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Review Article

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An Overview of Climate Change Mitigation, Mitigation Strategies, and Technologies to Reduce Atmospheric Greenhouse Gas Concentrations: A Review

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Abstract

Natural and human-induced climate change could have major adverse consequences for the world's ecosystems and societies. It is caused by the emission of greenhouse gases, which trap long wave radiation in the upper atmosphere and thus raise atmospheric temperatures as well as produce other changes in the climate system. In order to minimize these negative impacts, different strategies are suggested, among which the two major ones are adaptation and mitigation. The review was based on secondary data obtained through various sources such as textbooks, journals, conference papers, and published and unpublished materials, with an emphasis on mitigation, which is intended to either reduce the emissions of greenhouse gases from sources that are warming our planet or increase the various ways through which greenhouse gases can be removed from the atmosphere. To this end, concepts of sources and sinks were defined and major sources and sinks with possible ways to decrease emissions from sources and enhance sinks were reviewed. Furthermore, various mitigation technologies were examined sector by sector. Finally, as a case study, climate change mitigation in the energy and agriculture sectors in Ethiopia were also reviewed.

Keywords: Greenhouse Gas; Mitigation; Source; Sink; Emission

1. Introduction

Climate change is emerging as the defining challenge of our time because it brings higher temperatures, sea level increases, more intense rainstorms, droughts, and heat waves [1]. Greenhouse gases generated by human activity, primarily carbon dioxide, as well as methane, ozone, and several others, have risen sharply as the world's population expands, industrialization spreads, and the consumption of resources accelerates [2]. Greenhouse gases and aerosols affect climate by altering incoming solar radiation and outgoing infrared (thermal) radiation that are part of Earth's energy balance. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system [3].

Increasing recognition of the scale of the problems posed by global climate change has led scientists and policymakers alike to consider approaches to mitigate the warming trend. According to [4], to address this issue of highest importance for future generations, several options are available. The first is to reduce drastically the emissions of GHGs at the global scale, which would require rapid changes in mitigation strategies. The second one is adaptation measures that are built by society to limit the physical, economic, and social consequences of climate change.

An anthropogenic intervention known as mitigation aims to lessen greenhouse gas sources or improve sinks [3]. It is intended to reduce the emissions of greenhouse gases that are warming our planet or increase the various ways through which greenhouse gases can be removed from the atmosphere.

The objective of this review paper is to assess an overview of climate change mitigation (sources and sinks of GHGs across major economic sectors), mitigation strategies, and technologies to reduce the concentration of greenhouse gases in the atmosphere, as well as review climate change mitigation in the energy and agriculture sectors in Ethiopia as a case study.

2. Greenhouse Gases

A greenhouse gas (GHG) is any gas in the atmosphere that absorbs and reemits heat, thereby keeping the planet's atmosphere warmer and adversely affecting climate change [5]. According to [6], there are four main greenhouse gases:

- Carbon Dioxide (CO_2)
- Nitrous Oxide (N_2O)
- Methane (CH_4)
- Fluorinated Gases

3. Major Sources of Green House Gas Emissions

Greenhouse gases are introduced to the atmosphere from two main sources, natural and anthropogenic sources [7]. The anthropogenic sources are CO_2 emissions from fossil fuel use, deforestation, and shifting cultivation; CH4 emissions from rice paddy wetlands, ruminants, and fossil fuel; CFCs emissions from solvents, aerosols, and packaging; and N_2O emissions from fossil fuel and agricultural practices.

3.1. Major Greenhouse Gases Atmospheric Concentration

Burning fossil fuels, destroying forests, and other human activities have contributed significantly to the increase in greenhouse gases in the atmosphere since the Industrial Revolution began in the 1700s [8]. Figure 1 displays the atmospheric carbon dioxide concentrations in parts per million (ppm) from hundreds of thousands of years ago to 2015.

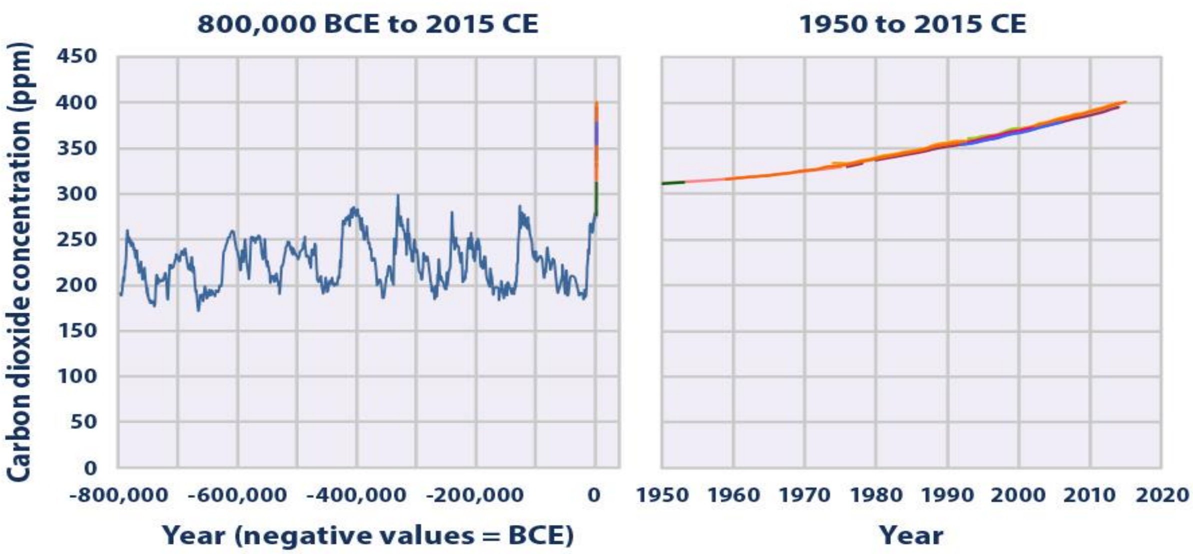

Figure 1: Global Atmospheric Concentrations of Carbon Dioxide over Time Source :[8]

3.2. Earth's Radiative Forcing

Radiative forcing (RF) describes the perturbation of the radiation energy balance of the Earth [9]. It can be interpreted to represent the heating power of the atmosphere's surface system. Positive RFs cause global average surface warming, while negative RFs cause global average surface cooling. The increased amount of greenhouse gases in the atmosphere, which is dependent on GHG emissions and sinks, as well as the reflection of incoming solar radiation, produces RF. Radiative forcing is usually expressed in watts per square meter (W/m2) averaged over a particular period of time, and quantifies the energy imbalance that occurs when the imposed change takes place [3]. It is obvious that the climate systems are warming, and many of the changes that have been seen since the 1950s are unprecedented throughout centuries to millennia. Figures 2 and 3 illustrate how the warming climate has warmed the atmosphere and ocean, reduced the amount of snow and ice, and increased sea level.

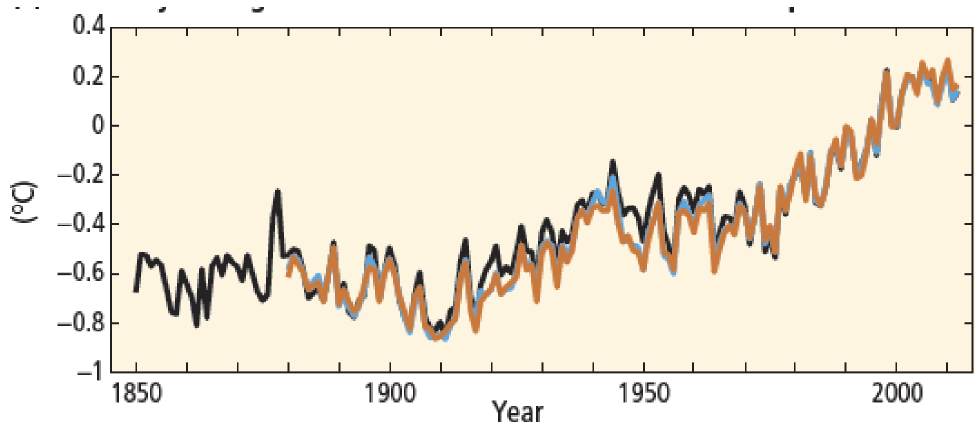

Figure 2: Globally Average Combined Land and Ocean Surface Temperature Anomaly
Source: [9]

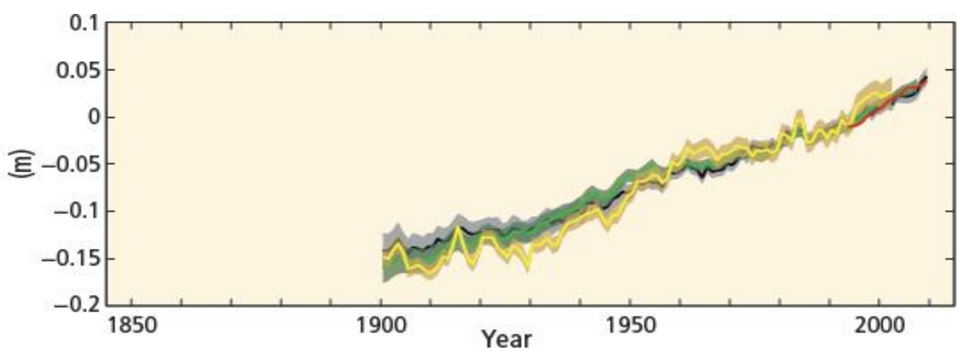

Figure 3: Globally averaged sea level change Source: [9]

3.3. The Global Warming Potential of GHGs

A specific greenhouse gas's global averaged relative radiative forcing effects are meant to be assessed using global warming potentials (GWPs). It is described as the overall radiative forcing, which includes both direct and indirect effects, integrated over time as a result of the emission of a unit mass of gas in comparison to some reference gas [10]. The global warming potential (GWP) is an index with CO_2 having an index value of 1, and the GWP for all other GHGs is the amount of warming they contribute relative to CO_2. For instance, compared to 1 kg of CO_2, 1 kg of methane generates 25 times greater warming over a 100-year period, giving methane a GWP of 25. The potential for global warming of the main greenhouse gases is illustrated in Table 1 below.

	Greenhouse gases	**Global warming potential**
1	Carbon dioxide (CO_2)	1
2	Methane (CH_4)	25
3	Nitrous oxide (N_2O)	298
4	Hydrofluorocarbons (HFCs)	124 – 14,800
5	Perfluorocarbons (PFCs)	7,390 – 12,200
6	Sulfur hexafluoride (SF_6)	22,800
7	Nitrogen trifluoride (NF_3)[3]	17,200

Source: [5]

Table 1: Global Warming Potential of Major Greenhouse Gases

3.4. Global Emissions Sources by Economic Sector

Over the last three decades, all greenhouse gas emissions have increased by an average of 1.6% per year, with CO_2 emissions from fossil fuel use growing at 1.9% per year. The largest growth in greenhouse gas emissions has come from energy supply and industry [3].

4. Greenhouse Gas Effects

The sun's energy interacts with greenhouse gases like carbon dioxide, methane, nitrous oxide, and fluorinated gases in the Earth's atmosphere to produce the greenhouse effect [11]. The sun generates energy at relatively short wavelengths, primarily in the visible or near-visible (e.g., ultraviolet) region of the spectrum, which controls Earth's climate. The amount of solar energy that is directly reflected back into space at the top of the Earth's atmosphere is about one-third. The surface and, to a lesser extent, the atmosphere absorb the remaining two thirds. The Earth must, on average, emit the same amount of energy back into space in order to balance the energy taken from outside sources [3].

5. Sinks of Greenhouse Gases

A GHG sink is a physical unit or process that removes a GHG from the atmosphere [12]. These include biological sinks such as trees in forests, agricultural crops, and other vegetation. Manipulated biological systems, such as agricultural lands, forest tracts, and land converted to other uses, can be sinks as well as sources diffused over very large areas. CO_2 that is removed from the atmosphere by man-made increases in biological sinks (e.g., afforestation, reforestation) is included as a removal in GHG project accounting [13].

6. Mitigation by Sectors

Sectors that have potentially significant emissions of greenhouse gases include: energy, transport, heavy industry, building, agriculture, and forestry. The mitigation option for each sector is discussed below.

6.1. Energy Supply

The GHG emissions in the energy sector (which are largely CO2) come mainly from fuel combustion. According to the [9], there is a multiplicity of options for reducing energy supply-related GHG emissions, including:

- Energy efficiency improvements
- Emission reductions in fuel extraction as well as in energy conversion, transmission, and distribution systems
- Fossil fuel switching
- Low-GHG energy supply technologies such as renewable energy (solar, wind, radiation, tides, waves, and geothermal)
- Carbon dioxide capture and storage (CCS) technologies could reduce the lifecycle GHG emissions of fossil fuel power plants.

6.2. Transport

Light-duty passenger vehicles are the main source of transportation-related GHG emissions in the transportation sector [14]. While the carbon price program increased electricity and biomass fuel usage, it decreased oil consumption. An oil-based transportation strategy would be replaced by electric and biofuel-powered forms of transportation when a carbon tax was implemented. According to [15], there are two fundamental approaches to reducing transport-related GHG emissions:

1. Reduce automobile use by encouraging electric public transit, walking, and cycling;
2. Promote the use of low-emission vehicles, including electric cars, by providing the necessary infrastructure and offering financial incentives to vehicle owners to change behavior.

6.3. Buildings

The heating and hot water systems in residential buildings are mostly to blame for all direct emissions in the household sector. As a result, there have been major fluctuations in the weather, which have an impact on emission trends. These emissions can be lowered by lowering the amount of energy and gas required for building operations. To achieve this, more energy-efficient building structures and/or energy-efficient equipment might be included. By transitioning from the production of high-emitting energy to clean energy, emissions can be reduced.

6.4. Industry

Energy-intensive industrial processes today make about one-third of all energy usage worldwide. Around 70% of this energy is provided by fossil fuels, and industry is responsible for 40% of all global CO_2 emissions [16]. An ongoing and concentrated effort is needed to reduce emissions from industry, including:

- Maximize energy efficiency potential by replacing older, inefficient processes with current, best-available technologies and best-practice technologies.
- Demonstrate and deploy fuel switching to low-carbon energy.
- Accelerate research into industrial CO_2 capture and rapidly demonstrate integrated industrial CO_2 capture and storage (CCS) plants.
- Alter product design and waste protocols to facilitate reuse and recycling in order to close the materials loop.

6.5. Agriculture, Forestry, and Other Land Use (AFOLU)

Agriculture is responsible for 6.8 Gt of CO_2 equivalent (e) annually, or 14% of all GHGs [3]. Land use change, including tropical deforestation, is responsible for about 17% of global GHG emissions. Several mitigation strategies in the agricultural and forestry sectors have been acknowledged as useful in order to stabilize atmospheric CO_2 concentrations between 450 and 550 ppm. Reduced deforestation and degradation of tropical forests (REDD), sustainable forest management (SFM), and afforestation and reforestation (A/R) are a few of these. They include reducing tillage to increase soil carbon storage in agricultural soils, lowering non-CO_2 emissions through better crop and animal management and agroforestry practices, and restoring soil biomass [17].

7. Mitigation Technologies

Climate change mitigation requires steep reductions in greenhouse gas emissions. New sustainable solutions to provide low-carbon energy production will be needed. According to [18], a broad range of GHG mitigation technologies exist, including reduction, sequestration and capture/use.

7.1. Reduction

Reduction options involve avoiding or substituting for GHG-producing activities.

Fuel switching: In the energy sector, switching from high- to low-carbon content fuels can be a relatively cost-effective means to mitigate GHG emissions because it also improves combustion efficiency and reduces quantities of criteria pollutants.

Efficiency improvements (industrial): Changes to conventional combustion technologies have the potential to improve their energy efficiencies. According to [19], efficiencies of 45-55% can be achieved by utilizing unused waste heat for electricity generation.

Transitions to renewable energy: the majority of the energy utilized for power, heating, and transportation comes from non-renewable carbon-based sources. They are therefore the main source of anthropogenic CO_2 emissions to the atmosphere. By substituting renewable energy for the fossil fuel-based energy they currently use, utilities and their customers are increasingly able to cut or completely eliminate GHG emissions.

7.2. Sequestration options

The long-term storage of carbon in soils, oceans, and other "sinks" for carbon is known as sequestration. Forest sequestration, agricultural sequestration, and geological sequestration are the three main types of carbon sequestration programs.

7.3. Capture/use options

Additionally, GHGs can be absorbed or captured, processed, and/or used in some way. This category includes the absorption of CO_2 in biomass that is later used in goods or to replace fossil fuel energy sources, as well as the methane capture from landfills, dairy farms, and wastewater treatment facilities (for flaring or electricity generation).

8. Climate Change Mitigation in The Energy and Agriculture Sectors in Ethiopia – Case Study

Ethiopia's current contribution to the global increase in GHG emissions since the industrial revolution has been practically negligible. Even after years of rapid economic expansion, today's per capita emissions of less than 2 t CO_2e are modest compared with the more than 10 t per capita on average in the EU and more than 20 t per capita in the US and Australia. Overall, Ethiopia's total emissions of around 150 Mt CO_2e represent less than 0.3% of global emissions [20]. More than 85% of GHG emissions in 2010 came from the agricultural and forestry sectors, which produced 150 million tons of CO_2. They are followed by power, transportation, industry, and buildings, which contributed 3% each [20].

8.1. Current Emissions from Energy Supply/ Power, And Agriculture

According to the Climate Analysis Indicators Tool (CAIT) climate data explorer for Ethiopia (http://cait.wri.org/profile/Ethiopia), for the years 1990-2013, latest emission values, excluding land use change and forestry (LUCF), were 123.37 percent with per capita GHG emissions of 1.30 t CO_2 e presenting a 99.26% absolute change from the earliest emission values to the latest value. Total emissions values including LUCF were at 143.01% with per capita emissions of 1.51t CO_2 e and 48.80% as an absolute change from the earliest to the latest value [21]. The highest emission contributions are from agriculture, energy, and LUCF, respectively.

The majority of country emissions are from livestock (42%) and deforestation (37%); therefore, reduction goals are focused on agriculture, forestry, and other land use (AFOLU). According to [22], the largest contributors to future GHG emissions will be agriculture (emissions are expected to reach 70–160 MtCO_2e in 2030) and the industrial sector (50–70 MtCO2e in 2030).

By 2030, when emissions from land use, land use change, and forestry (LULUCF) are anticipated to reach 400 MtCO_2e, Ethiopia plans to reduce emissions by at least 64% below the Ethiopian business as usual (BAU) scenario [20]. Without including LULUCF, the comparable GHG emission reduction target for 2030 is 40% below BAU, or 185 MtCO_2e. Under the framework of Ethiopia's Climate Resilient Green Economy (CRGE) plan, which is integrated in Ethiopia's Second Growth and Transformation Plan, full implementation of the (Intended Nationally Determined Contributions) INDCs is contingent on financing, technology transfer, and capacity building support.

8.1.1. Energy Supply or Power

With hydro power accounting for more than 90% of total power generation capacity and the use of on- and off-grid diesel generators managed by the Ethiopian Electric Power Corporation, the electric power industry only accounts for very low emissions [23]. 3% of the nation's total emissions, or less than 5 Mt CO_2e, are currently produced by the energy sector. The average percentage of GHG emissions from electric power generation in all countries is higher than 25% [20].

8.1.2. Agriculture

GHG emissions in agriculture are mostly caused by animals and crops, respectively. There were more than 50 million cattle and about 100 million other animals throughout the year of strategy planning. Methane emissions from digestion and nitrous oxide emissions from excretions are the main greenhouse gas sources produced by livestock. According to estimates, livestock emissions reached 65 Mt CO_2e in 2010, accounting for more than 40% of all emissions at the time. The usage of fertilizer (10 Mt CO_2e) and the release of N_2O from crop residues that are reintroduced into the ground (3 Mt CO_2e) are the two main ways that crop agriculture adds to the concentration of greenhouse gases [20].

8.2. Nationally Appropriate Mitigation Actions (NAMAs)

In line with commitments within the Copenhagen Accord, the EPA, on behalf of the Federal Democratic Republic of Ethiopia, submitted the country's voluntary, nationally appropriate mitigation actions to the Executive Secretary of the UNFCCC in January 2010. The NAMA contains aspirational targets for actions across sectors to mitigate climate change, which should be afforded financial and technological assistance from industrialized nations under commitments made in the Copenhagen Accord. According to [20], a summary of the NAMA 2010 projects and targets submitted in Ethiopia is as follows:

8.2.1. Electricity generation from renewable energy for the grid system

8.2.1.1. Hydropower

10 hydropower generation facilities to be completed with 5632 MW of electric power generation capacity by 2015

8.2.1.2. Hydro-power project under study

• Hydro electric power generation studies are to be completed with a potential capacity of 8915 MW.

Wind projects

• Seven wind power projects, with a total of 762 MW of electric power generation capacity, are to be completed by 2013.

8.2.1.3. Geothermal projects

• 6 geothermal projects with a total of 450 MW of electric power generation capacity are to be completed in 2018.

8.2.2. Biofuel Development for Road Transport and Household Use

• Produce ethanol
• Produce /biodiesel

8.2.2. Electricity generation from renewable energy for off-grid use and direct use of renewable energy

• Solar home systems
• Small hydroelectric power generation facilities
• Wind pump
• Solar pumps
• House biogas
• Biodiesel stove
• Institutional biogas plant

8.2.4. Agriculture

• Application of compost to agricultural land for increased carbon retention by the soil
• Implementation of agroforestry practices for livelihood improvement and carbon

8.3. Strategy and Goals for a Climate –Resilient Green Economy (CRGE)

Based on the goals established by the late Prime Minister Meles Zenawi, the Ethiopia Climate Resilient Green Economy (CRGE) Strategy was released in 2011. By 2025, Ethiopia is expected to create a green economy that is climate resilient and middle-income. The nation intends to move in a direction that promotes a green economy. The four pillars of the CRGE include infrastructure, agricultural, forestry, electricity, transportation, and industrial sectors. Six government ministries and more than sixty initiatives are to be implemented under the CRGE plan, which takes a sectoral approach. To deliver this over a 20-year period, it will cost an estimated $150 billion in USD. Instead of 400 MtCO2e in 2030 under the "business as usual" (BAU) scenario, the green growth path aims to reduce national greenhouse gas emissions to 150 MtCO_2e [20]. The CRGE, which is acting as a prototype for a national green growth strategy for other nations around the world, has enabled the establishment of national goals, the creation of a special financing facility, a registry, and a monitoring, review, and verification (MRV) system, as well as the identification of sixty sectoral initiatives. The CRGE initiative, which employs a sectoral approach, has so far prioritized and identified more than 60 initiatives that could assist the nation in achieving its development objectives while limiting 2030 GHG emissions to levels similar to 2010, which is about 250 Mt CO_2e less than is anticipated under a conventional development path. The green economy plan is based on four pillars:

1. Improving crop and livestock production practices for higher food security and farmer income while reducing emissions;
2. Protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks;
3. Expanding electricity generation from renewable sources of energy for domestic and regional;
4. Leapfrogging to modern and energy-efficient technologies in transport, industrial sectors, and buildings.

9. A Case Study Project

As a case study, two initiatives from the agriculture and energy industries were chosen.

9.1. Project for the energy sector, according to [23], Summary report on the Adama I wind power project was as follows:

Project's objective:

Through supply of energy play a meaningful role in improving the lives of the rural people and improve the country environment by reducing uses of fossil fuel, fire wood, which results in environmental pollution and deforestation and soil degradation.

Accomplishments

The installation of the 34 sets of Gold Wind GW77/15KW wind power units resulted in a total installed capacity of 51 MW, producing 162.7 GWh annually at full load hours.

Benefits of the project

Environmental benefits

The alarming rates of deforestation in Ethiopia that are contributing to climate change and global warming are partially a result of the need for fuel wood, which lowers the carbon sink, or the amount of carbon dioxide that is stored.

But because of the project, there won't be any fuel wood hunting, which is better for the environment.

Social and health

Use of fuel wood endangers women's and young children's health as they spend several hours a day in smoky cook houses, leading to lung cancer, cataracts, bronchitis, tuberculosis, higher infant mortality rates, and low birth rates. The household has been relieved of the social and health problems caused by using wood as fuel as a result of the project's implementation.

Economic benefits:

In order to give women and children enough time for education and more lucrative occupations, foraging for fuel wood must be a taxing chore. The time spent seeking for fuel wood can be better spent on things that would bring in more money. The project's beneficiaries will earn more money by using the extra time to engage in other income-producing activities.

9.2. Agriculture sector: According to [24], research was conducted in the Gergera area to improve integrated watershed management with climate smart agriculture, yielding the following results:

The project's objectives: to increase climate-smart agriculture's ability to improve ecosystem resilience and food security.

Accomplishments

Major achievements include the planting of fertilizer trees like faidherbia Albida as well as the introduction of high-value trees and crops including legume bushes, fruit trees, fodder, fiber, firewood, and timber trees. Based on the incorporation of agroforestry technologies and rural institutional engagement, the project established an improved model for integrated watershed management. There have been varied benefits for about 456 households. More than 60 hectares of damaged slopes and gullies were improved with valuable tree, shrub, and grass species for both economic and ecological reasons.

A spring with water for drinking (human and cattle), irrigation, and home usage was created below the check dam as a result of the gully's upkeep and repair (Figure 4). A total of 87 landless youngsters are currently using 5.5 ha of productive land that was once part of the valley, while 23.5 ha of agriculture were spared from being submerged by floodwaters. In addition, one Rural Resources Centre (RRC) was established, with ownership transferred to a Gergera Cooperative made up of 15 landless youth, women, and subsistence farmers, to serve as a source of income and employment opportunities for these vulnerable groups while additionally providing the watershed communities with high-quality planting materials and agricultural inputs.

(a) (b)

Figure 4: Gergera area before (a) and after (b) check dam intervention Source: [24].

Benefits of the project

Environmental benefits

The project promoted climate-smart agriculture to achieve environmental sustainability. The CSA focuses its efforts on mitigating and adapting to the effects of climate change. The initiative addressed inadequacies in land management, such as poor use and management of grazing pastures and slope rehabilitation.

Social and health

There have been varied benefits for about 456 households. Rural institutions as well as the backward classes of the community, such as women, the impoverished, and young people, were strengthened. Water was made available for irrigation, home usage, and drinking (by people and animals).

Economic benefits:

Both revenue and food production are rising. One Rural Resources Centre (RRC) was constructed, and ownership was transferred to a Gergera Cooperative of 15 landless women, youth, and subsistence farmers, in order to provide job and income opportunities for these at-risk groups. The RRC also provided the watershed villages with high-quality planting materials and agricultural inputs, as well as technical help.

9.3. Lessons Discovered

The community became interested in environmental management and conservation efforts after learning about their advantages. The following significant lessons have also been discovered from farmers in the Gergera region:

- Consultation with stakeholders is crucial before, during, and after the project.
- The community became more conscious of the damaging effects that using fuel wood had on the environment and their health.
- Within the watershed, a union or cooperative organization strengthens the initiative.

9.4. Challenges

The most difficult challenge during project implementation was convincing the entire community.

10. Conclusion and Recommendations

10.1. Conclusion

A major issue facing the entire world is climate change. Because of human activity, atmospheric concentrations of greenhouse gases (GHG) have dramatically risen from pre-industrial levels. Through the "Greenhouse Effect," emissions of greenhouse gases caused by humans significantly affect Earth's climate. In order to limit long-term climate damage, mitigation activities entail either a direct reduction in anthropogenic emissions or an improvement in carbon sinks.

10.2. Recommendations

• Promote technology transfer so that effective mitigation techniques are disseminated as rapidly as possible.
• Integrated local and regional level climate change mitigation action should be done.
• International and multidisciplinary research programs should be established or enhanced to focus on understanding the possibility of changes resulting in major and rapid increases in atmospheric greenhouse gases.
• Improve each country's or region's knowledge of emissions and sinks of greenhouse gases in order to slow the problem of global warming.
• If governments are to play a leading role in mitigation attempts, then all sectors require tougher regulation and more effective enforcement and inspection.

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