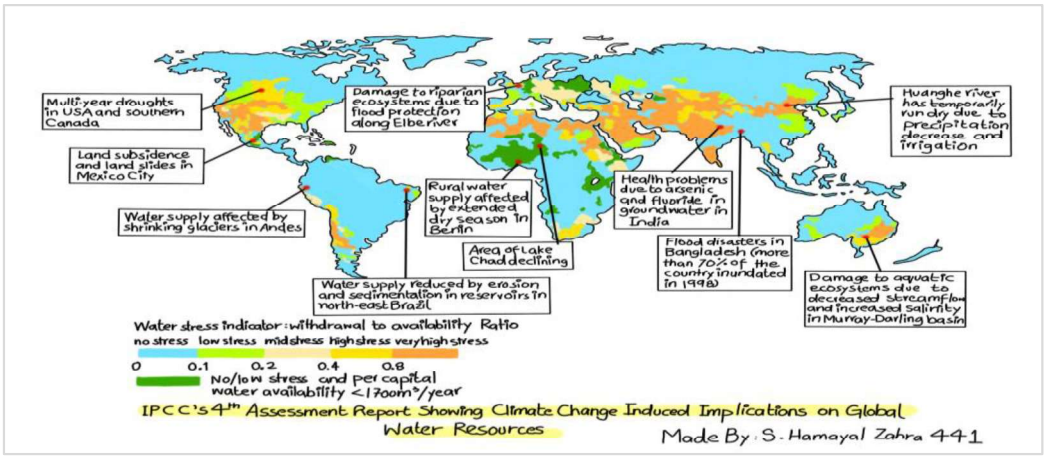


Figure-1: Impacts of Climate change on Water resources throughout the World

2. EARTH'S WATER RESOURCES

Earth is covered with 70% or water and only 30% of land. Even though one-third of the earth is water but still human can only utilize only a minor percentage of water. The distribution and flow of water throughout the earths system is very important for the smooth functioning of ecosystems and sustaining life. Water distribution among the reservoirs is mainly driven by different phenomenon of water cycle. Via, evaporation, precipitation, rainfall, cloud formation, run-off, and infiltration, the water circulates in different earth systems and water bodies. Almost all the Earth's water is saltwater, which terrestrial species do not use. The largest freshwater resource is glaciers, whereas surface runoff found in rivers and lakes is the most valuable resource for human use. In the hydrologic cycle, water is a natural resource in which water from the ocean easily moves to surface and back again. Often, this water is in form of pipelines and the dams , human intervention distracts natural water supplies to meet the local requirements. Tensions over water supplies are likely to escalate as the demand for water increases. smarter technologies and Conservation initiatives will help to make sure that water distribution around the world is more equitable. There are two types of water resources that exist on earth, one is the saline water resources and the other is the freshwater resources. About 97.5% of the earth's water is saline and the remaining 2.5% is freshwater (Huntington, 2006).

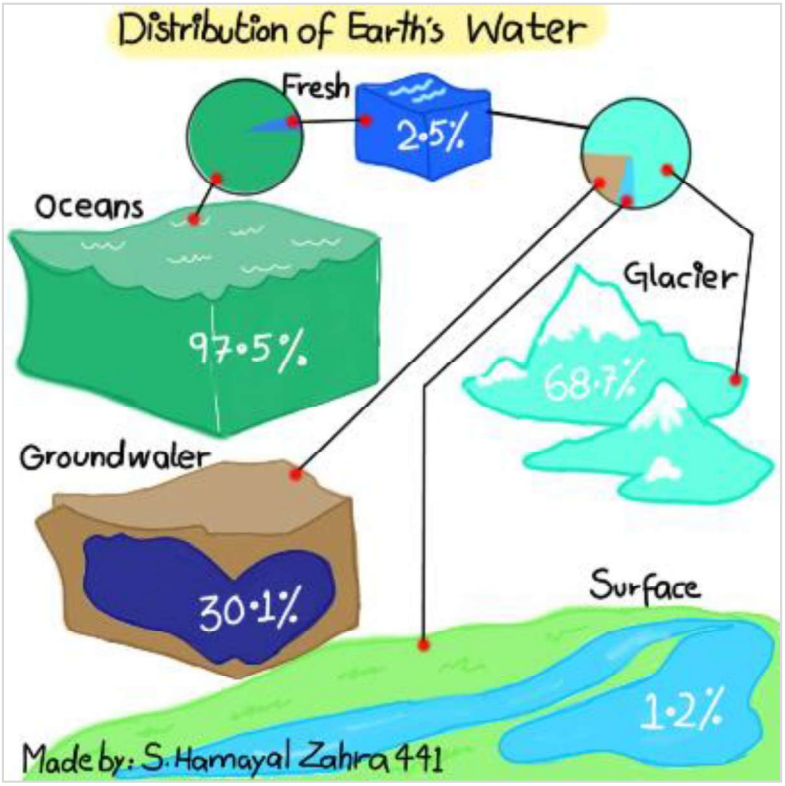


Figure-2: Distribution of Earth's Water

2.1. Saline Water Resources

Saline water resources comprise 97.5% of earth's total water. The total volume of water covered by saline water resources is 1.38 billion cubic kilometers. Saline water resources include oceans, seas, and bays. Ocean water because of salinity cannot be used for the drinking purpose unless salts and other impurities present in it are extracted. Desalination is a system through which salt is being removed from water. Although the microscopic particles and salts can be extracted through several procedures from which reverse osmosis is the significant procedure. Reverse osmosis forces the salty water Via filters with small pores that eliminate salt and other bacteria, huge amounts of water are required by reverse osmosis (Stein et al., 2020).

2.2. Freshwater Resources

The freshwater comprises only 2.5% of the total earth's water but all aquatic and terrestrial life including human beings depend upon this water resource because of its favorable palatability. Approximately 1% of freshwater is available to the humans for their usage and consumption, which is just 0.007% (the total volume of water in Earth). Freshwater is further divided into three sub-categories named as surface water, ground water, and glaciers and icecaps (Li et al., 2020).

2.2.1. Surface water

The water that exists in lakes, rivers, wetlands, springs, and streams is called as surface water. Surface water comprises 1.2% of the total freshwater. The lakes cover 20.9% of surface water while ground ice, rivers, soil moisture, living things, atmosphere, and wetlands stores 69%, 0.49%, 3.8%, 0.26%, 3.8% and 2.6% of water, respectively. This water is mainly used for the drinking purpose, agriculture, recreation, industry, transport and hydroelectric power and livestock. Over 63% public source water is extracted through surface water and agricultural Irrigation receives 58% supply of water from the surface water resource. Industries receive approximately 98% water from surface water systems for their usage and for the production purpose. Therefore, the protection of surface water is essential. Watershed companies regularly measure the flow of streams and the surface water quality. To warn the floods and drought conditions stream flow is monitored. Naturally, sediment, bacteria, debris may be carried by water that flows away into the stream. A measure of water quality and the suspended sediment measurement in water is turbidity. The more water becomes turbid, the lower the quality of water (Jia et al., 2020).

2.2.2. Groundwater

Ground water comprises about 30.1% of the freshwater resources and globally used as a drinking water source for more than 2-billion people each day. The volume of ground water in the world is 23.4 million cubic kilometers. About 60% of the groundwater serves in irrigation purposes throughout the world and the rest is used in domestic and industrial purposes. Ground water contributes any of the water source exists under the soil layers. Basically, the groundwater is most

abundant according to the other water resources for the usage of human beings that water percolates across layers of clay, rocks, and soil into the ground, almost all of it absorbs to uppermost layer and that layer deliver water to the plant life. This region is known as the unsaturated region in this region, almost all the pores are occupied by the air, instead of the water and the gravity helps to push water downward into earth. Ultimately, water enters to saturated region, in which all pores are occupied with the water. When we talk about the water table then it is the separation/parting between unsaturated and saturated zone. Aquifers are water-holding regions of permeable rock. Generally, aquifers composed of bedrock and have several cracks and linked pores like sandstone, gravel, limestone. The layers of clay and shale are porous and, therefore, create weak aquifers. When we talk about the aquifer it is "recharged" by percolating via the layers of rock and soil through precipitation from above. In exchange, through the spring's groundwater absorbs surface water, and surface water may also recharge the supply of groundwater (Herman et al., 2020)

2.2.3. Glaciers and icecaps

Out of 2.5% of total freshwater, about 68% of the freshwater is stored and trapped in glaciers, icecaps, and ice sheets. The volume of water covered by glaciers and icecaps is about 24 million cubic kilometers. These glaciers and ice cover also fed major rivers of the world and are a source of drinking water for people living in higher altitudes. It is possible to melt and use ice caps and glacier water, but the energy to move these frozen caps in large amounts and to melt them, is economically expensive (Herman et al., 2020)

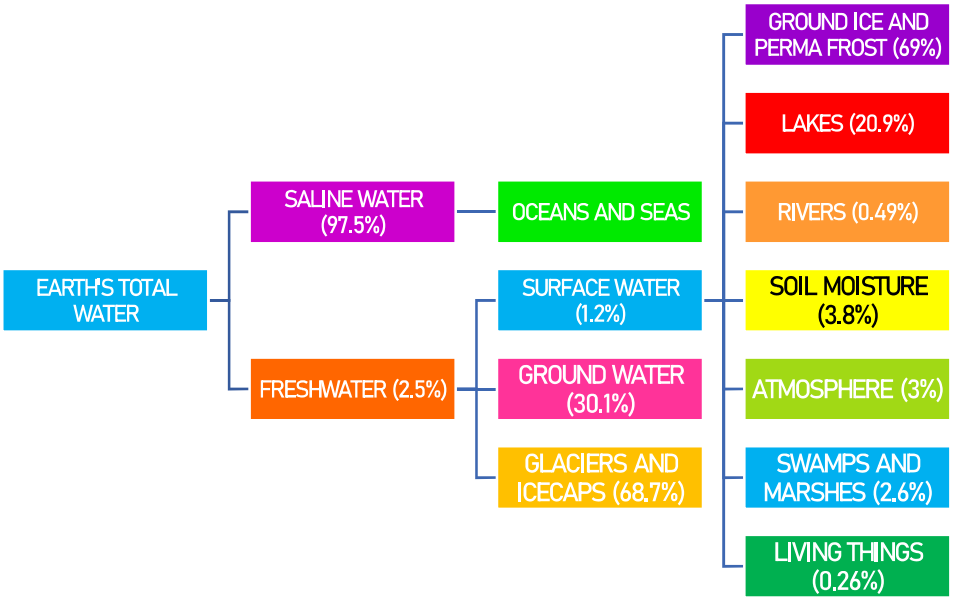


Figure-3: Earth's Water resources

3. IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES

The impacts of climate change on water resources are of a significant concern because 70% of earth is water and only 2.5% of the water is freshwater so these figures highly depend on the climatic conditions that are being changed currently. The primary implications of climate change on water resources giver rise to secondary implications and each impact is interrelated to many other implications affecting urban, rural, agricultural, and industrial level.

3.1. Change in Water-cycle

The flow and distribution of water throughout the earth systems primarily depends upon water cycle. Disruption in the natural course of water cycle means disturbance in water distribution. The primary impact of climate change is the alteration of water cycle.

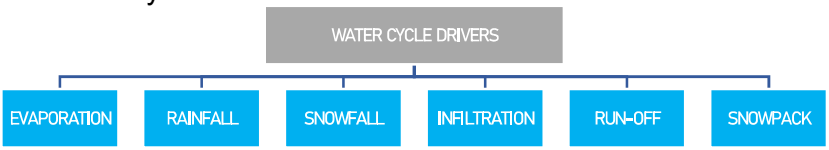


Figure-4: Drivers of Water Cycle

Drivers of water cycle such as evaporation, precipitation, snowpack, runoff, infiltration, and clouds etc. are directly being affected due to climate change. How changes due to climate change are occurring in water cycle in terms of its drivers along with the secondary implications that are linked with the primary ones are discussed further in detail (Rodell et al, 2015).

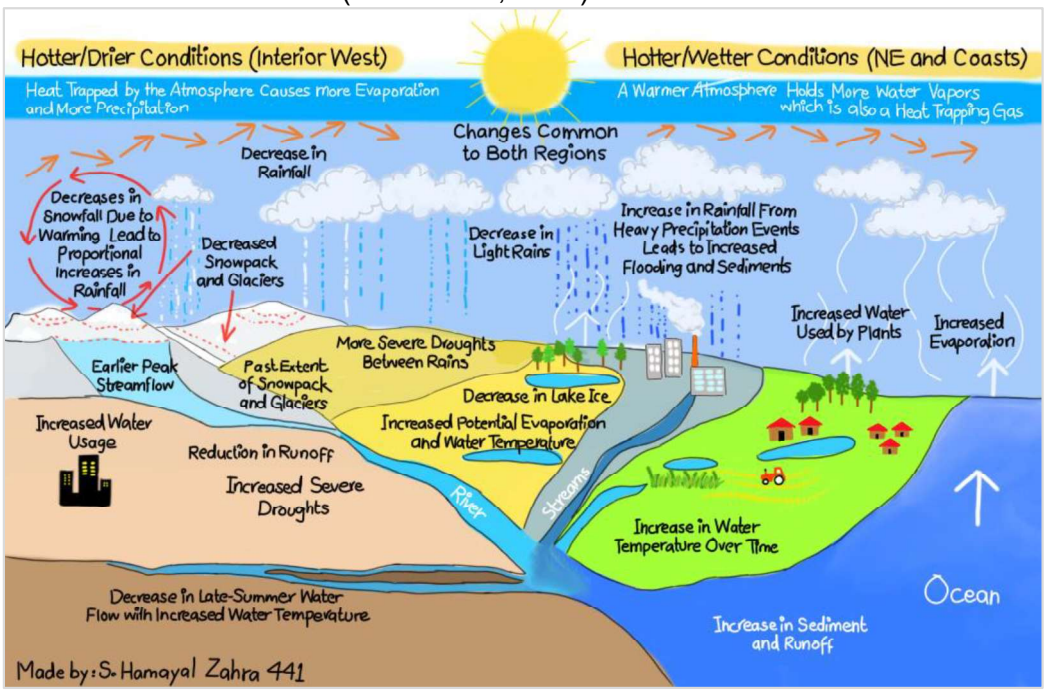


Figure-5: Changes in Water Cycle

3.2. Evaporation: Droughts

Due to hot climate, the rate of evaporation from different water bodies is higher than it used to be before climate change. The capacity of warmer air to carry moisture is more than the cool air. Therefore, due to climate change the air is becoming warmer and is drawing more moisture from oceans, rivers, lakes, plants, and soils resulting into extreme weathers. Due to this change, the interior western areas are facing hotter and drier conditions and undergoing droughts, while the north-eastern and coastal areas are facing hotter and wetter conditions and becoming humid. The droughts have become frequent in different parts of the world. For example, western Canada had faced droughts with duration of 40 years in the last two centuries. Similarly, many regions in Europe, Asia, and Africa are also facing severe drought events (Dai et al, 2018).

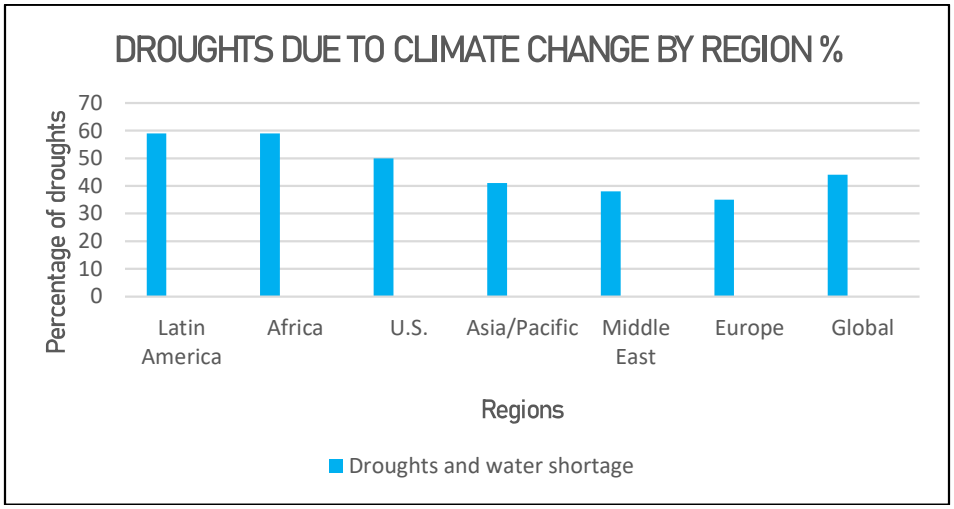


Figure-6: Percentage of Droughts occurring per Region

3.3. Precipitation: Floods

Where the rate of evaporation is high, the rate of precipitation will be higher in the form of heavy rainfalls and snowfalls. Some areas are receiving more than average precipitation annually while some areas are dried. Due to climate unseasonal heavy rainfalls are occurring frequently worldwide and resulting in floods which not only cause thousands of annual deaths but also damages millions and billions of properties. For example, a massive flood in langmoche lake of Nepal killed many people and destroyed billions of assets in 1985 (Nan et al, 2011). The floods due to climate change mostly occurs in Asia by 34 percent annually followed by other continents mentioned in the graph below (Schiermeier et al, 2018).

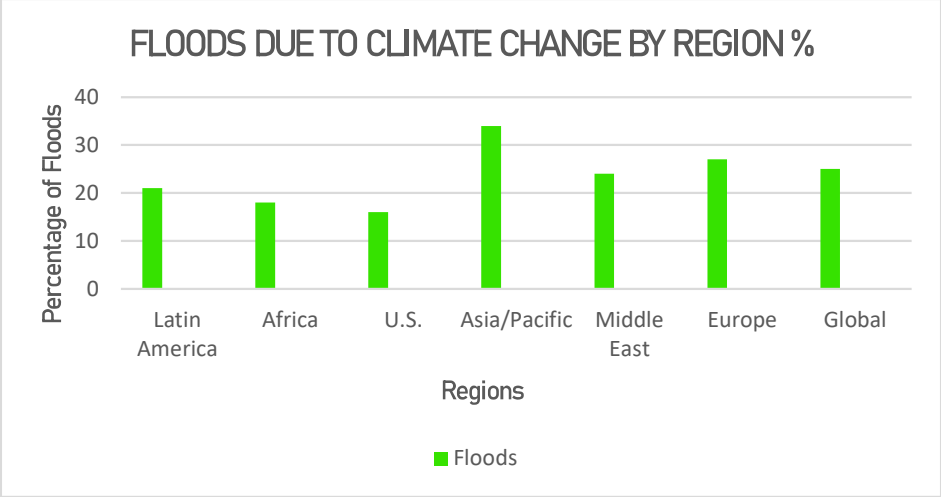


Figure-7: Percentage of Floods occurring per Region

3.4. Surface runoff and infiltration: Groundwater table

Due to change in precipitation pattern, the surface run-off and infiltration of water is drastically altered which also has affected groundwater table. The groundwater table of interior Western parts of the world is decreasing while the water table of coastal and Northeastern areas is increasing resulting in overflowing, salination, and water logging issues (Arnone et al, 2018).

3.5. Glacier and snowpack melting: Sea-level rise

Around the world, there are several river systems that are majorly formed by the melting of glaciers and snowpack but due to rapid melting of ice, the sea-level is rising 0.2-0.4mm every year. Now, due to warmer weather, the snowpack and permafrost melts early before time. The glaciers in the arctic region melted away $540km^2$ in 1998 due to global warming. Greenland ice is also shrinking, and large chunks are sliding near to the sea every passing year. The Alaskan glacier is melting and shrinking in size by $50km^3$ each year. The Gangotri glacier in Himalayas has reduced in size by 1.5km in 69 years. Since, little ice age period, the European alps have lost 35% of its surface area. A massive glacier loss has been observed since 1990 in Asia, Europe, and arctic islands of Canada. 95% of the Arctic ice that was the oldest and thickest will be already gone before 2100 (Nan et al, 2011). The melting of glaciers is also resulting in loss of habitat of species that live in freezing regions such as polar bears and penguins etc. making them endangered. Due to sea-level rise many coastal cities and island are sinking in such as Jakarta, Venice, Hawaii, New York, and San Diego etc. The mostly affected coastal areas that are sinking are the ones in United States as shown in the graph (Golledge, 2020).

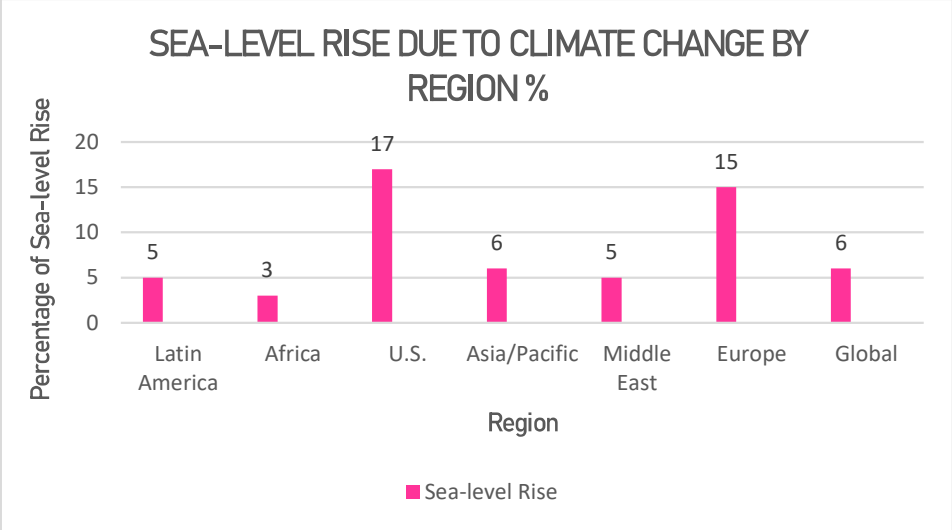


Figure-8: Percentage of implications of sea-level rise occurring per Region

3.6. Saltwater intrusion: Water Insecurity

The freshwater obtained from the glacier melt is now melting on double rates and due to over melting the sea-level is rising continuously resulting into extrusion of saline water in the freshwater reservoirs making it unpalatable for drinking or agricultural use and affecting aquatic life and coastal areas. For example, Karachi being a coastal city of Pakistan, faces constant water shortage because of sea-water intrusion in the groundwater aquifers (Elhamid et al, 2020).

3.7. Water Storage and availability: Water scarcity

Due to floods, droughts, saltwater extrusion and other climate change related-water pollutions, the water availability and supply in in urban, rural, and industrial sectors is badly affected. Also because of floods, massive scale sedimentations have reduced the water storage capacity of reservoirs resulting water storage and supply issue. Due to sedimentation deposits, 1% of the water storage capacity of the world is lost each year. Currently, the percentage of water availability is very unequally distributed in different continents with respect to percentage of population in these continents as mentioned in the table and graph (Zakar et al, 2020).

Table 01: Percentage of Population vs Water Availability per Continent

Continents	Water %age	Population %age
Asia	36	60
Australia	5	1
North America	15	8
South America	26	6
Africa	11	13
Europe	8	13

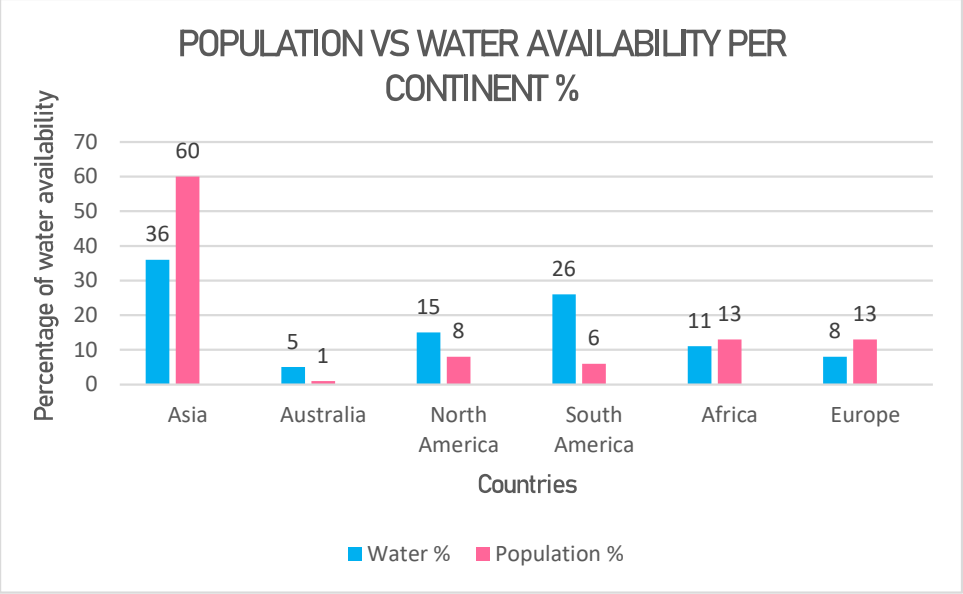


Figure-9: Percentage of Population vs Water Availability per Continent

3.8. Water Quality: Pollution and sanitation issues

Climate change is also degrading quality of water. Despite the usage of persistent organic pollutants (POPs) had banned a century ago but their traces in the air were trapped in the glacier ice and now due to climate change the rapid glacier melt is releasing these POPs in the freshwater streams polluting them. For example, because of glacier melt, a Canadian lake receives glacier melt water which is polluted with 50-97% of the POPs. Water pollution due to algal blooms or eutrophication can also be seen due to warmer temperature of water. Similarly, the warmer temperature of water also gives favorable environment for the growth of deadly pathogens resulting into water-borne diseases such as cholera, and dengue. All these climate change induces water pollution and sanitation issues and gives rise to health risks concerns for aquatic and terrestrial life including human beings (Howard et al, 2016).

3.9. Agricultural setback: Food insecurity

The income of about 40% of the world's population depends upon agriculture but due to severe droughts and heavy precipitations each year millions of acres of crops and cropland are destroyed either because of floods or droughts which cost a loss of billions of dollars and creating food insecurity among increasing populations. About 7-million hectares of agricultural land is ruined each year. For example, the agricultural lands such as the ones in Maharashtra, India lost 30% of the crops due to unseasonal heavy rainfall in October 2018 (Tito et al, 2018).

3.10. Overall water implications due to climate change: In the following table and graph are represented the %age of catastrophes due to different water

resource related disasters due to climate change in different regions of the world such as, Latin America, Africa, U.S., Asia, Middle east, and Europe.

Table 02: Percentage of Different Climate Change impacts occurring per Region

Region	Droughts %age	Floods %age	Sea-Level Rise %age
Latin America	59	21	5
Africa	59	18	3
U.S.	50	16	17
Asia/Pacific	41	34	6
Middle East	38	24	5
Europe	35	27	15
Global	44	25	6

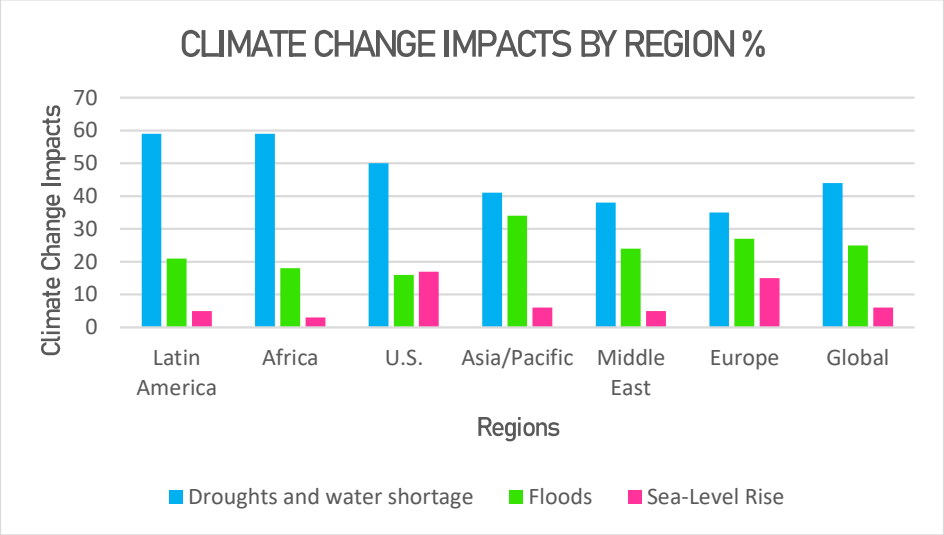


Figure-10: Percentage of Different Climate Change impacts occurring per Region

4. SOLUTIONS: MITIGATION AND ADAPTATION

There can be two type of solutions for the impact of climate change on water resources. These can be either mitigation strategies or adaptation strategies.

As far as mitigation strategies are concerned, the major role can be played by limiting the CO_2 emissions and controlling other greenhouse gases emissions. For that, we need to make new policies and implement earlier policies in line with this issue. For instance, use of clean fuel, increase in vegetative cover, carbon tax and limiting the increase in global temperature.

To add with, the adaptation strategies are the other forms of solution for the impacts of climate change on water resources. It can be achieved by making people more aware of this burning issue and building their capacities to adapt themselves to the changing climatic conditions. Moreover, through changing

lifestyles accordingly, infrastructure development that can contain the effects, education, and awareness and through other multiple steps. The following lines discuss these two different types of solution strategies in detail.

4.1. Improving Natural Infrastructure

Improving natural infrastructure by managing forest and wetlands can be helpful in fighting with the sea level rise, floods, and soil erosion problems powered by the climate change issue. These include growing more and more mangroves along shores to protect them from tornedoes and sea level rise. Another strategy could be, growing more and more inland trees that result in decrease of soil erosion as well as carbon sequestration can be enhanced. These natural techniques act as a buffer against extreme weathers and are more sustainable yet cost-efficient (IUCN, 2018).

4.2. Increase Water Storage Capacity

An adaptive action in this respect can be increasing the water storage capacity in each country through building new dams and maintaining the level of underground water by using techniques like rainwater harvesting and water recharge pits and shafts etc. to absorb runoff water in excess. This will not only store water, but it will also save the major cities and agricultural fields from the disastrous floods and droughts which have become more frequent due to the climate change issue. Moreover, this can play role in mitigation of the causes of climate change by generating clean, renewable energy contrary to the polluting coal powered energy (Fecht, 2019).

4.3. Making Businesses and Agriculture Water Efficient

It is predicted that with climate change getting intensified with each passing year, the world will face water scarcity issues in near future and some part of the world is presently facing this issue. This demands the efficient use of water in agriculture and industrial production where most of the water is used. For example, in Pakistan 94% of water is used in agriculture (Frenken, 2012). Moreover, the industries also use water in an inefficient way and after using it they throw it openly into water reservoirs untreated.

In this context following are some of the solutions

- Products that are water efficient should be designed after their lifecycle analysis for water consumption.
- In agriculture, new seeds should be designed that require less water yet producing more yield.
- The industries must be abiding by law to treat the water to NEQs level before discharging them.
- The channels and water carriage infrastructure should be developed in a way that does not cause loss of water during passage.

4.4. Improvement in the management of waste water

On daily basis millions of liters of water become waste after use. Presently, in many developing countries and even in developed countries there is no proper management of this waste water, which increases burden on the water resources. In some countries it is being managed but the management process has created some problems; the emission of greenhouse gases during the treatment of this waste water accounts for approximately 3% to 8 % of all Green House Gases Emissions.

The emissions are basically the results of the emissions that are emitting from the required energy production and through direct emissions during the biochemical processes of waste treatment during biological microbial activity.one of the most deleterious greenhouse gases, the methane gas, is produced as a direct emission during this process. But this energy that is being utilized is far less than the energy that is saved because of the waste water treatment.

To be innovative, the management of the waste water can be made energy efficient by devising a closed cycle for its whole process. That is to use the methane gas that is the biogas to generate energy for the treatment process of waste water. In this way, the energy required for the process will be produced from within the process and the emissions that the process generates will then be used for energy production which is both clean and sustainable and win, win situation for waste treatment and resource consumption. Those countries which are already practicing this technique are making significant financial savings through this eco designed process. Same should be followed in the developing world as well (UNESCO, 2020).

4.5. Help through Climate Fund

Currently one of the major problems most countries are facing is to design their economies according to the global climatic conditions and following sustainable development goals. The problem they face in this respect is the huge capital investment to direct themselves accordingly. This issue can be sorted out by the help of the green climate fund and other climate funds that the developed world must pay to the developing countries after the Paris Agreement 2016. Through this capital aid the developing world will be able to the adaptation of the impacts of climate change on the water resources as well as they will get help to design their developing infrastructure to mitigate the causes of this burning issue (IUCN, 2018).

4.6. Strengthening and Making Policies on Integrated Water Resource Management

Making policies accordingly can also help in combating the impacts of climate change on water resources. Government should develop policies to apply integrated water resource management to ensure water resource conservation along with socioeconomic development. In this way the government can enforce the people to follow individual steps to minimize their emissions and adapt

themselves to the changing needs of climate change impacts. In other words, we can say that it will be acting locally and thinking globally (IUCN, 2018).



Figure-11: Solutions: Adaptation and Mitigation

5. CONCLUSION

Accessible water resources are already very limited, but the rapid climate change is causing more shrinkage and depletion of water resources by disrupting the natural process of hydrological cycle. And at the same time, the human population is rising at exponential rates which means the demand for water per capita is also increasing. The climate change has created a tension between the availability of water resources and its demand among people resulting in secondary implications such as droughts, floods, famines, casualties, and the list goes on. Because, developing countries are following the footsteps of the developed countries to grow their economies by extensive industrialization and GHG emissions, so it is impossible to cease climate change at present, even today, if the world cut down its GHG emissions, it will still take decades to lower down the pace of climate change and its implications on water resources. Therefore, nations need to think mutually and work coherently on both mitigation and adaptation approach because either single approach is not going to be effective so, mitigation and adaptation towards climate change induced impacts on water resources can collectively help

to conserve water resources and fulfil water demand otherwise, under water stress, nations would collapse.

So, it is concluded that while drafting a strategy regarding the impacts of the climate change on the water resources, it must be kept in mind that the strategies should focus on the two major aspects of mitigation and adaptation.

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