सत्यमेव जयते

Ministry of Housing and Urban Affairs
Government of India

Training Module on

GHG Estimation and Climate Adaptation

Sustainable Cities Integrated Approach Pilot in India

gef

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

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Component 3: Partnerships, Knowledge Management and Capacity Building

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CONTENT
The given module is prepared by compiling information sourced from various knowledge products and training modules prepared by Ministry of Housing and Urban Affairs (MoHUA), National Institute of Urban Affairs (NIUA) and Central Public Health and Environmental Engineering Organization (CPHEEO) for knowledge dissemination and capacity building of municipal officials.

THE FULL MODULE SHOULD BE REFERENCED AS FOLLOWS
NIUA (2022) “Training Module on GHG Estimation and Climate Adaptation”. Text from this report can be quoted provided the source is acknowledged.

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BASIC PROJECT INFORMATION

Project Title	Sustainable Cities Integrated Approach Pilot in India
Project Component	Component 3 - Partnerships, Knowledge management and capacity building
Project Deliverable	Delivery of tailored training and capacity building activities in 5 pilot cities – Bhopal, Guntur, Jaipur, Mysuru and Vijayawada
Project start date	December 2019
Duration of Project	2 Years
About this Module	This module is a part of the second deliverable for the project to provide training modules for three sectors.

ABOUT THE PROJECT

"Sustainable Cities Integrated Approach Pilot in India" is one of the child projects under GEF's Sustainable Cities Programme in the GEF 6 cycle. The aim of the project is to integrate sustainability strategies into urban planning and management to create a favourable environment for investment in infrastructure and service delivery, thus building resilience of pilot cities. The three main project components comprise- Sustainable Urban Planning and Management, Investment Projects and Technology Demonstration and Partnerships and Knowledge Management Platform.

National Institute of Urban Affairs (NIUA) has been engaged to undertake the implementation of Component 3 – Partnerships, Knowledge Management and Capacity Building. As a part of this component of the Project, a Training and Assistance Needs Assessment (TANA) was conducted from February 2020 to August 2020 for the ULBs of five cities - Bhopal, Jaipur, Mysuru, Vijayawada and Guntur to assess and identify the needs of the ULB officials to prepare on-the-job training modules.

ABOUT THE TRAINING MODULE

Based on the results of TANA, training modules on Solid Waste, Wastewater and Water Management have been developed by NIUA. The modules are an outcome of the activity 2 of the project which included the following tasks:

- On the basis of TANA results, training modules were prepared for relevant stakeholders
- For developing the Module & Pedagogy, NIUA has synergized the experience of practitioners and subject experts.
- The modules have been finalized in coordination with experts and officials from cities.

This module on GHG Estimation and Climate Adaptation is a part of the series of modules that would supplement the training activities.

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List of abbreviations and acronyms

ACCCRN	Asian Cities Climate Change Resilient Network
AOB	Ammonia Oxidizing Bacteria
BMC	Bhopal Municipal Corporation
BOD	Biological Oxyegn Demand
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CMWSSB	Chennai Metro Water Supply and Sewerage Board
COD	Chemical Oxygen Demand
EMCP	Enhanced Malaria Control Project
EPR	Extended Producer Responsibility
FAS	Free Air Space
FSSM	Fecal Sludge and Septage Management
GHG	Greenhouse Gas
GWP	Global Warming Potential
IDRC	International Development Research Centre
IPCC	Intergovernmental Panel on Climate Change
IUWM	Integrated Urban Water Management
JDA	Jaipur Development Authority
JJM	Jal Jeevan Mission

JNNURM	Jawaharlal Nehru National Urban Renewal Mission
JSA	Jal Shakti Abhiyan
LCA	Life Cycle Assessment
LULC	Land Use Land Cover
MBT	Mechanical Biological Treatment
MJSA	MukhyaMantri Jal Swavlamban Abhiyaan
MoEFCC	Ministry of Environment and Forests & Climate Change
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
NAFCC	National Adaptation Fund for Climate Change
NAPCC	National Action Plan on Climate Change
NEP	National Environment Policy
NLCP	National Lake Conservation Plan
NOB	Nitrite Oxidizing Bacteria
NPCA	National Plan for Conservation of Aquatic Ecosystems
NRCP	National River Conservation Plan

Chapter
1

Climate Change and Urban Services

Summary

This chapter seeks to introduce the concepts and phenomena related to climate change. From an urban perspective, it is also important to know how the urban services impact and interact with climate and how climate impacts the urban services.

Training Objectives

- To understand the basics of climate change and its impact on water and waste resources
- To identify impact of climate change and its sectoral implications on water and waste sector
- To recognise the risks faced in water and waste management in India.

Training Outcomes

- Able to understand the importance of water and waste management
- Able to understand the importance of conservation of water.
- The important concepts and definitions on climate change
- An understanding of climate change and urban services in India

Chapter Contents

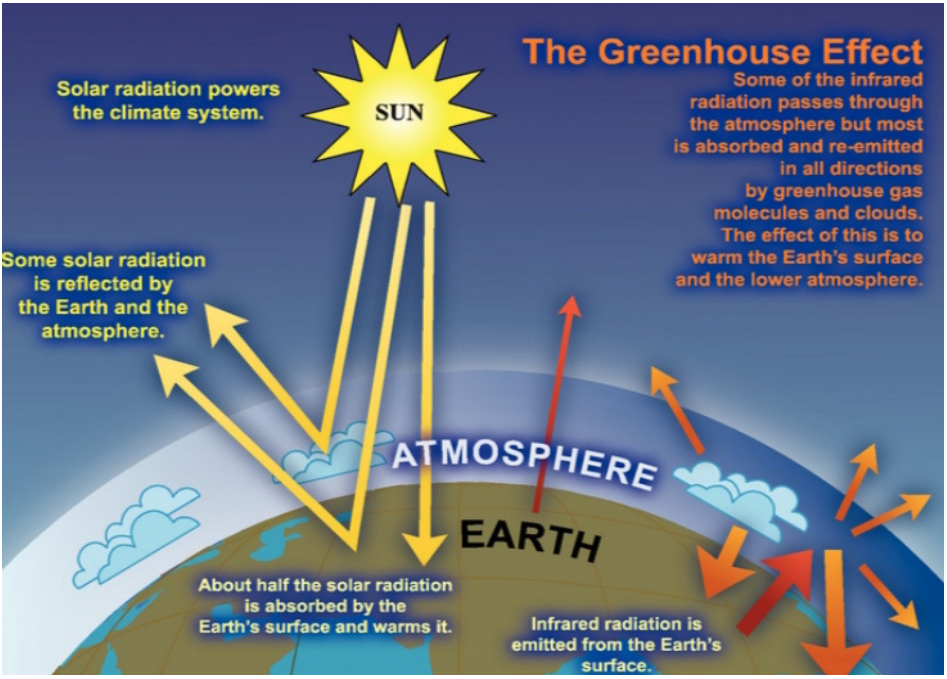
1.1 Introduction

The last sixteen decades have witnessed gradual changes in climate, indicating a trend towards global warming. Several geographical factors such as latitude, distance from the sea, vegetation, topography, etc. cause extensive climate fluctuations from place to place. Climate also varies over time, seasons and year, or over larger scales of times. The Earth has witnessed extreme climate change variations including the ice ages and extreme periods on account of natural factors such as volcanic eruptions, changes in the Earth's orbit, and the amount of energy released from the sun. According to the Intergovernmental Panel on Climate Change (IPCC), anthropogenic (human-induced), climate change or the greenhouse gases (GHGs) emitted from human activities since the Industrial Revolution leading to climate change as observed in the warming of the atmosphere and oceans, melting of glaciers, and rise in sea level has extensive impacts on human and natural systems.

Climate refers to weather averaged over an extended period, typically considered 30-year intervals, the standard averaging period by the World Meteorological Organisation (WMO).

Climate change may be defined as the long-term variation of temperature and weather patterns in a particular location or the earth as a whole.

Figure 1.1: Model of Green House Gas impact



Source – IPCC (2007)

1.2 Why learn about climate change?

Throughout history, people and societies have adjusted to and coped with changes in climate and extremes with varying degrees of success. Climate change (drought in particular) has been at least partly responsible for the rise and fall of civilizations. Earth's climate has been relatively stable for the past 12,000 years and this stability has been crucial for the development of our modern civilization and life as we know it. Modern life is tailored to the stable climate that we have become accustomed to. As our climate changes, we will have to learn to adapt. The faster the climate changes, the harder it could be.

While climate change is a global issue, it is felt on a local scale. Cities and municipalities are therefore at the frontline of adaptation. In the absence of national or international climate policy direction, cities and local communities around the world have been focusing on solving their own climate problems. They are working to build flood defenses, plan for heatwaves and higher temperatures, install water-permeable pavements to better deal with floods and stormwater and improve water storage and use.

Although the major impacts of climate change induced by greenhouse gases include a rise in the number of extreme weather events, famine caused by food supply disruptions, and increased wildfires, there are other impacts caused due to increased waste, which is also gaining attention among scientists. Rapid urbanization, climate change, inadequate maintenance of water and wastewater infrastructures and poor solid waste management lead to flooding, water scarcity, water pollution, adverse health effects and rehabilitation costs that may overwhelm the resilience of cities. These megatrends pose urgent challenges in cities as the cost of inaction is high.

1.3 Concepts and Definitions

This section discusses in brief the concepts and definitions around climate change. These include greenhouse effect, climate change and adaptation.

Greenhouse effect

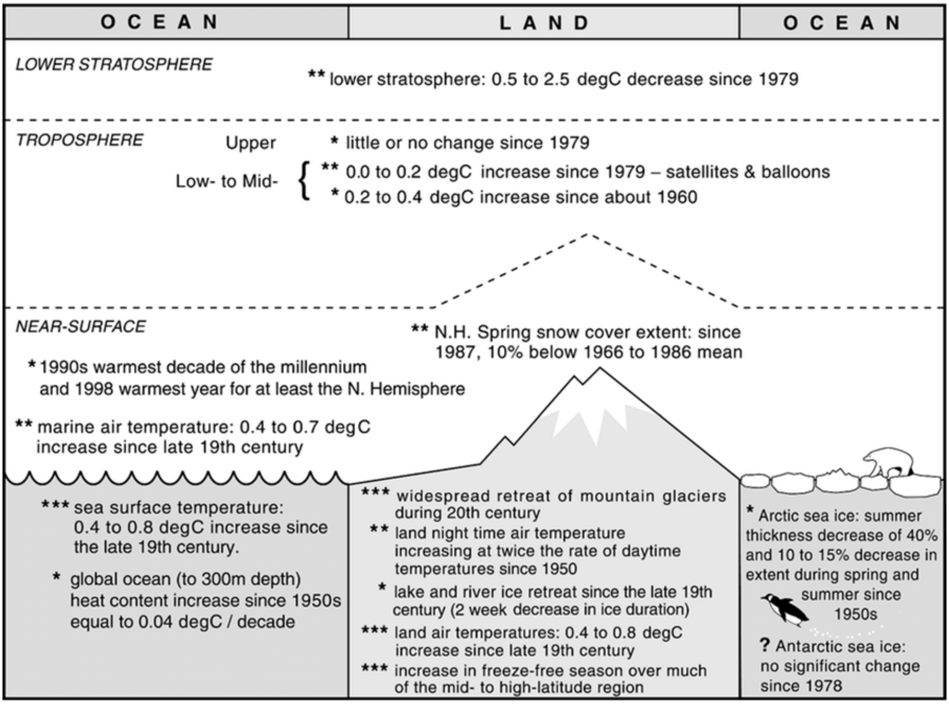
The sun radiates solar energy on the earth, much of it is released back into space, and the rest is absorbed by the surface of the Earth and the atmosphere. The energy received by the earth from the sun is balanced by the flow of energy to space from the earth. This exchange of energy maintains the global mean temperature and any disturbance in the amount of incoming or outgoing energy disrupts the earth's radiative equilibrium; causing global temperatures to rise or fall. The greenhouse effect refers to the increased concentrations of GHGs (mainly carbon dioxide, methane, and nitrous oxide) or the rising levels of GHGs in the atmosphere contributing to global warming or increased temperatures in the earth's atmosphere and at its surface (see Figure 1.1).

The greenhouse effect is intensified when further GHGs (such as CO_2) are added to the atmosphere causing warming of Earth's climate. The greenhouse effect is the main cause of climate change. While many of these GHGs occur naturally, human activities have led to the rise in the concentration of some of these, carbon dioxide (CO_2) being the largest contributor to global warming. Other GHGs are emitted in lesser quantities such as methane, nitrous oxide, fluorinated gases. The recent IPCC report, Sixth Assessment Report (AR6) 2021 underlines the continued increase in GHG concentration in the atmosphere since the fifth assessment report in 2011. According to the report Carbon dioxide (CO_2), has reached annual averages of 410 ppm, 1866 ppb for methane (CH_4), and 332 ppb for nitrous oxide (N^2O) in 2019 (IPCC, 2021). Climate change is also caused by natural factors such as changes in solar radiation or volcanic activity (estimated for plus or minus 0.1°C to total warming between 1890 and 2010). The IPCC AR6 also points out that for every 1000 $GtCO_2$ of cumulative CO_2 emissions is estimated to cause an approximate 0.27°C to 0.63°C increase in global surface temperature.

The new IPCC report is "a code red for humanity"

UN Secretary-General António Guterres

Figure 1.2: Indicators of Climate Change



Source – IPCC (2001)

Source of Greenhouse gases

Globally, greenhouse gas emissions have grown by 50% from 1990 to 2018 (Ge, et al., 2020). While emissions dipped notably in 2016, recent data suggests that carbon dioxide emissions rose each year since then. Globally, the primary sources of greenhouse gas emissions are electricity and heat (31%), agriculture (11%), transportation (15%), forestry (6%) and manufacturing (12%). Energy production of all types accounts for 72% of all emissions. The energy sector includes transportation, electricity and heat, buildings, manufacturing and construction, fugitive emissions and other fuel combustion.

The other top sectors that produce emissions are agriculture, such as livestock and crop cultivation (12%); land use, land-use change and forestry, such as deforestation (6.5%); industrial processes of chemicals, cement and more (5.6%); and waste, including landfills and waste water (3.2%).

Change in Climate

The estimated rise in global average temperature by around 1°C since pre-industrial times[1], is mainly attributed to emissions of GHGs, aerosols, and changes in land use and land cover (LULC) altering the atmospheric composition, and subsequently energy balance of the earth. It is expected to reach 1.5°C between 2030 and 2052 in the current circumstances. Climate change has contributed to a significant increase in weather and climate extremes[2] globally (e.g., heat waves, droughts, heavy precipitation, and severe cyclones), changes in precipitation and wind patterns (including shifts in the global monsoon systems), warming and acidification of the global oceans, melting of sea ice and glaciers, rising sea levels, and changes in land and ocean ecosystems.

[1] This change in climate refers to the human induced changes. For climate change mitigation, these human induced changes are of central focus, while climate change impact studies concern with the total warming (both natural and human induced).

[2] An extreme weather event is defined as an event that is rare (rarer than the 10th or 90th percentile of a probability density function) at a particular place and time of year which may vary from place to place. When a pattern of extreme weather persists for a longer period of time or a season, it may be classified as an extreme climate event (e.g., drought or heavy rainfall over a season) IPCC DDC Glossary (ipcc-data.org).

Figure 1.3: Climate change impacts

Temperature	• Warming above global mean temperature • Each decade warmer than the previous since 1850 • Increased hot extremes • Reduced cold extremes
Precipitation	• Global average precipitation increased since 1950, faster rates since 1980s. • Increased frequency and intensity of heavy precipitation events. • Increasing reduction in snow and ice in Himalayan Glaciers.
Sea level rise	• Global mean sea level increased by 0.2m between 1901 and 2018.
Extreme Events	• More frequent and severe droughts. • Increased rainfall variability related to El Nino. • Increase in extreme rainfall and winds due to tropical cyclones • Intense rainfall events causing landslides & floods. • Inc. incidence of hot waves and rise in temperature.

Source – IPCC (2021)

Mitigation and Adaptation in relation to Climate Change

Climate change response involves two possible approaches: reducing and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere ('mitigation') and/or adapting to the climate change already in the pipeline ('adaptation').

- **Mitigation – reducing climate change** – involves reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing sources of these gases (for example, the burning of fossil fuels for electricity, heat or transport) or enhancing the "sinks" that accumulate and store these gases (such as the oceans, forests and soil). The goal of mitigation is to avoid significant human interference with the climate system, and "stabilize greenhouse gas levels in a timeframe sufficient to allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (IPCC, 2014).
- **Adaptation – adapting to life in a changing climate** – involves adjusting to actual or expected future climate. The goal is to reduce our vulnerability to the harmful effects of climate change (like sea-level encroachment, more intense extreme weather events or food insecurity). It also encompasses making the most of any potential beneficial opportunities associated with climate change (for example, longer growing seasons or increased yields in some regions).

For better understanding, the mitigation strategies currently adopted for various sectors including waste management is provided in the Table 1.1 along with projections for 2030.

Table 1.1: GHG mitigation strategies for various sectors

Sector	Key mitigation technologies and practices currently commercially available	Key mitigation technologies and practices projected to be commercialized before 2030
Energy supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of Carbon Capture and Storage (CCS, e.g. storage of removed CO_2 from natural gas).	CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and solar PV.
Transport	More fuel-efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning.	Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries.
Buildings	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases.	Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar PV integrated in buildings.
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non CO_2 gas emissions; and a wide array of process-specific technologies.	Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture.
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertilizer application techniques to reduce N_20 emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency.	Improvements of crops yields.
Forestry/ forests	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use.	Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing technologies for analysis of vegetation/ soil carbon sequestration potential and mapping land use change.
Waste management	Landfill methane recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimization.	Bio covers and biofilters to optimize CH_4 oxidation.

According to the 2014 report on Climate Change Impacts, Adaptation and Vulnerability from the United Nations Intergovernmental Panel on Climate Change, governments at various levels are also getting better at adaptation. Climate change is starting to be factored into a variety of development plans: how to manage the increasingly extreme disasters we are seeing and their associated risks, how to protect coastlines and deal with sea-level encroachment, how to best manage land and forests, how to deal with and plan for reduced water availability, how to develop resilient crop varieties and how to protect energy and public infrastructure.

Figure 1.4: Global Warming Impacts

With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture.

a) Annual mean temperature change (°C) at 1°C global warming

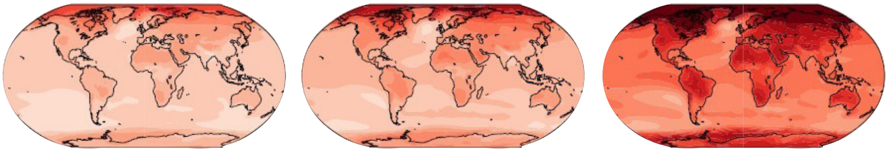
Warming at 1°C affects all continents and is generally larger over land than over the oceans in both observations and models. Across most regions, observed and simluated patterns are consistent.

Observe change per 1°C global warming

Simulated change per 1°C global warming

b) Annual mean temperature change (°C) relative to 1850-1900

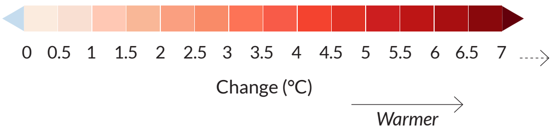
Across warming levels, land areas warm more than oceans, and the Arctic and Antarctica warm more than the tropics.



Simulated change at 1.5° global warming

Simulated changes at 2°C global warming

Simulated changes at 4°C global warming



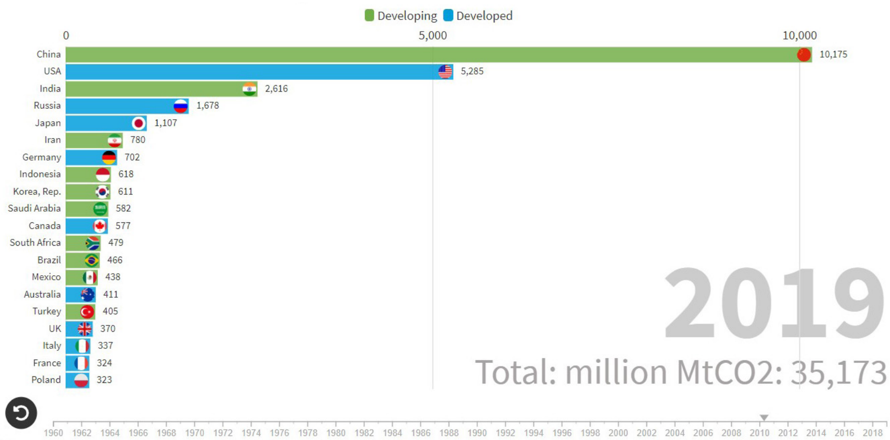
Source – IPCC (2021)

1.4. Current Global Scenario of GHG Emissions

The economic progress achieved in the past six decades, along with a rapid expansion of global population, has come with a colossal environmental cost. While global GDP per capita has nearly tripled since 1960, CO_2 emissions have quadrupled during the same period.

In December 2015, the Paris Agreement was adopted and set a worldwide common goal to limit temperature increase to +2/1.5°C. Today, the world's top three emitters – China, the United States, and India – account for around 50% of global CO_2 emissions, and the world's top 20 emitters account for 80%.[3]

Figure 1.5: Yearly CO_2 emissions in Million $MtCO_2$, 1960-2019



Source – UNCTAD

As per the Paris Agreement, yearly cuts of 8% are required to keep the planet under the global warming threshold of 2 degrees Celsius. As shown in Figure 1.5, the list of top emitters includes both developed and developing countries alike. Therefore, equal efforts from all governments across the globe despite the development divide is the need of the hour to win the battle against climate change.

Efforts are being taken by various countries across the globe to becoming more energy efficient and reduce their yearly CO_2 emission rates. Data from UN climate change news reports that, in developed countries, between the years 1990-2018, there is a reduction in GHG emissions by about 13 %. Developed countries, in the view of future demands, beyond 2020, have set their emission targets and expanded their policies and responsibilities with the focus on increasing the use of renewable energy in electricity production phasing out coal, carbon pricing and electrifying road transport.

[3] *Mott, G., Razo, C. and Hamwey, R., 2021. Carbon emissions anywhere threaten development everywhere. [online] UNCTAD|Prosperity for all. Available at: <https://unctad.org/news/carbon-emissions-anywhere-threaten-development-everywhere>*

Similarly, many developing countries are also taking steps that can significantly help in reducing the greenhouse gas emissions and meet the desired targets. A few countries implement ratio targets, such as China (" lower carbon dioxide emissions per unit of GDP by 60% to 65% from the 2005 level") and India ("reducing the emissions intensity of GDP by 20–25%, over 2005 levels, by 2020").[4]

1.5. Relevance of GHG emission reductions in developing countries

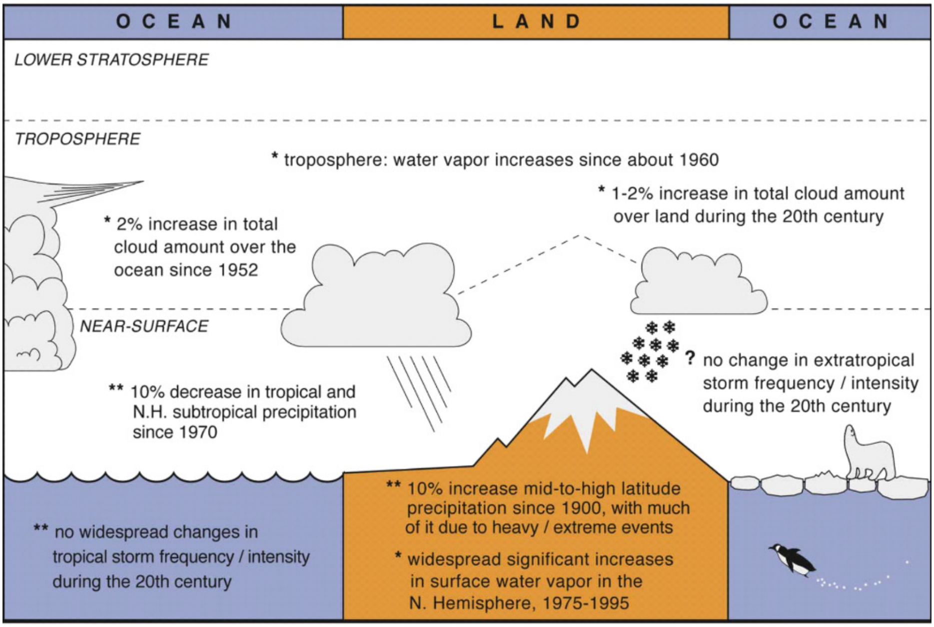
Developing countries and emerging economies would not only considerably reduce their GHG emissions at comparably low costs, but would also significantly contribute to improving public health conditions and environmental protection if they were to put in place sustainable waste management systems. GHG emissions produced by the waste management sector in developing countries and emerging economies are highly relevant, in particular because of the high percentage of biodegradable components contained in the waste streams. Over and above this, stepping up recycling could further reduce emissions, although it must be pointed out that the recyclable components of waste in developing countries and emerging economies are lower than in industrialised countries.

1.6 Impact of Climate Change

According to the IPCC, an increase in temperature will imply large-scale impacts on human life and the environment. The increased mean temperature in most land and ocean regions leading to extreme weather in most inhabited regions, heavy precipitation in several regions, and high probability of drought and precipitation deficits in some regions, rise in sea level to be 0.2 m between 1901-2018 exposing small islands, low-lying coastal areas and deltas to several impacts, including increased saltwater intrusion, flooding, and damage to infrastructure and other adverse impacts on biodiversity and ecosystems which is expected to rise with a sea-level rise at 2°C above pre-industrial levels.

[4]*Enerdata| Intelligence+Consulting. 2021. GHG emissions in developing countries - issues and perspectives for COP-26. [online] Available at: <https://www.enerdata.net/publications/executive-briefing/ghg-emissions-trends-developing-countries-cop26.html>*

Figure 1.6: Hydrological and Storm-related indicators of climate change impacts



Asterisk indicates Confidence Level : (i.e. assessment)

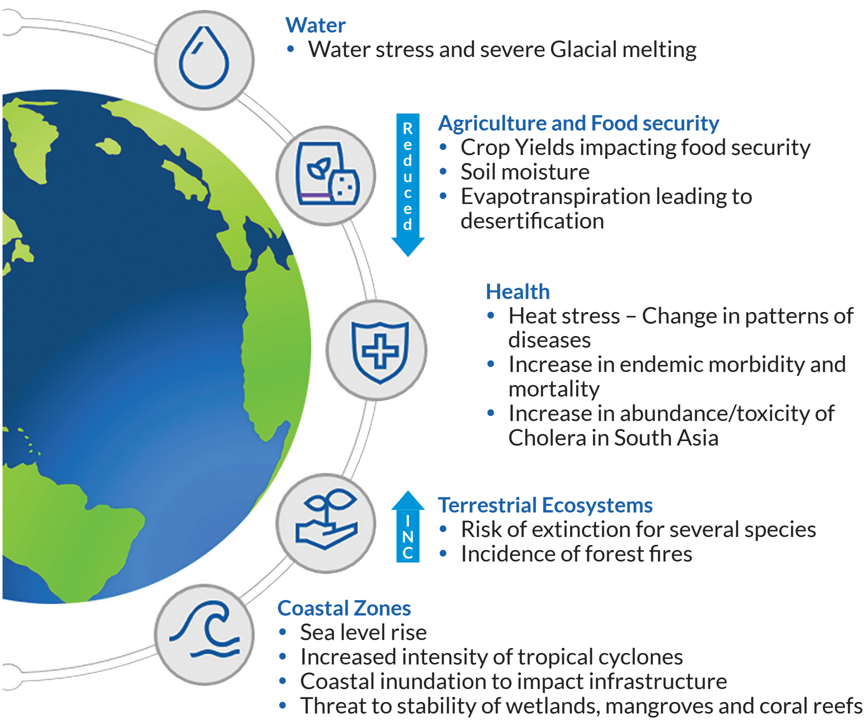
***** Virtually certain (probability > 99%)**
**** Very likely (probability > 90% but ≤ 99%)**
*** Likely (probability > 66% but < 90%**
? Possible (probability > 33% but ≤ 66%)

Source – IPCC (2001)

Changes in Climate and implications

The Global surface temperature is estimated to have increased by 1.09 [0.95 to 1.20] degrees C more in 2011–2020 than 1850–1900. With a 0.5 degree C increase in global temperature, there will be visible impacts on the frequency of hot extremes including heatwaves. Projections indicate a rise by more than 1.5 °C above pre-industrial levels in the next two decades.

Figure 1.7: Sectoral Impacts of Climate Change



Source- Authors

Climate adaptation measures

The earth is undergoing rapid changes as a result of increased human activities. These changes in natural cycles are seen at the global and regional scales, and they impact the urban water cycle and its management. Components of the urban water cycle, like water supply, wastewater treatment, and urban drainage are generally planned for life-spans over several decades. Hence there is a need for us to pay heed to these changes in the context of how these systems will be designed and operated in the 'City of the Future'.

Climate change and variability are affecting water resources and their management in many parts of the country. Water plays an important role in adaptation to climate change, and as such needs to be given central priority in national strategies for sustainable development and pubic security. Severe weather fluctuations, such as frequent and severe storms and hurricanes have an impact on the Sustainable Development Goals (SDGs).

Cities concentrate population, infrastructure, economic activity and wealth, and will therefore be disproportionately affected by the local impacts of climate change. In addition, cities located in coastal areas and/or on the banks of rivers are particularly vulnerable to sea-level rise and flooding. Cities are also characterised by the predominance of impermeable surfaces – which are less capable of absorbing increased rainfall and therefore increase the intensity of rainfall-runoff – and are prone to the urban heat island effect which amplifies heat waves. Unplanned urbanization contributes exceedingly to the derangement of urban environments, especially when it extends over fragile lands.

Overly populated cities are also prone to overuse of their natural resources; the depletion is further intensified by their uneven distribution. Slums, characterised by high density and poor geology often located on the edges of sanitation corridors on untenable land overridden by legal issues, make it difficult for water sanitation and other basic infrastructure servicing. These may form a substantial ecological footprint, with overflowing waste and wastewater in poorly drained settlements further discharged into the ground, polluting groundwater aquifers.

1.7 Waste Management and Climate Change Impact

Every waste management practice generates GHG, both directly (i.e. emissions from the process itself) and indirectly (i.e. through energy consumption). However, the overall climate impact or benefit of the waste management system will depend on net GHGs, accounting for both emissions and indirect, downstream GHG savings. The actual magnitude of these emissions is difficult to determine because of poor data on worldwide waste generation, composition and management and inaccuracies in emissions models. Although currently OECD countries generate the highest levels of methane from landfills, those of developing nations are anticipated to increase significantly as better waste management practices lead to more anaerobic, methane producing conditions in landfills.

Estimates of GHG emissions from waste management practices tend to be based on life-cycle assessment (LCA) methods. These studies have provided extremely useful analyses of the potential climate impacts and benefits of various waste management options. However, due to data availability and resources, LCA studies are primarily focused on scenarios appropriate for developed countries. The climate benefits of waste practices result from avoided landfill emissions, reduced raw material extraction and manufacturing, recovered materials and energy replacing virgin materials and fossil-fuel energy sources, carbon bound in soil through compost application, and carbon storage due to recalcitrant materials in landfills. In particular, there is general global consensus that the climate benefits of waste avoidance and recycling far outweigh the benefits from any waste treatment technology, even where energy is recovered during the process. Although waste prevention is found at the top of the 'waste management hierarchy' it generally receives the least allocation of resources and effort.

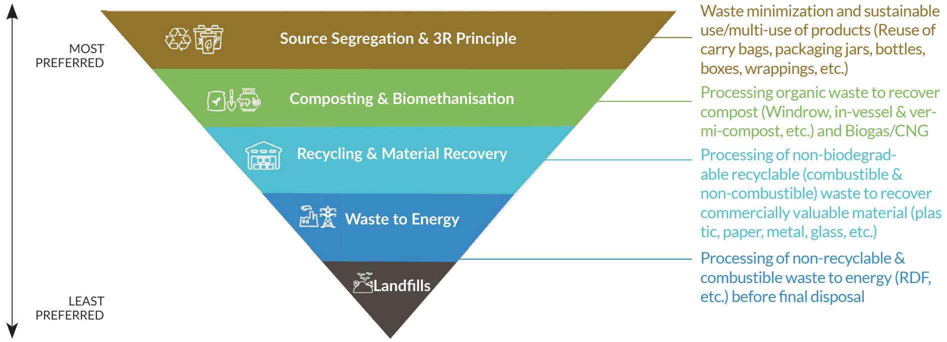
A range of activities focused on waste and climate change are currently being led by international organizations. There is clear recognition of the considerable climate benefit that could be achieved through improved management of wastes. Programmes, such as Integrated Waste Management, Cleaner Production, and Sustainable Consumption and Production could be measures to mitigate climate impact. There is also strong interest in Clean Development Mechanism (CDM) projects in the waste sector. CDM activity has focused mainly on landfill gas capture (where gas is flared or used to generate energy) due to the reduction in methane emissions that can be achieved.

However, there is a lack of a cohesive approach, which has resulted in gaps, duplication, and regional disparity is programmes offered. A central mechanism is needed to collaborate with existing organizations to ensure accessibility to and dissemination of relevant information across the globe, effective use of resources to achieve climate benefit through integrated waste management, promotion of best practice, and rapid transfer of simple, effective, proven technologies and knowledge to developing countries.

Waste management hierarchy promotes the 4R followed by landfill, incineration and controlled dump which favours minimisation of GHG emissions

The climate benefits of waste practices result from avoided landfill emissions, reduced raw material extraction and manufacturing, recovered materials and energy replacing virgin materials and fossil-fuel energy sources, carbon bound in soil through compost application, and carbon storage due to recalcitrant materials in landfills. In particular, there is general global consensus that the climate benefits of waste avoidance and recycling far outweigh the benefits from any waste treatment technology, even where energy is recovered during the process. Although waste prevention is found at the top of the 'waste management hierarchy' it generally receives the least allocation of resources and effort. The informal waste sector makes a significant, but typically ignored, contribution to resource recovery and GHG savings in cities of developing nations.

Figure 1.8: Waste Management hierarchy for minimization of GHG emissions



Source - Authors

Methane emissions from landfill are generally considered to represent the major source of climate impact in the waste sector. Waste contains organic material, such as food, paper, wood, and garden trimmings. Once waste is deposited in a landfill, microbes begin to consume the carbon in organic material, which causes decomposition. Under the anaerobic conditions prevalent in landfills, the microbial communities contain methane-producing bacteria. As the microbes gradually decompose organic matter over time, methane (approximately 50%), carbon dioxide (approximately 50%) and other trace amounts of gaseous compounds (< 1%) are generated and form landfill gas. Methane and carbon dioxide (CO_2) are greenhouse gases (GHG), whose presence in the atmosphere contribute to global warming and climate change. Methane is a particularly potent GHG, and is currently considered to have a global warming potential (GWP) 25 times that of CO_2 when a time horizon of 100 years is considered. Controlled burning, in waste incinerators, also generates CO_2 emissions. Where incinerators generate energy, GHG may also be credited – this is discussed in the following section. Where incinerators do not generate energy, they will be net energy users, which will also contribute to their total GHG emissions. Advanced thermal treatment technologies, such as gasification and pyrolysis, may emit fewer emissions compared to mass-burn incineration. Aerobic composting processes directly emit varying levels of methane and nitrous oxide, depending on how the process is managed in practice. Closed systems, such as enclosed maturation bays or housed windrows, reduce emissions through use of air filters (often bio- filters) to treat air exiting the facility. CO_2 will be gradually released as the compost further degrades and becomes integrated with soil-plant systems.

However, there is a lack of a cohesive approach, which has resulted in gaps, duplication, and regional disparity is programmes offered. A central mechanism is needed to collaborate with existing organizations to ensure accessibility to and dissemination of relevant information across the globe, effective use of resources to achieve climate benefit through integrated waste management, promotion of best practice, and rapid transfer of simple, effective, proven technologies and knowledge to developing countries.

1.8 Climate Change and Water Management in India

For a developing nation like India, with over 1.3 billion population and already existing high levels of social vulnerability and climate variability, climate change is an enormous challenge. The IPCC Special Report on Ocean and Cryosphere in a Changing Climate, calls attention to the warming oceans, shrinking cryosphere, and melting glaciers that directly impact water security in several ways (IPCC, 2019). Climate change impacts hydrological resources and water availability through an increase in the intensity of extreme precipitation events and rises in the intensity of flooding in several areas especially humid regions (Tabari, 2020) increased frequency of droughts, exacerbate the already falling groundwater tables, melting glaciers, sea-level rise impacting water security, human and system health, and other socioeconomic impacts such as migration and conflicts (World Bank, 2019).

The Indian subcontinent is anticipated to have increased precipitation during summer and an increase in extreme weather events including cyclones, floods, and droughts, and induce long-term changes in the mean renewable water supply (IPCC, 2021). The frequency of droughts has increased since the 1960s due to increased monsoon precipitation (Mishra, et al., 2016). The country is already facing several extreme events as recorded in the previous decade, in the form of droughts. The droughts of 2016 covering around 10 states, affected 330 million people with economic losses of $100 billion, and the 2017 droughts that severely impacted several areas of western India (Goyal & Surampalli, 2018) may be less severe than those expected events in the future (Aadhar & Mishra, 2020). Similarly, an increase in floods on account of the three-fold increase in precipitation has been observed in many regions (Ali, et al., 2019), due to high frequency in rainy days and heavy rainfall especially in the peninsular region of India (Guhathakurta, et al., 2011). Several devastating flooding events especially in the last two decades, including the 2005 floods in Mumbai, the 2013 floods in Uttarakhand, the 2015 floods in Chennai, and the 2018 floods in Kerala established the above (Hunt & Menon, 2020). Global warming is also expected to raise the sea level thus altering seawater, the fresh water and groundwater equations and also increasing the frequency of coastal flooding in coastal cities (Vitousek, et al., 2017). Increased frequency of heatwaves, heavy precipitation events, droughts, increase in intense tropical cyclones, sea-level rise, flooding, saltwater intrusion are the major impacts of climate change in urban areas or cities. Also, developing and least developed countries will face disproportionate and severe impacts. Water management and water withdrawals have altered the amount, seasonality, and variability of river discharge, especially in small and human-dominated catchments and also cause droughts in several regions (IPCC, 2021).

> The human induced warming is intensified locally in Cities with increased severity of heatwaves. Urbanization also increases mean and heavy precipitation over and/or downwind of cities and resulting runoff intensity (IPCC, 2021)

Urban areas are to address the issues of water availability (due to reduced ground resources, and increased water demand on account of higher temperatures and rising population) and water quality (on account of increased runoff resulting in erosion and sedimentation and damage to water infrastructure due to flooding). The IPCC AR6 reinforces improved land and water management for reducing climate change and adapting to some of its adverse consequences (IPCC, 2021). The National Action Plan on Climate Change (NAPCC) by the Government of India (GoI), in 2008, commissions the National Water Mission (NWM) for addressing the challenge of climate change in the water sector. With the main goal of ensuring integrated water resource management helping to conserve water, minimizing wastage and ensuring more equitable distribution both across and within states, several initiatives for water supply and demand management and institutional reforms are being led by the NWM including the recent launch of 'Catch the Rain' campaign launched in 2021 for creation of rainwater harvesting structures and improving storage capacities.

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Chapter
2

Estimating GHG Emission for Solid Waste Management

Recap

The previous chapter introduced in brief the concepts related to climate change and the global scenario and relevance of GHG emission. It also dealt with the waste management and water supply sector to understand their impact on climate change.

Training Objectives

- To get an overview of the GHG emissions from waste management activities and their contribution to climate change.
- Understand the GHG estimation model to quantify the GHG emissions from individual treatment technologies.

Training Outcomes

- Develop an understanding of mitigation and adaptation measures and strategies to manage GHG emissions from SWM
- Understanding of available tools to assess savings in GHG emissions from different technologies.
- Acquire knowledge on selection of appropriate technology options based on net GHG calculations.

Chapter Contents

2.1. Introduction (Ahluwalia & Patel, 2018)

Greenhouse gases (GHGs) have been a source of growing concern on account of changing climate patterns and extreme weather events throughout the planet. However, over the last century and a half, human activities have added considerably to GHGs in the atmosphere, and that continues to result in global warming, causing the earth's average temperature to rise and thereby leading to change in climatic patterns. Solid waste sector is a significant contributor of GHG emissions globally. Greenhouse gases are emitted not only while the waste is managed (as during transportation) but also when it is left to decay in dumpsites. A significant amount of embodied emissions is associated with poor waste management, which can be avoided with proper handling, resource recovery and recycling.

The main channels through which solid waste management affects GHG emissions are listed below:

- Consumption without regard for resource conservation creates excess demand for extraction and manufacturing of goods from virgin materials, all of which contributes to greenhouse gas emissions in varying amounts at different stages of production and consumption.
- Mixing wet waste with dry waste at the source of generation results in several negative downstream effects.
- The increased volume of unprocessed mixed waste adds to transport demand which in turn increases fossil fuel consumption for collection and transportation of waste from the source of generation to the landfill sites.
- When the mixed waste is dumped at landfill sites, it releases methane gas that is generated from anaerobic decomposition of biodegradable waste present in the waste.
- Leachate oozing out of decomposing biodegradable matter releases nitrous oxide.
- Any act of burning of waste releases carbon dioxide and other harmful gases

Of all these activities, the International Solid Waste Alliance (2009) estimates that emissions from landfill sites, due to decomposition of biodegradable waste, are the biggest source of GHG emissions from waste sector global

2.1.1. Linkages of Greenhouse Gases and Solid Waste Management

GHGs have been a source of growing concern on account of changing climate patterns and extreme weather events throughout the planet. GHGs create a natural blanket around the Earth's atmosphere by preventing some of the sun's heat energy from radiating back into space, thus keeping the earth warm. However, over the last century and a half, human activities have added considerably to GHGs in the atmosphere, and that continues to result in global warming, causing the earth's average temperature to rise and thereby leading to change in climatic patterns.

Solid waste sector is a significant contributor of GHG emissions globally. The InterGovernmental Panel on Climate Change (IPCC) estimated that post-consumer waste accounted for up to 5 per cent of the total global GHG emissions in 2005 (IPCC 2007). Greenhouse gases are emitted not only while the waste is managed (as during transportation) but also when it is left to decay in dumpsites. A significant amount of embodied emissions is associated with poor waste management, which can be avoided with proper handling, resource recovery and recycling. Waste minimisation at source in all sectors of an economy has considerable downstream GHG reduction potential. GHG emissions from solid waste disposal on land as reported to UNFCCC by India in 2015- 16 increased at the rate of 3.1 per cent per annum between 2000 and 2010.

Waste management activities generate carbon dioxide (CO_2, ~ 50 per cent), methane (CH4, ~ 50 per cent) and nitrous oxide (N_2O, < 1 per cent) gas, among others. As per IPCC (2007), the global warming potential of methane and nitrous oxide are 25 times and 298 times higher than that of carbon dioxide over a 100-year period. However, in the short run, i.e. a 20-year horizon, the same gases are 72 times and 289 times stronger than carbon dioxide in global warming potential, respectively. Clearly, the choice of time horizon can have a profound effect on the estimate of climate impact of emissions. (Fuglestveldt et al 2001).

Waste prevention and recycling are real ways to help to mitigate climate change. The greenhouse gases emissions from solid waste and landfill activities have a significant contribution in climate change. The main source of manmade methane gas is from landfills. Due to aerobic and anaerobic degradation, greenhouse gases like methane, carbon dioxide, and nitrogen dioxide are produced from the landfill, which contributes directly to global warming. Methane, also popular as a potent greenhouse gas that is 28 times potent than carbon dioxide, which can trap heat in the atmosphere.

Waste prevention and recycling-jointly referred to as waste reduction-help us better manage the solid waste we generate. But preventing waste and recycling also are potent strategies for reducing greenhouse gases. Together they:

- Reduce emissions from energy consumption. Recycling saves energy. That's because making goods from recycled materials typically requires less energy than making goods from virgin materials. And waste prevention is even more effective. Less energy is needed to extract, transport, and process raw materials and to manufacture products when people reuse things or when products are made with less material. The payoff? When energy demand decreases, fewer fossil fuels are burned and less carbon dioxide is emitted to the atmosphere.

- Reduce emissions from incinerators. Diverting certain materials from incinerators through waste prevention and recycling reduces greenhouse gas emissions to the atmosphere.
- Reduce methane emissions from landfills. Waste prevention and recycling (including composting) divert organic wastes from landfills, reducing the methane released when these materials decompose.
- Increase storage of carbon in trees. Forests take large amounts of carbon dioxide out of the atmosphere and store it in wood, in a process called carbon sequestration. Waste prevention and recycling of paper products can leave more trees standing in the forest, continuing to absorb carbon dioxide from the atmosphere.

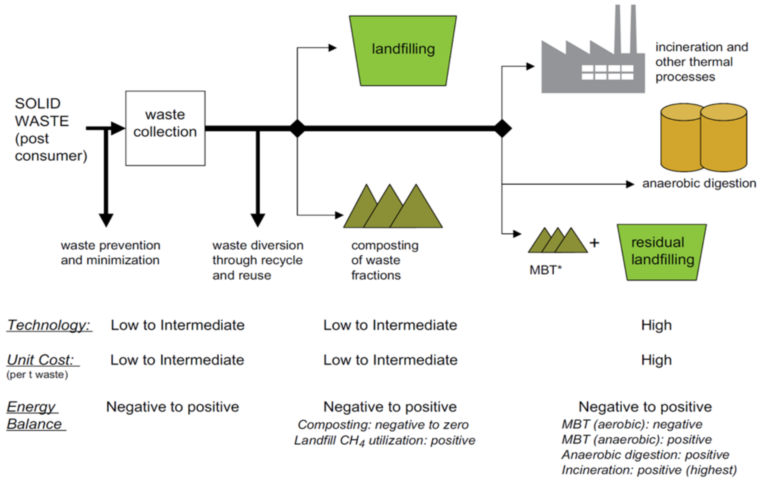
These changes present complex challenges to the waste management industry that must be addressed and planned for. For example, one challenge is an increasing frequency of large-scale weather events and natural disasters, which are creating more debris that must be managed and which affects the characteristics of landfilled waste. Landfill design needs to incorporate precipitation changes and increased threats due to weather variability, flooding, and sea-level rise. Precipitation changes affect gas generation rates and require a diligent reaction to maintain effective gas collection. Because of weather pattern changes, risks of cover material erosion and swales have increased for landfills in both wet and dry climates, which may require stronger natural caps or the use of emerging technologies for alternate cover. Additionally, landfills are affected by an increase in the variability of precipitation and rapid changes between weather extremes.

It is clear that waste management facilities must adapt to these changes in addition to scenario building for pandemics to maintain effective operations. Adaptations available include making changes to landfill design and planning, such as incorporating precipitation changes into the modeling of leachate and gas generation or increasing the distance between the bottom liner and groundwater. Systems should be regularly evaluated and areas needing repairs should be corrected quickly and diligently. Gas generation models should be updated regularly and collection systems need to be expanded or adjusted to account for precipitation increases or decreases.

More frequent and intense storms are creating challenges for cover material management, liquids management, and maintaining slope stability. Facilities should implement innovative uses of both existing technology and new or emerging technologies. Communities with waste management facilities should include waste management infrastructure in emergency management plans, including maintaining landfills and collections operations and using landfills as both temporary debris storage and as an option for final disposal.

Since climate change effects vary by region and locale, many facilities are developing a specific plan for adaptation and management. To reduce the inevitable costs of adaptation and maintain responsiveness to weather changes, a reactive approach is being abandoned in favor of a proactive approach. The below figure 2.1 shows the Technology gradient for waste management with technology complexity (low to high), unit cost (low to high) and energy balance(negative to positive). For example: the 'high technology' end, there are also advanced thermal processes for waste such as pyrolysis and gasification which is more complex than low to intermediate technologies. Here, MBT is Mechanical Biological Treatment and Technology means complexity of technology is classified has low to high

Figure 2.1: Technology gradient for waste management



Source – IPCC, (2007)

2.2 GHG emissions in relation to SWM processes/ technologies

For the majority of waste management scenarios, the climate impact is considered from the point of waste generation to the point of material reuse, recovery, and final disposal. In the case of recycling and waste prevention, a climate benefit is examined in terms of avoided primary manufacture of materials. The climate impact of the production of a marketable product from recovered materials, and the replacement of raw materials with recovered product, is included.

The focus is primarily on the climate impacts of direct and indirect emissions from waste treatment, recovery, and disposal processes. Climate change impacts of waste management require discussion of upstream, direct, and downstream GHG contributions. Upstream contributions are from inputs of energy and necessary materials; direct emissions are from system operations; and downstream contributions and savings relate to energy and material substitution and carbon storage.

Brief description of SWM technologies

To understand the GHG emissions of various SWM processes, it is paramount to have an idea of the technologies perse. Below is a brief description of each technology/ process in SWM. The available waste processing technologies are broadly classified into three categories.

- Disposal of waste
- Biological treatment
- Thermal treatment

These processes can be classified into three groups based on the technique adopted – Disposal techniques, Aerobic and Anaerobic decomposition of waste, Thermal decomposition. The disposal of waste is the most basic form which involves only containment. Sanitary landfills are examples of this process. Decomposing the solid waste can be undertaken using two methods – Aerobic and Anaerobic. The process of decomposing the waste in the presence of air is called Aerobic process. Composting and Mechanical Biological Recovery of waste are examples of this process. Anaerobic decomposition of waste is in the absence of air and Biogas and biomethanation are examples of these processes. Thermal decomposition is destruction of waste using by burning. Incineration technology is an example of this process.

In biological process, the biodegradable organic portion of waste is broken down into gaseous products (CO_2, Methane gas etc.) and water molecules leaving behind carbon rich byproduct called compost. CO_2 emissions coming from biological process are not considered to contribute to global warming since this carbon has a biogenic origin, i.e. this carbon has been previously fixed biologically. Although generated in small amounts, N_2O and CH_4 have a great contribution to global warming since they have a warming potential 28 (CH_4) and 265 (N_2O) times higher than that of CO_2. Biological processes can be further divided into two categories-

- Aerobic treatment (in presence of Oxygen)
- Anaerobic treatment (absence of Oxygen)

Thermal process is applied to destroy the harmful potential of wastes together with energy recovery. In this process, the waste components are incinerated in controlled oxygen supply so that maximum heat energy can be recovered without causing the air pollution. During incineration, the waste undergoes chemical changes to release gaseous byproduct, water vapour along with heat energy. The heat energy can be utilized for generating electricity through boiler. The efficiency of heat recovery depends upon the calorific value of incinerated waste.

The different types of waste management processes/technology and its GHG linkages is elicited in the table below:

Table 2.1: Comparison of Solid Waste Technologies

Parameters	Sanitary landfill	Composting	Anaerobic digestion (Biogas plants/ bio-methanation plants)	Thermal treatment / Incineration
Basic Process	Disposal	Biological treatment	Biological treatment	Thermal treatment
Ideal Types of Waste	Municipal solid waste, construction and demolition waste, wastewater sludge, non-hazardous industrial wastes	Food waste (including wastes from households, restaurants and markets), fats/oils/ grease, paper and cardboard, landscaping and garden waste (e.g. hedge-clippings, leaves)	Food waste (including wastes from households, restaurants and markets), fats/oils/ grease, slaughterhouse waste (depending local regulations), and garden waste	Mixed municipal solid waste, medical waste, demolition wood, auto shredder residue, dried sewage sludge, and some industrial solid wastes
Greenhouse Gas Emissions	Significant; can be captured by landfill gas recovery	Reduced	Significant; captured and used to generate energy	Considered renewable & biogenic origin is usually in the range of 33-50 percent which is considered as 40-60% climate neutral
Primary output	Landfill gas (where recovered), leachate	Compost	Methane, digestate	Ash and emission of flue gas (particulate matter, heavy metals, dioxins, sulfur dioxide and hydrochloric acid
Secondary output	Electricity and/or heat (where landfill gas is recovered)	--	Electricity and/or heat; liquid or solid fertilizer	Heat and sometimes electricity

Parameters	Sanitary landfill	Composting	Anaerobic digestion (Biogas plants/ bio-methanation plants)	Thermal treatment / Incineration
Types of GHG emissions	Typically, Landfill gas is composed of about 50% methane, 45% carbon dioxide, and 5% other gases including hydrogen sulfides and volatile organic compounds	Microbial activities of anaerobic and aerobic conditions during composting process leads to the production of CO_2, CH_4, N_2O and NH_3, with the CO_2 and CH_4 production given by insufficient O_2 and N_2O depending on the temperature and nitrate content and aeration rate. A waste pile being composted, that is managed to ensure rapid decomposition and low odors will have low GHG. Values from the literature suggest that maximum emissions from piles would be 2.5 percent of the initial Carbon and 1.5 percent of the initial Nitrogen to volatilize as CH_4 and N_2O. If a pile contains 75 percent organic matter on a dry weight basis with a C:N ratio of 30:1, this would translate to about one ton of Carbon evolving as methane for each 100 dry tons. That same pile would have 0.02 tons of Nitrogen that would evolve as N_2O. It should be noted that these are conservative estimates and actual GHG release can easily be an order of magnitude lower. (West Coast Conference, n.d.)	Biogas consists of 60%-70% methane, 30%-40% carbon dioxide and trace amounts of other gases (eg. Hydrogen sulfide, ammonia, hydrogen, nitrogen gas, carbon monoxide ((University of North Texas Libraries Government Documents Department, 2011)	Climate relevant gases emitted from incineration are mainly CO_2 (carbon dioxide) as well as N_2O (nitrous oxide), NOx (oxides of nitrogen) NH_3 (ammonia) and organic C, measured as total carbon. CH_4 (methane) is not generated in waste incineration during normal operation. It only arises in particular, exceptional, cases and to a small extent (from waste remaining in the waste bunker), so that in quantitative terms CH_4 is not to be regarded as climate-relevant for incineration. CO_2 constitutes the chief climate-relevant emission of waste incineration and is considerably higher, by not less than 10, than the other emissions. The incineration of 1 Mg of municipal waste in MSW incinerators is associated with the production/release of about 0.7 to 1.2 Mg of carbon dioxide (CO_2 output). The proportion of carbon of biogenic origin is usually in the range of 33 to 50 percent. The climate-relevant CO_2 emissions from waste incineration are determined by the proportion of waste whose carbon compounds are assumed to be of fossil origin. The allocation to fossil or biogenic carbon has a crucial influence on the calculated amounts of climate-relevant CO_2 emissions. (IPCC, n.d.)

Parameters	Sanitary landfill	Composting	Anaerobic digestion (Biogas plants/ bio-methanation plants)	Thermal treatment / Incineration
Energy conversion efficiency (kWh/ tonne of municipal solid waste)	65 (landfill gas)	--	165 - 245	500 - 600
Capital costs (US$/ annual tonne)	5 - 52 (US$/tonne over lifetime)	30-400	220-660	190-1000
Operating costs (US$/tonne)	7 – 30 (but can be as high as 120)	12-100	22-57	12-55
Carbon Finance potential	Yes (where landfill gas is recovered)	Yes	Yes (where biogas is recovered)	Yes (where energy is recovered)
CDM (Carbon finance methodology)	AMS-III.G.	AMS-III.F. AMS-III.AF.	AMS-III.A.O.	AMS-III.E.
Mass Reduction of Waste (%)	--	50%	50%	80-85%
Land Requirement (m^2/tonne)	Generally large	0.065 – 10.8	1.61 – 6.45	Much smaller than that for landfill but ash must be disposed
Operational complexity	Requires specialized training, careful maintenance, and post-closure care	Proper training required	Proper training required	Technically complex, requires highly skilled training and careful maintenance
Average Range of Waste Throughput (tonnes/day)	50-10,000	2.5 - 300	0.5 - 500	5 – 1000 (common range is 200 – 700)

Source - Authors

2.3 Available estimation methods for calculating GHG emissions in SWM technologies

Greenhouse Gases and Global Warming Potential - Two characteristics of atmospheric gases determine the strength of their greenhouse effect. The first is their ability to absorb energy and radiate it (their "radiative efficiency"). The second is the atmospheric lifetime, which measures how long the gas stays in the atmosphere before natural processes (e.g., chemical reactions) remove it. These characteristics are incorporated in the Global Warming Potential (GWP), a measure of the radiative effect (i.e. the strength of their greenhouse effect) of each unit of gas (by weight) over a specified period of time, expressed relative to the radiative effect of carbon dioxide (CO_2). This is often calculated over 100 years, though it can be done for any time period. Gases with high GWPs will warm the Earth more than an equal amount of CO_2 over the same time period. A gas with a long lifetime, but relatively low radiative efficiency, may end up exerting more warming influence than a gas that leaves the atmosphere faster than the time window of interest but has a comparatively high radiative efficiency, and this would be reflected in a higher GWP.

The table 2.2 presents atmospheric lifetime and GWP values for major greenhouse gases from the Fifth IPCC Assessment Report (AR5) released in 2014. These values are periodically updated by the scientific community as new research refines estimates of radiative properties and atmospheric removal mechanisms (sinks) for each gas. Despite carbon dioxide's comparatively low GWP among major greenhouse gases, the large human-caused increase in its atmospheric concentration has caused the majority of global warming. Likewise, methane is responsible for a large portion of recent warming despite having a GWP much lower than several other greenhouse gases because emissions have increased drastically.

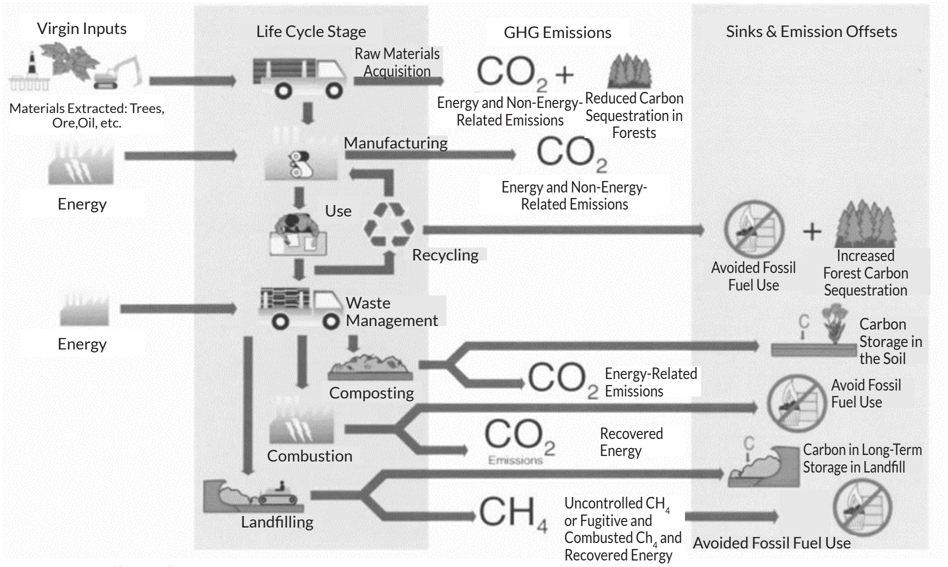
Table 2.2: Global Warming Potential and Atmospheric Lifetime for major Greenhouse Gases

Greenhouse gas	Chemical formula	Global Warming Potential, 100-year time horizon	Atmospheric Lifetime (years)
Carbon Dioxide	CO_2	1	100*
Methane	CH_4	28	12
Nitrous Oxide	N_2O	265	121
Chlorofluorocarbon-12 (CFC-12)	CCl_2F_2	10,200	100
Hydrofluorocarbon-23 (HFC-23)	CHF_3	12,400	222
Sulfur Hexafluoride	SF_6	23,500	3,200
Nitrogen Trifluoride	NF_3	16,100	500

** No single lifetime can be given for carbon dioxide because it moves throughout the earth system at differing rates. Some carbon dioxide will be absorbed very quickly, while some will remain in the atmosphere for thousands of years.*

Source – IPCC (2014)

Figure 2.2: Material-Energy life cycle flows with associated GHG sources and sinks



Source – EPA, (2002)

Organic biomass decomposes anaerobically in a sanitary landfill. Landfill gas, a by-product of the anaerobic decomposition is composed of methane (typically about 50%) with the balance being carbon dioxide and other gases. Methane, which has a Global Warming Potential 21 times greater than carbon dioxide, is the second most common greenhouse gas after carbon dioxide.

Greenhouse gas emissions from waste management can readily be reduced. Within the European Union, the rate of GHG emissions from waste has declined from 69 mtCO2e per year to 32 million tCO2e per year from 1990 to 2007 (ISWA, 2009).

Methodology for estimating the GHG emissions of an area (city, state or country)

The calculation method used in the SWM-GHG estimation spreadsheet (provided as annex to this document, as an excel spread sheet), follows the Life Cycle Assessment (LCA) method. Different waste management strategies/processes/technologies can be compared by calculating the GHG emissions of the different processes adopted, treatment and recycling (typically glass, paper and cardboard, plastics, metals, organic waste) and disposed of waste fractions over their whole life cycle – from "cradle to grave", adopted in a given area/place like a city, town or state/country. The spreadsheet sums up the emissions of all residual waste or recycling streams respectively and calculates the total GHG emissions of all process stages in CO_2 equivalents. The emissions calculated also include all future emissions caused by a given quantity of treated waste, including transportation of that particular waste from its generation point until its final destination. This means that when waste is sent to landfill, for example, the calculated GHG emissions, given in tonne CO_2 equivalents per tonne waste, include the cumulated emissions this waste amount will generate during its degradation. This method corresponds to the “Tier 1” approach described in IPCC (1996, 2006).

How to use the GHG emission calculation spreadsheet

The spreadsheet has certain ‘fixed values’ (these are universal values used for GHG calculations), ‘indicative values’ (fields marked in orange colour), which can be changed if exact values for the place is available and the ‘Input values’ (fields marked in green colour, which needs to be filled based on the best data and latest information available or derived from laboratory analysis.

The spreadsheet calculates the GHG emissions and provides a report with charts to understand the good practices or bad practices adopted by the given city/town and so on, vis-à-vis the GHG emissions.

Calculation method

The GHG emissions are calculated based on the net emissions from:

- **Processing of waste** - technologies and techniques for processing SW (like composting, incineration, bio gas, bio-methanation, recycling etc.,). This also includes avoided emissions due to recycling of the products, vis-à-vis the emissions caused if virgin material was to be used to make the product. This avoided cost also includes the Life Cycle Emissions for making the product pre-waste scenario. Hence, GHG emissions for processing of waste includes ‘Pre’ and ‘Post’ Waste processing emissions. The processing waste also includes the additives used which may sometimes lead to GHG emissions – like chemicals used.
- **Transportation of waste** – to and fro from the point of generation of the waste, to the waste processing facility and to the final consumption or disposal of the processed waste.
- **Energy consumption (Electricity and fuel**) – The energy consumption of waste treatment/processing facility is also considered for the calculations. This energy could be in the form of electricity consumption for processing or fuel used.

Each type of waste (like plastics, metal, organic matter, glass, paper, textiles) have available GHG constants which are suggested values. In case of non-availability of specific GHG emission values, these constants could be used. These suggested values are already provided in the spreadsheet.

An emission for any waste stream is thus calculated as follows:

Table 2.3: Emission Calculation

GHG emission of Plastic (or any other type of waste) for a given city	=	Self emission from processing	+	Transportation	+	Use of additives	+	Energy consumption	-	Avoided emissions if any
GHG emissions in CO_2 Equivalent		(Suggested value of GHG emission factor in CO_2 Equivalent X Quantity of Plastic waste)		(Suggested value of GHG emission factor in CO_2 Equivalent X distance travelled in Kms)		(very negligible for most of the technologies currently available)		(Suggested value of GHG emission factor in CO_2 Equivalent X Electricity consumption for the particular technology used)		(Suggested value of GHG emission factor in CO_2 Equivalent for the particular product manufacturing)

IPCC (2006)

Example of a case study of Bangalore City:

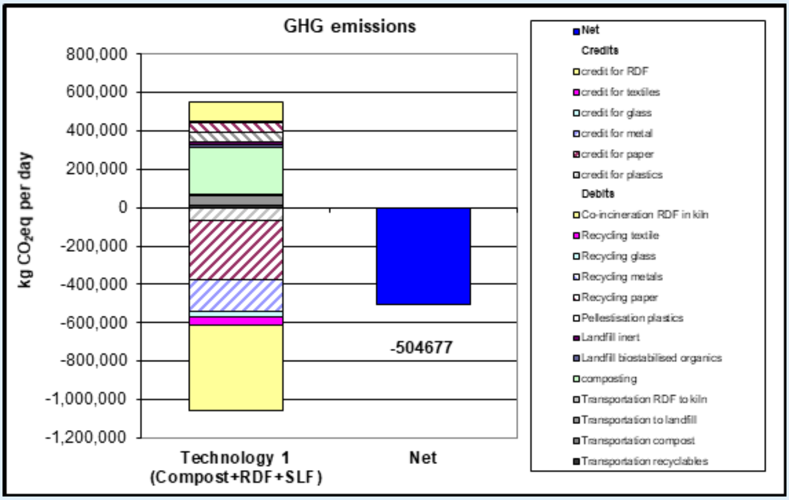
The GHG emissions of Bangalore City based on the SWM practices currently adopted is given below to understand how to use the GHG spreadsheet. Input values used are for 5000 tonnes per day of SWM.

Input values used for the GHG Computation

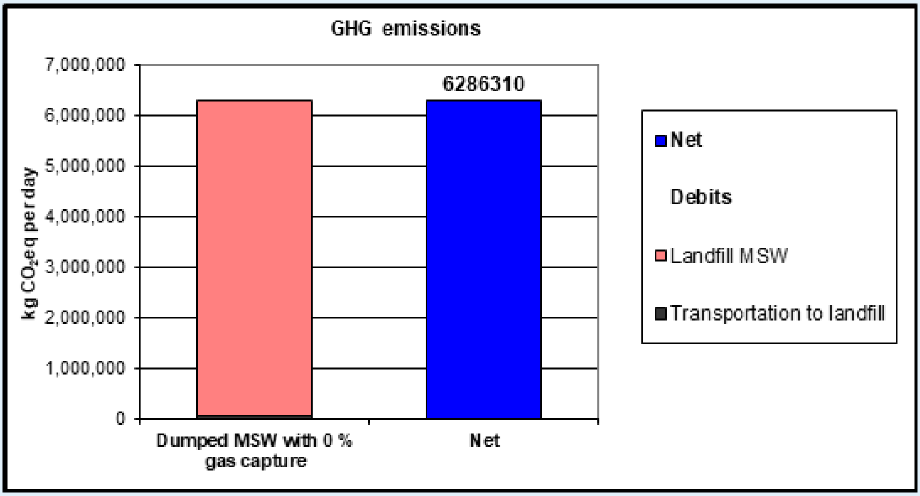
MSW generated	5000 TPD Actual %
Biodegradables (Wet Waste) TPD Recyclables	40%
-Paper TPD	8%
-Plastic /Rubber TPD	8%
-Metal TPD	2%
-Glass TPD	2%
-Rags/ Textiles TPD	3%
-Others	17%
Sub total Recyclables TPD	40%

Scenario 1: The city uses composting, RDF and SLF technologies to process its SW

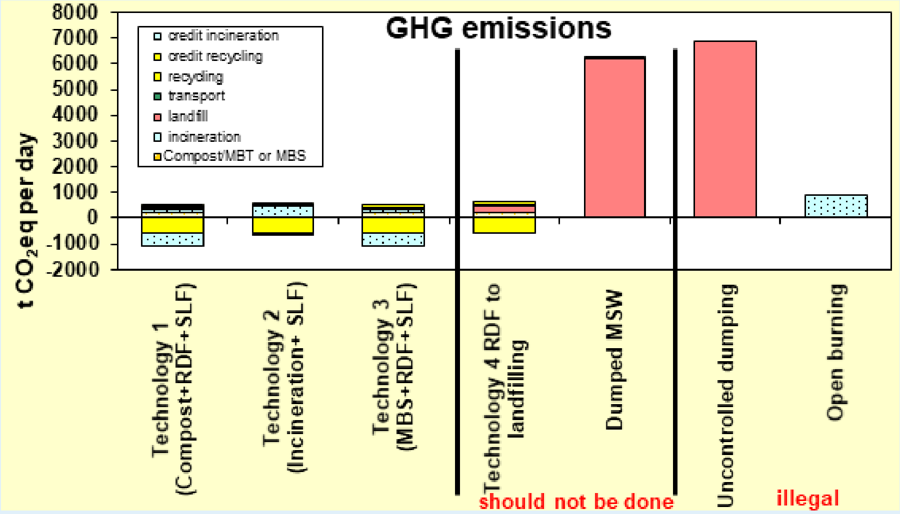
Overall GHG emissions in Kg CO_2 equivalent per day for the city of Bangalore is found to be negative. The technologies of composting, RDF and Sanitary Landfill processess used currently helps the city to mitigate GHG effectively.



Scenario 2: The city does not process its wastes and dumps it into landfills without capturing methane gas. Such a scenario, the GHG emissions will be positive, which means the city contributes to faster climate change impacts.



Scenario 3: The scenario of utilising various technologies to treat waste is applied to the city of Bangalore. The corresponding GHG emission scenario is given in the chart below:



Estimating the GHG emissions for Waste Transportation

MSW transportation consumed a significant amount of fossil fuel and led to GHG emissions due to fossil-fuel combustion. Two major types of fossil fuel are used for waste transportation in developing Asia, namely diesel and natural gas

Total GHG emissions from combustion of any kind of fossil fuel during waste transportation can be calculated as follows:

$$\text{EmissionsT} = \frac{\text{Fuel(units)}}{\text{Waste(tonnes)}} \times \text{Energy} \left(\frac{\text{MJ}}{\text{unit}}\right) \times \text{EF} \left(\frac{\text{kfCO}_2}{\text{MJ}}\right)$$

- EmissionsT – Emissions from transportation (kg CO_2/tonne of waste transported)
- Fuel (units) – Total amount of fossil fuel consumption per month, (diesel in Liters and Natural gas in kg)
- Waste (tonnes) – Total amount of waste transported per month
- Energy (MJ/unit) – Energy content of the fossil fuel (e.g. Diesel 36.42 MJ/L, Natural gas 37.92 MJ/kg)
- EF – CO_2 emission factor of the fuel (e.g. diesel: 0.074 kg CO_2/MJ, Natural gas: 0.056 kg CO_2/MJ)

Estimation of GHG emissions from landfilling

The amount of methane generated at the disposal sites would depend on many factors such as quantity and composition of waste, moisture content, pH, and waste management practices. In general, methane production increases with higher organic content and higher moisture content in the disposal sites.

The following mathematical formula has been used in IPCC model to quantify GHG emissions from the landfilling or open dumping. The IPCC Guidelines (pp 6.10-6.11, Reference Manual) present the FOD method in three equations. The first equation is to be used for an individual landfill, or possibly a group of specific landfills. A second equation, suitable for national and regional estimates, calculates emissions from all solid waste deposited in SWDS in one year. The purpose of the third equation is to estimate current annual emissions from waste disposal in current and previous years

EQUATION - 1

$$CH_4 \text{ generated in year t (Gg/yr)} = \sum_x [(A \bullet k \bullet MSW_T(x) \bullet MSW_F(x) \bullet L_0(x)) \bullet e^{-k(t-x)}]$$

for x = initial year to t

Where:

- t = year of inventory
- x = years for which input data should be added

- A = (1 – e–k) / k ; normalisation factor which corrects the summation k = Methane generation rate constant (1/yr)
- MSWT (x) = Total municipal solid waste (MSW) generated in year x (Gg/yr) MSWF (x) = Fraction of MSW disposed at SWDS in year x
- L0 (x) = Methane generation potential [MCF (x) • DOC (x) • DOCF • F • 16 / 12 (Gg CH4/Gg waste)]
- MCF (x) = Methane correction factor in year x (fraction)
- DOC (x) = Degradable organic carbon (DOC) in year x (fraction) (Gg C/Gg waste) DOCF = Fraction of DOC dissimilated
- F = Fraction by volume of CH_4 in landfill gas 16 / 12 = Conversion from C to CH_4

Sum the obtained results for all years (x).

EQUATION -2

$$CH_4 \text{ emitted in year t (Gg/yr)} = [CH_4 \text{ generated in year t} - R(t)] \bullet (1 - OX)$$

Where:

- R(t) = Recovered CH_4 in inventory year t (Gg/yr) OX = Oxidation factor (fraction)

Note that CH_4 recovered (R(t)) must be subtracted from the amount generated before applying the oxidation factor, because only landfill gas that is not captured is subject to oxidation in the upper layer of the landfill. In addition, the unit for the methane generation potential should be expressed by weight (Gg CH_4/Gg waste) and not volume (m3/Mg waste) as currently written in the IPCC Guidelines in order to make the outcome of the default and FOD methods consistent.

EQUATION - 3

$$CH_4 \text{ emissions (Gg/yr)} = [(MSW_T \bullet MSW_F \bullet L_0) - R] \bullet (1 - OX)$$

Where:

- MSWT = Total MSW generated (Gg/yr)
- MSWF = Fraction of MSW disposed at SWDS
- L0 = Methane generation potential [MCF • DOC • DOCF • F • 16/12 (Gg CH_4/Gg waste)]
- MCF = Methane correction factor (fraction)
- DOC = Degradable organic carbon [fraction (Gg C/Gg MSW)]
- DOCF = Fraction DOC dissimilated
- F = Fraction by volume of CH_4 in landfill gas
- R = Recovered CH_4 (Gg/yr)
- OX = Oxidation factor (fraction)

Note that all of the model parameters can change over time, depending upon waste disposal trends and waste management practices. Good practice is described below for each of the above model parameters

Estimation of GHG Emissions from Composting

As far as GHG emissions from organic waste degradation are concerned, composting is an aerobic degradation process whereby a large fraction of the degradable organic carbon in the waste material is converted into CO_2. Such CO_2 emissions have biogenic origin and would not be taken into account for GHG calculation. CH_4 can be formed due to anaerobic degradation of waste in deep layers of composting piles. However, such CH_4 is oxidised to a large extent in the aerobic sections of the compost piles. Composting can also produce emissions of N_2O in minor concentrations.

As CH_4 and N_2O emissions from fossil fuel combustion assumed to be negligible, and thus it was not included in this equation.

$$\text{Emissions}_{\text{Operation}} = \frac{\text{Fuel(units)}}{\text{Waste(tonnes)}} \times \text{Energy}\left(\frac{\text{MJ}}{\text{unit}}\right) \times \text{EF}\left(\frac{\text{kfCO}_2}{\text{MJ}}\right)$$

- Emissions $_{\text{operation}}$ – Emissions from Operational activities (kg CO_2/tonne of waste transported)
- Fuel (L) – Total amount of fossil fuel consumption per month
- Waste (tonnes) – Total amount of organic waste utilisation per month
- Energy (MJ/unit) – Energy content of the fossil fuel (e.g. Diesel 36.42 MJ/L)
- EF – CO_2 Emission Factor of the fuel (e.g. diesel: 0.074 kg CO_2/MJ)

GHG emission from waste degradation is calculated as follows:

$$\text{Emission}_{\text{Degradation}} = ECH_4 \times GWP_{CH_4} \times E_{N_2O} \times GWP_{N_2O}$$

Where:

- Emissions $_{\text{Degradation}}$ – Emissions from organic waste degradation (kg CO_2/tonne of organic waste) E_{CH_4}- Emissions of CH_4 during organic waste degradation (kg of CH_4/tonne of waste); in this model, the default value of 0.4 (average value given by IPCC (IPCC, 2006)) is used. This value should be changed if the site specific data is obtained.
- GWP_{CH_4} - Global warming potential of CH_4 (21 kg CO_2/kg of CH_4)[2]
- E_{N_2O} - Emissions of N_2O during waste degradation (kg of N_2O/tonne of waste); in this model, the default value of 0.3 (average value given by IPCC (IPCC, 2006)) is used. This value should be changed if the site specific data is obtained.
- GWP_{N_2O}- Global warming potential of N_2O (310 kg CO_2/kg of N_2O)[2]

Total GHG emissions from composting is calculated by adding GHG emissions from operation and waste degradation

$$\text{Total GHG emissions from composting} = \text{Emissions}_{\text{Operation}} + \text{Emission}_{\text{Degradation}}$$

Estimation of GHG Emissions from Anaerobic Digestion

Among the biological treatment methods, anaerobic digestion would be the most cost-effective, due to the potential of high-energy recovery linked to the process and its limited environmental impact.

- $Emissions_{Operation} = (FC \times NCV_{FF} \times EF_{CO_2}) \times (EC \times EF_{el})$
- $Emissions_{Operation}$ – Emissions from operational activities (kg CO_2/tonne of organic waste)
- FC - Fuel consumption apportioned to the activity type (mass or volume/tonne of organic waste) NCV_{FF} - Net calorific value of the fossil fuel consumed (MJ/unit mass or volume)
- EF_{CO_2} - Emission factor of CO_2 by combustion of fossil fuel (kg of CO_2/MJ)
- EC - Electricity consumption for operation activities (MWh/tonne of organic waste)
- EF_{el} - Emission factor of country grid electricity production (kg CO_2-eq/MWh)
- GHG emissions (mainly CH_4) due leakages from the anaerobic digestion system can be calculated as follows:
- $Emissions_{Treatment} = E_{CH4} \times DM \times 1000 \times GWP_{CH4}$
- $Emissions_{Treatment}$ – Emissions from treatment of organic waste (kg CO_2/tonne of organic waste)
- E_{CH_4} – Emissions of CH_4 due to leakages (kg of CH_4/kg of dry matter)
- DM – Dry matter percentage in the influent (%) (DM =100 - % of water in the influent) 1000 – Conversion factor to calculate dry matter content per tonne of organic waste GWPCH4 – Global warming potential of CH_4 (21 kg CO_2/kg of CH_4)

Total GHG emissions from anaerobic digestion can be calculated by adding GHG emissions from operational activities and GHG emissions due to leakages.

$$\text{Total GHG emissions} = Emissions_{Operation} + Emissions_{Treatment}$$

Estimation of GHG Emissions from Incineration

The application of waste-to-energy technologies which are well-designed to suit the local situation would significantly contribute to GHG mitigation and energy recovery. All in all low efficiencies of incineration may result higher GHG emissions from overall combustion process. Incineration process is releasing a significant amount of CO_2 into the atmosphere and thus makes a real contribution to the greenhouse effect. However, as recommended in the IPCC guidelines, only the climate-relevant CO_2 emissions from the combustion of fossil based waste are considered for GHG emissions estimation (IPCC, 2006).

GHG emissions due to utilization of fossil fuel and grid electricity for plant operation can be quantified as explained in the following formula.

$$Emissions_{Operation} = (FC \times NCV_{FF} \times EFCO_2) \times (EC \times EF_{el})$$

- Emissions $_{Operation}$ – Emissions from operation (kg CO_2/tonne of combustibles)
- FC – Fuel consumption for on-site activities (mass or volume/tonne of combustibles)
- NCV_{FF} –Net calorific value of the fossil fuel consumed (MJ/unit mass or volume) EF_{CO2} – Emission factor of CO_2 by combustion of fossil fuel (kg of CO_2/MJ)
- EC – Electricity consumption for on-site activities (MWh/tonne of combustibles) EFel – Emission factor of country grid electricity production (kg CO_2-eq/MWh)
- IPCC recommended Tier 2 approach was adapted (IPCC, 2006) in this simulation to quantify the fossil CO_2 emissions from combustion of one tonne of wet MSW.
- CE = $(SW_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times 44/12$
- CE - Combustion Emissions kg CO_2/tonne of waste)
- SWi-total amount of solid waste of type i (wet weight) incinerated (kg/tonne of waste) dmi - dry matter content in the waste (partially wet weight) incinerated
- CFi -fraction of carbon in the dry matter (total carbon content), (fraction; 0.0-1.0) FCFi - fraction of fossil carbon in the total carbon, (fraction; 0.0-1.0)
- OFi - oxidation factor, (fraction; 0.0 – 100%) 44/12 - conversion factor from C to CO_2
- i - type of fossil based waste incinerated such as textiles, rubber and leather, plastics

When waste is incinerated, most of the carbon in the combustion product oxidises to CO_2. However, a minor fraction may oxidise incompletely due to the inefficiencies in the combustion process, which leave some of the carbon unburned or partly oxidised. However, for waste incineration, it was assumed that the combustion efficiencies are close to 100 percent so that OFi can be assumed as 1.

Once the quantification was done for CO_2 emissions from the above phases, life cycle GHG emissions from incineration can be calculated as follows;

- Total GHG emissions from incineration (kg of CO_2-eq/tonne) = OE + CE TE – Operation emissions (kg CO_2-eq/tonne of combustibles)
- CE – Combustion Emissions (kg CO_2-eq/tonne of combustibles)

2.4 Strategies to manage GHG emissions from SWM – Mitigation and Adaptation measures

Greenhouse gas mitigation opportunities- Efforts to reduce emissions from the municipal solid waste sector include generating less waste, improving the efficiency of waste collection, expanding recycling, methane avoidance (aerobic composting, anaerobic digestion with combustion of produced methane and capture, treatment and use of landfill gas). Energy generated from methane combustion can displace other fossil fuels either as a process energy resource or as electricity. Suitable technology options by waste management component are provided in Table 2.3 below.

Table 2.3: Technical GHG Mitigation Opportunities by Waste Management component

Waste Management Component	Technology Options
Waste Reduction	Design of longer-lasting and reusable products; reduced consumption.
Waste Collection	Use of alternative, non-fossil fuels (bio-fuel, etc.)
Recycling/ Material Recovery	Materials recovery facility (MRF) to process source separated materials or mixed waste, although source separated is the preferred option as the materials would have less contamination from other discards. MRFs use a combination of manual and mechanical sorting options. waste pickers could be used as a source of labor for manual sorting stages
Composting/Anaerobic Digestion	Institute composting programs ideally with source separated organics. As with recyclables source separated materials reduce the contamination associated with recovery from mixed waste. Compost the organic material after digestion to produce a useful soil conditioner and avoid landfill disposal. Finished compost applied to soils is also an important method to reduce GHG emissions by reducing nitrogen requirements and associated GHG emissions.
Incineration/Waste-to-energy/ Refused derived fuel (RDF)	Use the combustible fraction of waste as a fuel either in a dedicated combustion facility (incineration) with or without energy recovery or as RDF in a solid fuel boiler.
Landfill	Capture the methane generated in disposal sites and flare or use as a renewable energy resource.

Policy Recommendations for reducing GHG Emissions

Governments have a range of policy options to encourage waste management practices that will reduce greenhouse gas emissions. Practical approaches that could be applied in most cities include:

Public education to inform people about their options to reduce waste generation and increase recycling and composting. Pricing mechanisms, such as product charges can stimulate consumer behavior to reduce waste generation and increase recycling. A product charge is a cost assessment added to the price of a product and is tied to the cost of the desired waste management system. Consumers would pay for the waste management service when they buy the product. The fees collected would be directed to municipalities relative to the waste generated. An example of this economic mechanism is an excise tax on tires assessed by most states in the US. Product charges are a policy mechanism often better implemented by regional or national governments.

Another pricing mechanism well suited to urban areas is user charges tied to quantity of waste disposed. Consumers who separate recyclables pay a lower fee for waste disposal. This pricing policy can work well in locations where waste collection is from individual households so that waste quantities for disposal can be readily monitored. However, it may not be practical in many areas in developing countries, particularly in those where there are communal collection points associated with multi-unit households (such as apartment user charges tied to quantity or volume).

Preferential procurement policies and pricing to stimulate demand for products made with recycled post-consumer waste. Use of compost in public parks and other property owned by cities.

GHG Mitigation Opportunities from Waste Management activities Technology Options

- **Waste Reduction**: Design of longer-lasting and reusable products; reduced consumption.
- **Waste Collection**: Use of alternative, non-fossil fuels (bio-fuel, natural gas).
- **Recycling/Materials Recovery**: Materials recovery facility (MRF) to process source separated materials or mixed waste, although source separated is the preferred option as the materials would have less contamination from other discards. MRFs use a combination of manual and mechanical sorting options. Waste pickers could be used as a source of labor for manual sorting stages.

- **Incineration/Waste-to-energy/Refuse–Derived Fuel (RDF)**: Use the combustible fraction of waste as a fuel either in a dedicated combustion facility (incineration) with or without energy recovery or as RDF in a solid fuel boiler.
- **Landfill**: Capture the methane generated in disposal sites and flare or use as a renewable energy resource.
- **Mitigation – reducing climate change –** involves reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing sources of these gases (for example, the burning of fossil fuels for electricity, heat or transport) or enhancing the "sinks" that accumulate and store these gases (such as the oceans, forests and soil). (IPCC, 2014)
- **Adaptation – adapting to life in a changing climate –** involves adjusting to actual or expected future climate. The goal is to reduce our vulnerability to the harmful effects of climate change (like sea-level encroachment, more intense extreme weather events or food insecurity).

Throughout history, people and societies have adjusted to and coped with changes in climate and extremes with varying degrees of success. Climate change (drought in particular) has been at least partly responsible for the rise and fall of civilizations. Earth's climate has been relatively stable for the past 12,000 years and this stability has been crucial for the development of our modern civilization and life as we know it. Modern life is tailored to the stable climate we have become accustomed to. As our climate changes, we will have to learn to adapt. The faster the climate changes, the harder it could be. According to the 2014 report on Climate Change Impacts, Adaptation and Vulnerability from the IPCC, governments at various levels are also getting better at adaptation. Climate change is starting to be factored into a variety of development plans: how to manage the increasingly extreme disasters we are seeing and their associated risks, how to protect coastlines and deal with sea-level encroachment, how to best manage land and forests, how to deal with and plan for reduced water availability, how to develop resilient crop varieties and how to protect energy and public infrastructure.

Table 2.4: Summary of adaptation, mitigation and sustainable development issues for the waste sector

Technologies and practices	Vulnerability to climate change	Adaptation implications & strategies to minimize emissions	Sustainable development dimensions			Comments
			Social	Economic	Environmental	
Recycling, reuse & waste minimization	Indirect low vulnerability or no vulnerability	Minimal impactions	Usually positive Negative for waste scavenging without public health or safety controls	Positive Job creation	Positive Negative for waste scavenging from open dumpsites with air and water pollution	Indirect benefits for reducing GHG emissions from waste Reduces use of energy and raw materials. Requires implementation of health and safety provisions for workers
Controlled landfilling: landfill gas recovery and utilization	Indirect low vulnerability or positive effects: Higher temperatures increase rates of microbial methane oxidation rates in cover materials	Minimal implications May be regulatory mandates or economic incentives Replaces fossil fuels for process heat or electrical generation	Positive Odour reduction (non-CH gases)	Positive Job creation Energy recovery potential	Positive Negative for improperly managed sites with air and water pollution	Primary control on landfill CH_4 emissions >1200 commercial projects Important local source of renewable energy: replaces fossil fuels Landfillgas projects comprise 12% of annual registered CERs under CDM3 Oxidation of CH_4 and NMVOCs in cover so it is a smaller secondary control on emissions

Technologies and practices	Vulnerability to climate change	Adaptation implications & strategies to minimize emissions	Sustainable development dimensions			Comments
			Social	Economic	Environmental	
Controlled landfilling without landfill gas recovery	Indirect ow vulnerability or positive effects: Higher temperatures increase rates of microbial methane oxidation rates in cover materials	Minimal implications Gas monitoring and control still required	Positive Odour reduction (non-CH gases)	Positive Job creation	Positive Negative for improperly managed sites with air and water pollution	Use of cover soils and oxidation in cover soils reduce rate of CH_4 and NMVOC emissions
Optimizing microbial methane oxidation in landfill cover soils ('bio covers')	Indirect low vulnerability or positive effects: decreased rates at higher temperatures	Minimal implication or positive effects	Positive Odour reduction (non-CH gases)	Positive Job creation	Positive Negative for improperly designed or managed bio-covers with GHG emissions and NMVOC emissions	Important secondary control on landfill CH_4 emissions and emissions of NMVOCs Utilizes other secondary materials (compost, composted sludges) Low-cost low-techno logy strategy for developing countries
Uncontrolled disposal (open dumping & burning)	Highly vulnerable Detrimental effects: warmer temp. promotes pathogen growth and disease sectors	Exacerbates adaptation problems Recommend implementation of more controlled disposal and recycling practices	Negative	Negative	Negative	Consider alternative lower-cost medium technology solutions (e.g. landfill with controlled waste placement, compaction, and daily cover materials)

Technologies and practices	Vulnerability to climate change	Adaptation implications & strategies to minimize emissions	Sustainable development dimensions			Comments
			Social	Economic	Environmental	
Thermal processes l including incineration, industrial co-combustion, and more advanced processes for waste-to-energy (e.g., fluidized bed technology with advanced flue gas cleaning)	Low vulnerability	Minimal implications Requires source control and emission controls to prevent emissions of heavy metals, acid gases. dioxins and other air toxics	Positive Odour reduction (non-CH gases)	Positive Job creation Energy recovery potential	Positive Negative for improperly designed or managed facilities without air pollution controls	Reduces GHG emissions relative to landfilling Costly, but can provide significant mitigation potential for the waste sector. especially in the short term Replaces fossil fuels
Aerobic biological treatment (composting) Also a component of mechanical biological treatment (MBT)	Indirect low vulnerability or positive effects: Higher temperatures increase rates of biological processes	Minimal implications or positive effects Produces C02 (biomass) and compost Reduces volume, stabilizes organic C, and destroys pathogens	Positive Odour reduction (non-CH gases)	Positive Job creation Use of compost products	Positive Negative for improperly designed or managed facilities with odours, air and water pollution	Reduces GHG emissions Can produce useful secondary materials (compost) provided there is qualify control on material inputs and operations Can emit N_20 and CH_4 under reduced aeration or anaerobic conditions

Technologies and practices	Vulnerability to climate change	Adaptation implications & strategies to minimize emissions	Sustainable development dimensions			Comments
			Social	Economic	Environmental	
Anaerobic biological treatment (anaerobic digestion) Also a component of mechanical-biological treatment (MBT)	Indirect ow vulnerability or positive effects: Higher temperatures increase rates of biological processes	Minimal implications Produces CH_4, CO_2 and biosolids under highly controlled conditions Biosolids require management	Positive Odour reduction (non-CH gases)	Positive Job creation Energy recovery potential Use of residual bio solids	Positive Negative for improperly designed or managed facilities with odours, air and water polution	Reduces GHG emissions CH_4 in biogas can replace fossil fuels for process heat or electrical generation Can emit minor quantities of CH_4 during start-ups, shut-downs and malfunctions
Wastewater control and treatment (aerobic or anaerobic)	Highly vulnerable Detrimental effects in absence of wastewater control and treatment: warmer temperatures promote pathogen growth and poor public health	Large adaptation implications High potential for reducing uncontrolled GHG emissions Residuals (biosolids) from aerobic treatment may be anaerobically digested	Positive Odour reduction (non-CH gases)	Positive Job creation Energy recovery potential from anaerobic processes Use of sludges and other residual biosolids	Positive Negative for improperly designed or managed facilities with odours, air and water pollution and GHG emissions	Wide range of available technologies to collect, treat, recycle and re-use wastewater Wide range of costs CH_4 from anaerobic processes replaces fossil fuels for process heat or electrical generation Need to design and operate to minimize N_20 and CH_4 emissions during transport and treatment

Source - Bogner, et al. (2007)

2.5 Strategies for Climate Change Planning and Adaptation for Waste Management Facilities

Scientists and experts agree that climate change is a present-day threat to communities across the world, manifesting in both predictable and unpredictable ways. Coastal storms are increasing in strength and frequency, forest fires are becoming much larger and more destructive, annual precipitation is changing and increasing in variability, and widespread flooding is becoming more common.

These changes present complex challenges to the waste management industry that must be addressed and planned for. For example, one challenge is an increasing frequency of large-scale weather events and natural disasters, which are creating more debris that must be managed and which affects the characteristics of landfilled waste. Landfill design needs to incorporate precipitation changes and increased threats due to weather variability, flooding, and sea-level rise. Precipitation changes affect gas generation rates and require a diligent reaction to maintain effective gas collection. Because of weather pattern changes, risks of cover material erosion and swales have increased for landfills in both wet and dry climates, which may require stronger natural caps or the use of emerging technologies for alternate cover. Additionally, landfills are affected by an increase in the variability of precipitation and rapid changes between weather extremes.

It is clear that waste management facilities must adapt to these changes in addition to scenario building for pandemics to maintain effective operations. Adaptations available include making changes to landfill design and planning, such as incorporating precipitation changes into the modeling of leachate and gas generation or increasing the distance between the bottom liner and groundwater.

Systems should be regularly evaluated and areas needing repairs should be corrected quickly and diligently. Gas generation models should be updated regularly and collection systems need to be expanded or adjusted to account for precipitation increases or decreases.

More frequent and intense storms are creating challenges for cover material management, liquids management, and maintaining slope stability. Facilities should implement innovative uses of both existing technology and new or emerging technologies. Communities with waste management facilities should include waste management infrastructure in emergency management plans, including maintaining landfills and collections operations and using landfills as both temporary debris storage and as an option for final disposal.

Since climate change effects vary by region and locale, many facilities are developing a specific plan for adaptation and management. To reduce the inevitable costs of adaptation and maintain responsiveness to weather changes, a reactive approach is being abandoned in favor of a proactive approach.

Adaptation potential in the SWM value chain is somehow understated as compared to mitigation. The ill-effects of excessive rainfall and cyclones on landfills cannot be overstated, common effects being leachate overflow, water contamination and landfill slides. Even old landfills situated on floodplains can be an issue of grave concern. Such facilities need hydraulic protection from any such unforeseen calamities. Similarly, waste collection equipment and transportation fleet must be examined for their resilience under the changing climatic conditions of an area. Adaptation measures need to be practiced locally and the results are more or less immediate as compared to mitigation wherein the results are long term. A road map to assess the adaptive capacity of urban waste management systems and to frame them within the overall city adaptation/ disaster management strategy is required. IEC and awareness generation activities for implementing 3Rs effectively is need of the hour. A capacity building programme focusing on adaptation and mitigation aspects is must for municipal functionaries.

2.6 Climate change adaptation measures integrated in waste management systems

Extreme weather events

- Frequent collection at scheduled times (based on extreme weather forecasts) reduces risk of waste bags sitting at the curbside for too long and being carried away into streets or waterways by heavy rainfall, heavy wind, landslides or snow.
- Frequent collection is possible when shorter routes are designed making use of multiple decentralised transfer stations.
- Covered collection trucks and underground waste containers prevent waste from drifting away with extreme wind.
- Disposal sites must be compacted each day to force waste disposed to settle, preventing deadly landfill slides (most dangerous for communities living off waste salvaged in or around dump sites).
- Emergency recovery plans in place and up to date to cover a full range of weather events projected over the lifetime of the specific waste infrastructure.
- Landfill leachate collection system planned with enough capacity for heavy rainfall events.
- Extreme weather events generate a lot of waste from single use emergency equipment (water bottles, tents, plastic sheets, etc). Adapting these materials to be biodegradable or easily reusable and recyclable means lowering the impact of such disasters in a city's systems.
- Extreme weather events often generate immense amounts of debris waste from buildings as well as other destroyed materials and landscapes. Establishing a disaster waste management plan helps prepare cities for these extreme waste loads and better plan for recycling materials.

Drought

- Diverting organic waste from landfill through segregated organics collection contributes to preventing landfill fire outbursts.
- Fire-safety structures for landfills, including periodical cover with dry material.

Sea level rise

- Ensure the location of new waste disposal sites - historically close to rivers - is not vulnerable to sea level rise projected over the lifetime of the site.

Extreme heat

- Decentralised organic waste treatment plants (such as composting and anaerobic digestion) to reduce transporting distances, increase organic waste recovery and reduce risk of dumpsite fire.
- Decentralised waste transfer stations to allow for smaller waste collection vehicles and shorter trips for each worker, especially when the city relies on a labour-intensive system.
- Implement frequent organic waste segregate collection, distributing food waste caddies (reduces odours, pest and insects from rapidly degrading material) and promoting home composting where collection is not present.
- Scheduled collection: waste can be put outside only in a 2 hour buffer from the scheduled time of collection to avoid insects, pests (as well as risk of waste bags being carried away by extreme events).
- Protected and well aerated sorting facilities for resource salvagers/waste pickers to sort waste.
- Install water fountains across the city to reduce consumption of disposable bottles that steeply increase during heat waves.

Flooding

- Prevent waste blocking the drainage system by achieving universal waste collection and reducing litter by placing segregate street bins and promoting educational campaigns.
- Ensure landfill has more than one access route and effective drainage systems.
- Ensure waste transfer stations, disposal sites and storage areas are elevated and safe from floods, for example avoiding flood plains (low-lying near rivers or coastal areas) and develop adaptation plans for established sites located in flood areas.
- Aerated elevated or closed curbside collection containers.
- Adopt a post-flood action plan: floods will carry large quantities of waste that will end up in the open once the water level lowers down; cities should have a plan in order to quickly collect it and divert as much as possible, and to safely dispose of the residual waste.

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Chapter 3

Estimating GHG emissions for Wastewater Treatment Technologies

Recap

The previous chapter dealt in detail with the GHG emissions from the various solid waste processes. It explored in detail the methodologies to estimate the GHG emissions in the solid waste sector in urban areas.

Training Objectives

- To understand the linkages between wastewater treatment and GHG emissions
- To analyze GHG emissions across various treatment Technologies
- To get an overview of the estimation methods for calculating GHG emissions across various wastewater treatment technologies
- To explore different mitigation and adaptation measures to manage GHG emissions from wastewater treatment plants

Training Outcomes

- Understand the linkages between wastewater treatment and GHG emissions
- Gain exposure on various estimation methods for calculating GHG emissions across various wastewater treatment technologies
- Explore various mitigation and adaptation measures to manage GHG emissions from wastewater treatment plants

Chapter Contents

3.1 GHG Emissions and Wastewater Treatment

While efficient wastewater treatment is essential to protect human health, the environment and surrounding water quality, the greenhouse gases (GHG) emitted from wastewater treatment processes contribute to its carbon footprint. According to the Intergovernmental Panel on Climate Change (IPCC) reports, greenhouse gas emission from the waste sector corresponds to approximately 3% of the anthropogenic emissions on a global scale, and wastewater treatment constitutes approximately 20% of the waste sector (IPCC 2014).

Wastewater Treatment Plants (WWTPs) produce three of the most important GHGs-namely carbon dioxide (CO_2), methane (CH_4), and Nitrous Oxide (N_2O) during the treatment processes and additionally generate CO_2 and CH_4 from the energy demands of the plant[5]. However, the overall impact of the wastewater treatment systems on climate change may depend on the net GHGs emissions, accounting for both emissions and GHG savings. Hence, the role of wastewater treatment facilities in mitigation of GHG emissions is very crucial.

All wastewater treatment plants contribute to the greenhouse gas emissions either directly or indirectly. While the indirect greenhouse gas emissions can be attributed to the electricity consumption by the plant, the direct CO_2, CH_4 and N_2O emissions in wastewater treatment plant are from the treatment processes. These emissions directly depend on the type of treatment technology being used.

In aerobic processes, CO_2 is emitted due to the breakdown of organic matter in the treatment tanks, whereas in the anaerobic system, the fraction of biomass is converted into CO_2 and CH_4 through endogenous respiration. The degradation of wastewater and waste sludge in anaerobic treatment can produce CH_4. The rate of the CH_4 emissions depends on the quantity of the waste and temperature inside the system. The CH_4 emission increases with increase in temperature and sludge quantity. The principal factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic material in the wastewater. Common parameters used to measure the organic component of the wastewater are the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Under the same conditions, wastewater with higher COD, or BOD concentrations will generally yield more CH_4 than wastewater with lower COD (or BOD) concentrations.

The nitrification and denitrification processes lead to emission of N_2O due to degradation of nitrates, urea, protein and other nitrogen components in the wastewater. Nitrification is an aerobic process converting ammonia and other nitrogen compounds into nitrate (NO_3),

[5] *Yerushalmi, L., Shahabadi, M. and Haghighat, F., 2011. Effect of Process Parameters on Greenhouse Gas Generation by WastewaterTreatment Plants. Water Environment Research, (1061-4303).*

while denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into dinitrogen gas (N_2). Nitrous oxide can be an intermediate product of both processes, but is more often associated with denitrification.[6]

Wastewater treatment stands as the fifth largest source for contributing anthropogenic methane emission of about 9% of global CH_4 emission in 2000 and sixth largest contributor to the N_2O emissions accounting about 3% of global N_2O emissions worldwide. (Anastasios Zouboulis et al. 2015)

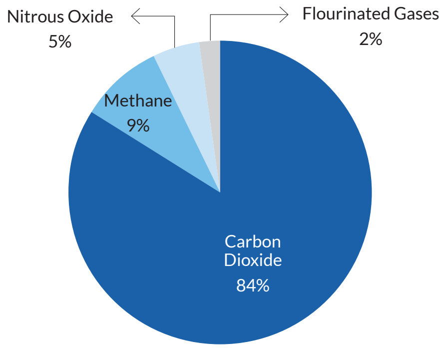
Table 3.1: Emissions from wastewater treatment global (Tg CO_2 Eq.)

GHGs	1990	2005	2007	2008	2009	2010	2011
CH_4 (Total waste emissions)	164.0	130.5	129.8	129.8	131.9	131.4	124.7
Wastewater treatment	15.9	16.5	16.7	16.6	16.6	16.6	16.4
N_2O (Total waste emissions)	3.8	6.4	6.5	6.7	6.8	6.7	6.8
Wastewater treatment	3.5	4.7	4.8	4.8	4.9	5.0	5.1

Source - EPA (2013)

The global warming potential (GWP) is calculated in terms of CO_2 equivalent, which means the global warming potential of the emissions are expressed in relation to carbon dioxide. Residence time of gases in the atmosphere is around 100 years. GWP values for CO_2, CH_4 and N_2O are 1, 28 and 265 as per GWP (IPCC, 2014). Even the small amount of gas with high GWP potential has greater effect than the low GWP gases. For instance, 1 kg of N_2O emission will have the same GWP of 265 kg of CO_2.[3]

Figure 3.1: Total global emissions in 2011 = 6,702 million metric tons of CO_2 equivalent



Source - EPA (2009)

[6] *Doorn, M., Towprayoon, S., Vieira, S., Irving, W., Palmer, C., Pipatti, R. and Wang, C., 2006. Chapter 6 WASTEWATER TREATMENT AND DISCHARGE. In: IPCC Guidelines for National Greenhouse Gas Inventories. [online] IPCC Guidelines for National Greenhouse Gas Inventories. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf*

GHG Emissions across Various Wastewater Treatment Technologies

For estimating the direct and indirect GHG emissions from the wastewater treatment plants, the processes involved across the value chain attributing to GHG emissions can be broadly classified into three scopes:

- **Scope 1: Emission from the Waste Water Treatment Plant (WWTP)**
    - CO_2 emission in the secondary treatment process, due to breakdown of organic compounds - endogenous respiration
    - CH_4 emission during Operation and maintenance of settlers and clarifiers
    - N_2O emissions during nitrification and denitrification processes
    - N_2O emissions from treated effluents being discharged into natural bodies
    - CH_4 and CO_2 emission due to sludge disposal

- **Scope 2: Emission from energy consumption** (for e.g. electricity consumed by raw sewage pumps, return sludge pumps blowers and aerators, etc.)

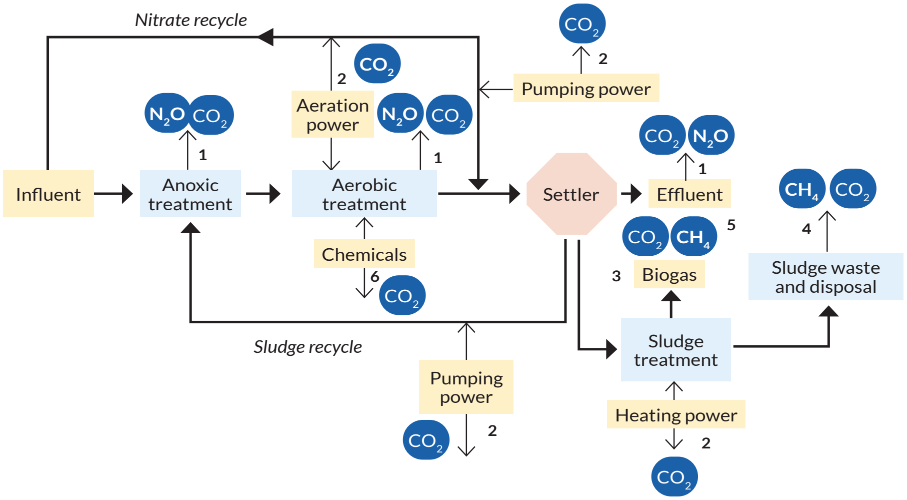
- **Scope 3: GHG emission from transportation and other activities of organization** (for e.g. GHG emissions that occur during the production of the chemicals that are used in the WWTP).

To estimate the GHG emissions of the wastewater treatment plants (WWTP) in a comparable way the considered emissions have to be listed. The selected boundaries are from Scope3 and are listed below (Bridle Consulting, 2007):

- CO_2 and N_2O emissions at bio-treatment, endogenous respiration, BOD oxidation nitrification CO_2 credit and nitrogen removal
- Energy use of plant, for aeration, mixing and pumping which leads to CO_2 emissions
- Sludge digestion, biogas CH_4 and CO_2
- Sludge disposal, truck emissions trip to reuse/disposal site, CO_2 emissions mineralization
- Power credit by use of biogas
- GHG emissions from chemical use

In figure 3.2 given below, a Wastewater treatment plant is schematically displayed. The different boxes show the treatment processes. The GHGs that can be released during the treatment processes are given in the circles. The numbers in the figure correspond with the numbers of the list of boundaries. Emissions that are not taken into account are indirect emissions from employers that occur when they travel towards work, thus for example the emissions of the car that is used by an employee. This is not taken into account as it is very specific for each WWTP and will be small compared to the other sources (Laura Snip, 2009).

Figure 3.2: Estimated greenhouse gas emissions of a wastewater treatment plant



Source - Laura Snip (2009)

3.2 Wastewater Technologies and their Relevance with respect to the Climate Change

Several designs and technologies of sewage treatment plants (STP) are available and the primary objective is always to produce water that is biologically and chemically safe and is also non-corrosive and non-scaling. Depending on the requirement, the appropriate selection and design of STPs and implementation of sanitation systems is selected. The basic criterion for efficacy of any good STP is to remove harmful chemical as well as biological contaminants, but there are other parameters such as land utilization, capital investments, power consumption and manpower requirements that play an equally important part in the selection of a technology.

We may categorize the wastewater treatment processes into four broad methods: physical methods, chemical methods, biological methods and energy intensive methods.

- **Physical methods** of wastewater treatment represent a body of technologies that are largely solid-liquid separation techniques, of which filtration plays a dominant role.
- **Chemical methods** depend on chemical interactions of the contaminants that are being removed from water.
- **Biological methods** depend on microorganisms for the degradation of organic matter both in aerobic and anaerobic systems.
- **Energy intensive treatments** include thermal methods such as sterilisation to provide high quality water fit for drinking; and/or are also used for processing of sludge

Few of the popular technologies for secondary treatment of wastewater which are particularly suited for buildings and apartments include the following:

- Activated Sludge Process (ASP)
- Extended Aeration (EA)
- Fluidized Aerobic Bed Reactor (FAB)
- Moving Bed Biofilm Reactor (MBBR)
- Sequencing Batch Reactors (SBR)
- Membrane Bioreactor (MBR)
- Natural treatment systems such as Root zone, Decentralized treatment system (DTS), Soil bio technology (SBT), DEWATS (referred to as Natural STP in the subsequent sections of this chapter).

The following Table 3.2 gives a list of popular technologies and the corresponding GHG emissions:

Table 3.2: Comparison of GHG emissions across Wastewater treatment Technologies

Parameters	Activated sludge process	Sequence batch reactor	Membrane bio reactor	Moving bed biofilm reactor	Natural sewage treatment system
Basic Process	Biological treatment includes addition of chemicals	Biological treatment includes addition of chemicals	Biological treatment includes addition of chemicals	Biological treatment includes addition of chemicals	Biological treatment without any chemical addition
Input	Raw sewage from domestic and municipalities				
Organic effluents from industrial processes					
Moderate strength effluents from industrial processes	Raw sewage from domestic and municipalities				
Effluents from industrial processes	Raw sewage from domestic and municipalities.				
Effluents from industrial processes	Raw sewage from domestic and municipalities.				
Effluents from industrial processes	Raw sewage from domestic and municipalities				

Parameters	Activated sludge process	Sequence batch reactor	Membrane bio reactor	Moving bed biofilm reactor	Natural sewage treatment system
Greenhouse Gas Emissions	Significant	Significant	Significant	Significant	Reduced, due to zero chemical addition and zero power technology
Primary output	Treated reusable water, sludge, Biogas	Treated reusable water, sludge, Biogas	Treated reusable water, sludge, Biogas	Treated reusable water, sludge, Biogas	Treated reusable water, sludge, Biogas
Secondary output	Electricity and/or heat (where biogas is recovered)	Electricity and/or heat (where biogas is recovered)	Electricity and/or heat (where biogas is recovered)	Electricity and/or heat (where biogas is recovered)	Electricity and/or heat (where biogas is recovered) and natural fertilizer
Types of GHG emissions	Microbial activities due to aerobic conditions lead to the production of CO_2 emission.				
Sludge produced during the treatment process emits CO_2 and CH_4, consists of 97.5% of methane and 2.5% of CO_2					
Electricity from grid for the operation of WWTP and Chemicals is the source of indirect GHG emission contributes about 0.03%					
	Microbial activities due to aerobic conditions lead to the production of CO_2 emission.				

Parameters	Activated sludge process	Sequence batch reactor	Membrane bio reactor	Moving bed biofilm reactor	Natural sewage treatment system
Sludge produced during the treatment process emits CO_2 and CH_4, consists of 97.7 % of methane and 2.3 % of CO_2					
Electricity from grid for the operation of WWTP and chemicals is the source of indirect GHG emission.					
	Microbial activities due to aerobic conditions lead to the production of CO_2 emission.				
Sludge produced during the treatment process emits CO_2 and CH_4. consists of 97.7% of methane and 2.3 % of CO_2					
Electricity from grid for the operation of WWTP and chemicals is the source of indirect GHG emission.					
	Microbial activities due to aerobic conditions lead to the production of CO_2 emission.				

Parameters	Activated sludge process	Sequence batch reactor	Membrane bio reactor	Moving bed biofilm reactor	Natural sewage treatment system
Sludge produced during the treatment process emits CO_2 and CH_4. 97.7% of methane and 2.3 % of CO_2					
Electricity from grid for the operation of WWTP and chemicals is the source of indirect GHG emission contributes about					
	Microbial activities due to aerobic conditions lead to the production of CO, CH_4 and N_2O gases.				
Sludge produced during the treatment process emits CO_2 and CH_4. consists of 65% of methane and 35% of CO_2					
The methane can be recovered and it can get reduced to					
Capital costs (Rs. /KLD)	20000-40000				
	30000-50000	40000-70000	25000-50000	18000-40000	
Operating costs (Rs. /KLD)	2000-4000	3000-6000	4000-7000	3000-5000	600-1000

Parameters	Activated sludge process	Sequence batch reactor	Membrane bio reactor	Moving bed biofilm reactor	Natural sewage treatment system
Land Requirement (m2/MLD)	1500-2500	200-2000	200-2000	200-2000	200-2000
Operational complexity	Requires specialized training, careful maintenance, and trained operator	Requires specialized training, careful maintenance, and trained operator	Requires specialized training, careful maintenance, and trained operator	Requires specialized training, careful maintenance, and trained operator	Requires Trained operator
Population (person)	>150	>150	>150	>150	>1

Source – Authors

3.3 GHG Emissions Estimation for various Wastewater Treatment Technologies and Processes

For the ease of estimating the GHG emissions across various value chain points of the wastewater treatment processes, the calculating method is explained as per the three broad scopes discussed in Section 3.2.1 of the chapter.

Calculation of emissions under Scope 1 - Emissions from waste water treatment plants

The Input data for calculating the Total CO_2 emissions for 1MLD treatment plant is listed in Table 3.3:

Table 3.3: Input data for calculating Total CO_2 emissions for 1MLD treatment plant

Common inputs for all technologies		
Input data	Values	Unit
Population	9000	
Percapita wastewater	115	LPCD
Flow rate	1000	m^3/day
BOD in	0.36	kg/m^3
BOD out	0.01	kg/m^3
COD in	0.6	kg/m^3
COD out	0.05	kg/m^3

Source: Author

Estimating CO_2 emissions[7]

On-site emission is regarded as the GHG emissions due to the biochemical treatment process of the extended aeration activated sludge system. It was considered that CO_2 is the GHG resulting from BOD removal in the wastewater. On-site CO_2 emission (GHGE on-site, CO_2) is figured out by multiplying BOD removal (B) (kg/m^3) and wastewater flow (Q) (m^3/d) and global warming potential (GWP) of carbon dioxide ($GWPCO_2$), whose value is '1'. Also, it is considered that CO_2 is formed as the result of microbial mass respiration.

- **GHGE on-site, CO_2:** On-site CO_2 emission
- **$MMRCO_2$:** CO_2 formed as the result of microbial mass respiration
- **B:** BOD removal (kg/m^3)
- **Q:** Wastewater flow (m^3/d)
- **$GWPCO_2$**: Global warming potential (GWP) of carbon dioxide (=1)
- **kd**: endogenous respiration indicator constant

$$MMRCO_2 = (B \times Q \times GWPCO_2)(1 - kd)$$

Partial CO_2 emission was figured out by multiplying MLVSS (living microbial mass), flow rate (Q) and GWP of CO_2.

- $PARCO_2$: Partial CO_2 emission
- MLVSS: living microbial mass (kg/m^3)
- Q: Wastewater flow (m^3/d)
- $GWPCO_2$: Global warming potential (GWP) of carbon dioxide (=1)

$$PARCO_2 = MLVSS \times Q \times GWPCO_2$$

Hence, total CO_2 emission in kg/d under **Scope 1** can be calculated as:

$$Total\ CO_2\ emission \left(\frac{kg}{d}\right) = MMR\ CO_2 + PARCO_2$$

Estimating CH_4 emissions

The stages across the treatment processes contributing to methane emissions in treatment plants are discussed as below along with their estimation method:

a. **CH_4wwt**: Methane emission from waste water treatment system

$$CH_4\,wwt = C \times Q \times GWPCH_4\ x\ MCFww\ x\ Boww\ x\ 0.89$$

[7] Yapıcıoğlu, P., 2021. *Minimization of greenhouse gas emissions from extended aeration activated sludge process*. Water Practice and Technology. [online] IWA Publishing. Available at: <https://iwaponline.com/wpt/article/16/1/96/78121/Minimization-of-greenhouse-gas-emissions-from>

b. **CH_4st**: Methane emission from sludge treatment

$$CH_4st = S \times MCFst \times DOCf \times DOCs \times 1.12 \times F \times \left(\frac{16}{12}\right) \times GWPCH_4$$

c. **CH_4wwd**: Methane emission from waste water discharge

$$CH_4wwd = Q \times GWPCH_4 \times Boww \times 1.12 \times C \times MCFld$$

d. **CH_4F**: Methane emission from anaerobic decay of the final sludge

$$CH_4F = S \times MCFsludge\ disposal \times 1.12 \times DOCs \times DOCf \times F \times \left(\frac{16}{12}\right) \times GWPCH_4$$

e. **CH_4fuww**: fugitive from waste water treatment

$$CH_4fuww = (1 - CFEww) \times MEPww \times GWPCH_4$$

f. **CH_4fust**: fugitive from sludge treatment

$$CH_rfust = (1 - CFEst) \times MEPst \times GWPCH_4$$

$$CH_4fT = CH_4fuww + CH_4fust$$

g. **CH_4flaring**: Methane emission due to incomplete flaring

$$CH_4flaring = \frac{CH_4wwt + CH_4st}{GWPCH_4}$$

- **C** - COD removal (kg/m3)
- **Q** - Wastewater flow (m3/d)
- **$GWPCH_4$** - Global warming potential (GWP) of CH_4
- **kd** - endogenous respiration indicator constant
- **MLSSd** - Microbial death kg/m3
- **MCFld**- Methane correction factor for discharge to lake
- **MCF**- Methane correction factor for disposal site
- **MCFww** -Methane correction factor for WWT Table 2
- **MCFst** - Methane correction factor for sludge treatment system
- **Boww** -Methane producing capacity of the wastewater in kg/ kg COD
- **DOCf**- Fraction of DOC dissimilated to biogas
- **DOCs**-Degradable organic content of the untreated sludge
- **F** -Fraction of CH_4 in biogas
- **CFES** -Capture efficiency of the biogas recovery equipment in the sludge treatment systems
- **MEPst**- Methane emission potential of the sludge treatment systems
- **MEPww**-Methane emission potential of wastewater treatment systems

Therefore, the total CH_4 emissions in kg/d under **Scope 1** can be calculated as:

$$CH_4Total = CH_4wwt + CH_4st + CH_4ww + CH_4F + CH_4fT + CH_4fl$$

Estimating N_2O emissions

The inputs required for estimating the N_2O emissions include:

- Total Nitrogen (kg/m^3)
- Emission Factor (=0.005)

$$N_2O = Total\ nitrogen\ \left(\frac{kg}{m^3}\right) \times\ Emission\ factor\ \times \frac{44}{28}$$

Calculation of emissions from indirect sources under Scope 2[8]

There are three constituents of off-site greenhouse gas emissions considered for estimation in this method. Electricity consumption for the operation of extended aeration process in the plant was used to estimate the off-site emissions. The second constituent is the off-site emission from methanol (chemical) use for denitrification for the removal of nitrogen in the extended aeration process. The other constituent of off-site emission is the sludge stabilization process.

The off-site emission related to the electricity consumption

The off-site emission related to the electricity consumption is figured out by multiplying the electricity consumption (EC_{total}) (kWh) of the extended aeration process and the specific emission factor ($EF_{electricity}$) of the electricity consumption (kg CO_2e/kWh).

Electricity consumption of the extended aeration process is obtained from the electricity bills and the electricity meters in the treatment plant. Electricity consumption of the plant contains the energy demand of the blower and air pumps ($EC_{blower\&air\ pumps)}$ for the aeration process and the energy depletion of the sludge pumps ($EC_{sludge\ pumps)}$. $EF_{electricity}$ is 0.497 kg CO_2e/kWh (International Energy Agency (IEA), 2016). The estimation model for total off-site emissions from electricity is based on the IPCC (D.Kyung, 2015).

- **GHG electricity**: The off-site emission related to the electricity consumption
- **EC_{total}** - Electricity consumption (kWh)
- **$EF_{electricity}$** - Emission factor of the electricity consumption (kg CO_2e/kWh)

$$GHG\ electricity\ = EC_{total} \times EF_{electricity}$$

Calculation of emissions under Scope 3 – Transportation and other utilities

The inputs required for estimating the emissions from transportation and other utilities comprise:

- Fuel consumption L/day
- Emission factor for Diesel (kg CO_2/L)

[8] *Yapıcıoglu, P., 2021. Minimization of greenhouse gas emissions from extended aeration activated sludge process. Water Practice and Technology. [online] IWA Publishing. Available at: <https://iwaponline.com/wpt/article/16/1/96/78121/Minimization-of-greenhouse-gas-emissions-from>*

GHGE transportation: The off-site emission related to transportation

$$GHGEtransportation = Fuel\ consumption\left(\frac{L}{Day}\right) \times Emission\ factor\left(kg\frac{CO2}{L}\right)$$

Total CO_2e emission from the treatment plant is summation of Scope 1, Scope 2 and Scope 3 emission. For different type of treatment plants, the emission varies with respect to design aspects of the respective technology. The following table represents the emissions from six different types of treatment technologies.

The off-site emission from the chemical use

Methanol addition as an added carbon source for denitrification to achieve nitrogen removal leads to the other off-site emission in the aeration tank. It can be estimated by means of multiplying daily methanol consumption ($L_{methanol}$) (kg/d) and the emission factor of methanol ($EF_{methanol}$) (D.Kyung, 2015). The emission factor of methanol is 1.54 kgCO_2e/kg methanol (Yapıcıoglu, 2021; D.Kyung, 2015). The off-site emission of the chemical use could be estimated using the equation below (D.Kyung, 2015).

- **GHGE chemical:** The off-site emission of the chemical use
- **$L_{methanol}$** - Daily methanol consumption (kg/d)
- **$EF_{methanol}$** - Emission factor of methanol (kg CO_2/kg methanol)

$$GHGEchemical = L_{methanol} \times EF_{methanol}$$

The off-site emission from the sludge stabilization process (IWA Publishing , 2021)

The other resource of off-site GHG emissions is the sludge stabilization process. Lime is used for the stabilization of waste activated sludge. It can be figured out by means of multiplying daily lime consumption (L_{sludge}) (kg/d) and the emission factor of lime (EF_{lime}) (IPCC 2006). The emission factor of lime is 0.43971 kgCO_2e/kg lime. $CaCO_3$ is used as the chemical.

- **GHGE sludge:** The off-site emission of the sludge stabilization process
- **L_{lime}** – Daily lime consumption for stabilization of sludge ($CaCO_3$ dose) (kglime/kgsludge)
- **L_{sludge}**- Daily sludge (kg sludge/d)
- **EF_{lime}** - Emission factor of Lime (kg CO_2/kg Lime)

$$GHGE\ sludge = L_{sludge} \times L_{lime} \times EF_{lime}$$

The off-site emission under Scope 1 is the total of the emissions from electricity and chemical consumption and sludge stabilization process. It can be estimated as below:

$$GHGE\ off-site = GHGEelectricity + GHGEchemical + GHGEsludge$$

Table 3.4: Emission from wastewater technologies for Typical 1MLD

WWTP technologies	Type of treatment	Scope					Total CO_2e kg/ day if poorly maintained	If treatment plants are well maintained
		1			2	3		
		CO_2	CH_4	N_2O	CO_2	CO_2		
Activated sludge process	Biological treatment without addition of chemicals	3115	1625.54	0.000314	37.62	0	1859.9	3152.6
Sequence batch reactor	Biological treatment with addition of chemicals	3115	1625.786	0.000314	66.671	0	1960.4	3181.6
Moving bed biofilm reactor	Biological treatment with addition of chemicals	2065	3615.824	0.000314	146.3	0	2332.5	2211.3
Membrane bio reactor	Biological treatment with addition of chemicals	3115	1625.786	0.000314	167.2	0	1997.1	3282.2
Waste Stabilisation pond	Biological treatment without addition of chemicals	3115	1227.779	0.000314	0	0	1790.8	3115.0
Natural STPs	Natural treatment	3115	3615.824	0.000314	0	0	2662.4	3115.0

Source - Authors

It may be noted that if Aerobic treatment STPs (ASP, SBR, MBR, MBBR) are operated well the net emission reduces to 2200- 3115 kg/day TCO_2e. Similarly, if the CH_4 emissions in natural STP are flared, the overall emissions reduce to 3115 TCO_2e kg/d. On the other hand, if methane is generated in Natural STPs, it is utilized for electricity generation and the net emission reduces to -335 to -3780 TCO_2e kg/day at 50% and 100% conversion efficiency respectively.

3.4 Strategies to manage GHG emissions from wastewater treatment plant – Mitigation and Adaptation measures

It can be noted in Table 3.4, the emissions are largely influenced by the operating conditions. A well-managed STP operating within the design parameters generate between 2200 - 3115 kg CO_2/ MLD of emissions. However, the same plants can produce almost twice (4300 - 5800 kg CO_2/ MLD) when operated badly. Hence, the most efficient method for reducing GHG emission is by modifying the operational condition of wastewater treatment plant, but the modification may not always be the best solution due to the operational limitations. Nowadays, most of the technologies available to remove GHGs are expensive or even not suitable to be applied to gaseous streams of the WWTPs.

N_2O emissions will depend mainly on the operational conditions (NO_2 – and O_2 concentrations) of the reactor systems. To reduce N_2O emission, high Sludge retention time should be maintained to reduce the concentration of ammonia and nitrate in the media. Furthermore, large bioreactor volumes are recommended to dispose of systems able to buffer loadings and reduce the risk of transient oxygen depletion. N_2O emissions can be also reduced if nitrous oxide stripping by aeration is limited since microorganisms would have more time to consume it.

Figure 3.3: Comparison of GHG Emissions between Conventional STPs and Natural STPs

Conventional STP

Comparison of GHG Emissions between Conventional STPs and Natural STPs

Natural Treatment Systems or Natural STP

GHG emissions Scenario

Conventional STP	Natural STP
A well-managed conventional technology working within its design parameters Low GHG emission	**A well-managed Natural STP working within its design parameters** Low GHG emissions comparable to conventional STP
Energy Capture/Harnessing Energy cannot be harnessed in conventional STPs. On the contrary, it consumes energy and, emits GHG to the tune of 37 to 167 KG per MLD	**Energy Capture/ Harnessing** Comparison of GHG Emissions between Conventional Aerobic STP's and Natural Bio STP Anerobic System
Reliability of technology Due to its heavy dependency on mechanical moving parts, these technologies are prone to failures. This increases the GHG emissions by more than double its usual levels	**Reliability of technology** Since the Natural STPs do not have any mechanical parts, the breakdowns are almost nil. Hence, the GHG emissions are stable during the lifetime of this system
Tolerance to Shock loading Cannot withstand shock loading. self-regulating capacity of these types of technologies is poor and this leads to higher emissions when increased wastewater flows	**Tolerance to Shock loading** The Natural STPs are adept to withstanding shock loading. Hence, GHG emissions are stable during the lifetime of the system

Source – Authors

Proper sealing of sludge digestion tank and disposal tanks can avoid GHG gas leakages, while it can be captured by hoods and burnt together with the biogas generated in the sludge digestion tank.

High values of SRT applied to the bioreactor promotes endogenous respiration of biomass, which increases the rate of oxidation of COD to CO_2 and reduces sludge production. The reduction in sludge production reduces methane production thereby decreasing the CO_2 emission.

Another possible option for reducing GHG emission is by trapping and treating them. There are number of technologies available to destroy or capture the emissions. For N_2O removal, traditional technologies such as selective catalytic reduction and non-selective catalytic reduction are currently used to control N_2O emission.

Many biological technologies have been initialized in the early 90's based on bio-filter system, which are capable of oxidizing CH_4 into CO_2. This allows major reduction in GHG emission. Since the global warming potential of carbon dioxide is lower than that of methane.

Removal of CO_2 gas can be possible through physical/chemical sorption and membrane separation methods. But the application of the system is associated with high capital and operational cost. So now a days CO_2 sequestration by cultivating microalgae is considered as attractive alternate method for carbon dioxide trapping.

Other ways to mitigate indirect emissions and enhance efficiency of the plant is by using energy efficient units and operation techniques. Use of renewable source for the generation of electricity or heat energy can reduce major indirect GHG emissions in the plant.

Natural STPs, on the other hand, permits capture of methane and flaring or even use as renewable energy source. This can offset almost 345 kg to 3700kg/ MLD (sink), depending on the technology used. Further, they also have an advantage of higher reliability as they are not dependent on electricity or chemicals for the treatment.

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Chapter 4

Climate Adaptation Strategies in the Water Sector

Recap

The previous chapter explores the various tools and methodologies to estimate GHG emissions across different Wastewater Treatment technologies.

Training Objectives

- To identify available climate adaptation strategies on water resources in the select Indian cities
- To provide a step by step guidance on calculation of GHG emissions in the domain of water management
- To highlight the lessons learnt from the two case studies provided
- To suggest dovetailing climate adaptation strategies for utillities

Training Outcomes

- Able to understand climate adaptation strategies and measures for utilities
- Gather an understanding of the GHG emissions calculations
- Gather an understanding of dovetailing strategies for utilities

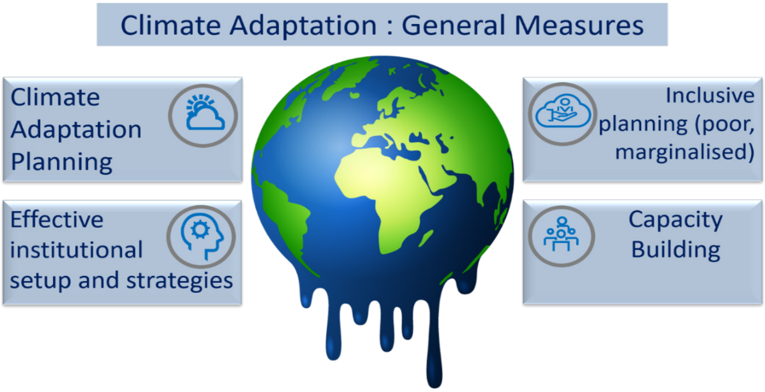
Chapter Contents

4.1 Introduction

Climate change and variability affect water resources and their management in many parts of the country. Water also plays a key role in climate change adaptation, and therefore, needs to be prioritized in national strategies for sustainable development and pubic security. Dense population, economic inequity, inadequate infrastructure, and poor planning exacerbate the climate change

Impacts on water resources in urban areas. These also form a substantial ecological footprint, with overflowing waste and wastewater in poorly drained settlements further discharged into the ground, polluting groundwater aquifers. While many integrated climate adaptation approaches exist in the country, this chapter offers evidence to suggest measures towards climate change adaptation in the water sector.

Figure 4.1: General measures for Climate Adaptation



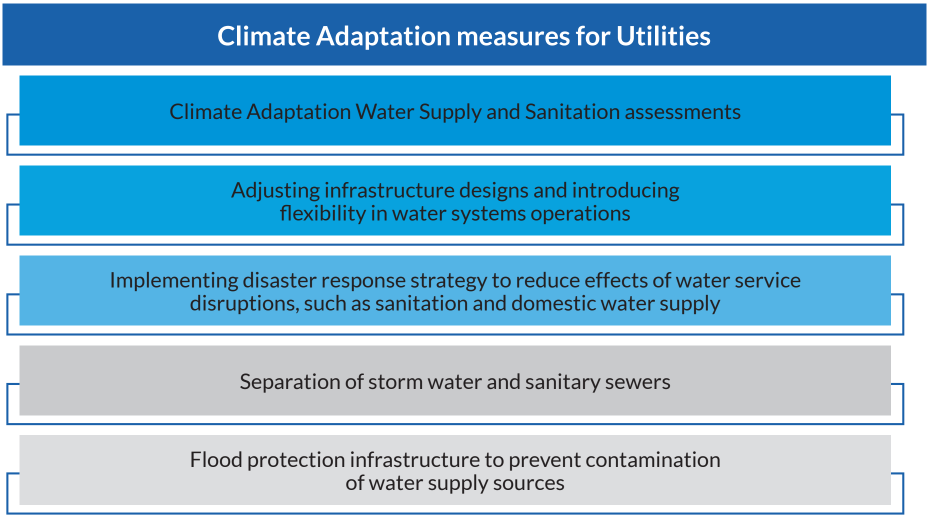
Source – Authors

4.2 Climate Change Adaptations

Sound planning should consider all driving forces. In some cases, placing the focus exclusively on climate change may lead a city to miss more obvious leverage points, which might be more cost-effectively addressed and lead to better results and greater co-benefits. Urban planning should, therefore, emphasise assessments and the attribution of impacts to driving forces.

Climate change manifestations through alterations in the water cycle pose significant risks to the urban water system including water supply, wastewater and stormwater. Extreme weather events already pose a serious threat to water and wastewater infrastructure, with predictions indicating an increased occurrence of such extreme events cities are to pay high priority to the same.

Figure 4.2: Climate adaptation measures for utilities



Source – Authors

Wastewater systems

The consequential impact of climate change on wastewater treatment infrastructure is extensive. The infrastructure of collection lines and wastewater treatment, including outfalls, pipelines and tanks, can be physically damaged by coastal flooding linked to sea-level rise and also by flooding caused by increased precipitation. The functionality of wastewater treatment can also be reduced by flooding: in the case of cities with combined sewer systems, heavy rainfall events can overwhelm wastewater treatment capacity, which usually results in increased overflows. Extreme events such as floods and droughts threaten the wastewater treatment plants by diluting or concentrating inflows. In coastal areas, flooding can lead to increased salinity of influents that can drastically alter the biological processes and impact the reuse of treated wastewater.

Stormwater and drainage systems

Drainage or stormwater systems will be most affected by the increased occurrence and intensity of the precipitation. Intense rainfall and a resultant increase in stormwater can surpass the capacity of stormwater entry points or cause sewer overflows in combined sewer systems, causing street flooding and associated health impacts. Combined sewer overflows challenge both stormwater and wastewater: excess stormwater cause overflows, conveyance of wastewater with combined pipes posing additional challenges. Moreover, drying and shrinking soils caused by droughts can generate cracks in stormwater drains and sewers, causing not only contamination but also increasing maintenance costs. Changes in vegetation and soil characteristics due to increased temperatures and higher rates of evapotranspiration can also change attenuation and infiltration rates, affecting soil retention capacity.

While enhancing financial capacity seems to play a role in driving current adaptation responses, it is to a lesser degree than could be expected: several cities around the world have started to initiate adaptation, often irrespective of national frameworks being in place. City networks are also being set up: these can stimulate national policies and act as a positive example, providing an important venue for the transfer of knowledge and technology. City networks exchange good practices on a wide range of issues— one example is Connecting Delta Cities.

Ultimately, the success of adaptation in cities critically depends on the availability of necessary resources, not only financial and natural but also linked to knowledge, technical capability, institutional resources and targeted tools (Bakker & van Schaik, 2009).

In general, the design of urban water supply, wastewater and stormwater infrastructure have built-in spare capacity to account for future growth in demand. Utilities across the globe encounter issues in integrating coping strategies into planning practices.

Water managers are also often forced to implement rationing or supply interruptions measures if reductions in water supplies are not planned already. These measures are not only unpopular but also costly since the hydraulic shocks associated with intermittent supply damage water supply infrastructure – decreasing the lifespan of equipment – and lead to increased maintenance and repair costs (Danilenko, et al., 2010).

4.3 Choosing flexibility

Current water management infrastructure tends to be inflexible and rigid towards changing circumstances, yet projections of climate change show that variability can change capacity requirements either regionally or across the year. More sustainable urban water management systems are designed to cope with varying and unpredictable conditions and achieve this through the implementation of flexible, and often decentralised options and technologies that take into account a range of future scenarios. A flexible system is characterised by its ability to adapt to changing requirements.

Table 4.1 provides examples of a flexible urban water system response to changing conditions as opposed to typical systems. Additional information on flexible solutions are available in modules of the SWITCH Training Kit, a series of modules developed under the project SWITCH – Managing Water for the City of the Future (Module 3 on water supply and Module 4 on stormwater management and Module 5 on wastewater management) (ICLEI European Secretariat, 2011).

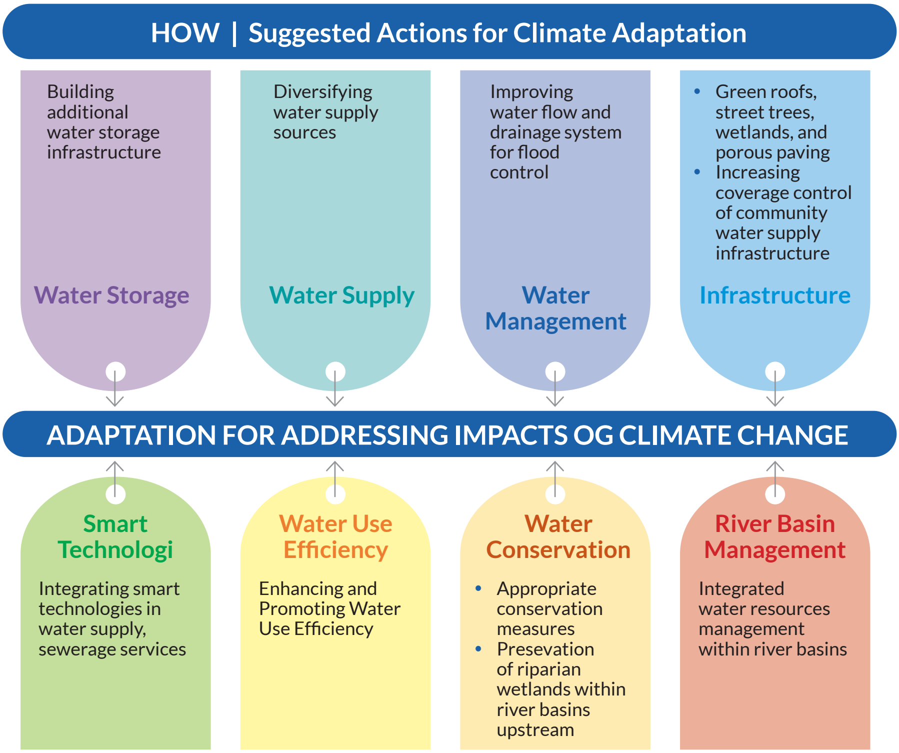
Table 4.1: Response of conventional versus flexible systems to changing conditions

Urban Water Management Aspect	Non-Exhaustive examples of Climate Change impacts	Current System response example	Potential response to a changing climate from a flexible system
Water Supply	Reduced water supply either seasonally or throughout the year	Increasing water supply through additional infrastructures such as dams, boreholes, desalination plants or bulk supply of water	Demand reduction through efficiency increases, active leakage management, behaviour change or pricing policies
			Sourcing of alternative supplies for non-potable demand: rainwater harvesting, reuse of treated wastewater
			Increasing sustainable storage capacity eg. Aquifer storage and recovery
Wastewater Management	Increased inflow of pollution caused by flooding	Improving treatment technology	Control of pollution at source and use of natural treatment techniques
	Flooding of wastewater treatment plants located near rivers or coasts	Construction of protective barriers or lifting of equipment	Use and appropriate citing of natural treatment techniques
Stormwater Management	Increased stormwater flows and combined sewer overflows	Improving and extending the infrastructure conveying stormwater away from the city	Attenuation of runoff through the use of Sustainable Urban Drainage Systems options, such as green roofs, porous paving, rainwater harvesting, detention ponds and basins

Source – ICLEI European Secretariat (2011)

Integrated Urban Water Management (IUWM) is a widely recognised integrated planning approach. Module 1 of the SWITCH Training Kit, elaborates further on IUWM (ICLEI European Secretariat, 2011). The Module of Urban Water Management developed under SCIAP in India but NIUA, of which this module is a part, discusses in detail the approaches of IUWM, Water Sensitive Urban Design (WSUD), and a few others. Decentralisation often defines the flexibility of non-conventional urban water systems. Decentralisation reduces the sensitivity by spreading risk which may be elaborated by the example of heightened risk faced by a city dependent on one or more large wastewater treatment plants as against a city that operates several smaller-scale natural treatment systems located in different areas. Decentralised solutions are often faster to install and more cost-effective to build and maintain. These considerations are particularly important in the face of changing conditions, which can easily render large investments in new treatment facilities or water supply infrastructure redundant.

Figure 4.3: Adaptation measures for addressing impacts of climate



Source – Authors

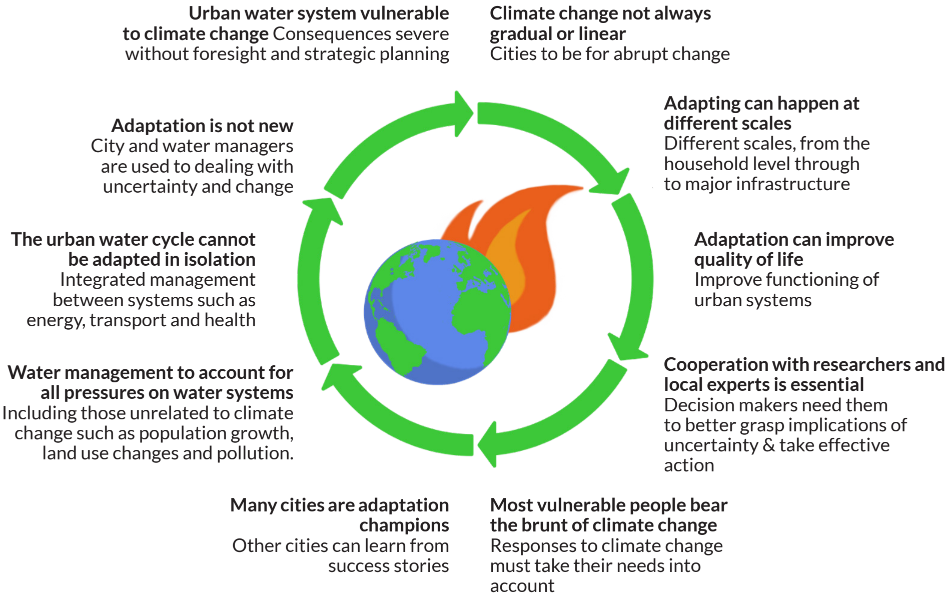
4.4 Water-Energy Nexus

The water and energy nexus in urban water utilities play a vital role in the current context. Water management is heavily reliant on energy for activities such as pumping, transportation, desalination, domestic water heating and the treatment of drinking water and wastewater. Water is also integral to energy production, through hydroelectric dams but also steam turbines and fossil fuel processing. The links between the two resources are becoming ever more apparent, particularly in the context of increasing resource scarcity and climate change.

At a time when many cities are trying to reduce greenhouse gas emissions to mitigate climate change, the intensive energy use of classic and conventional water infrastructure is a disadvantage. In planning mitigation and adaptation actions, cities must consider this interconnection between energy and water, to reduce the likelihood of unintended impacts.

Various sustainable water management options have the added advantage of reducing energy consumption, although in some situations more decentralised solutions can increase energy consumption, highlighting the need for constructive dialogue between water and energy managers (Kenway, 2010).

Figure 4.4: Key learning from Climate Change Adaptation in Water Sector



Source – Authors

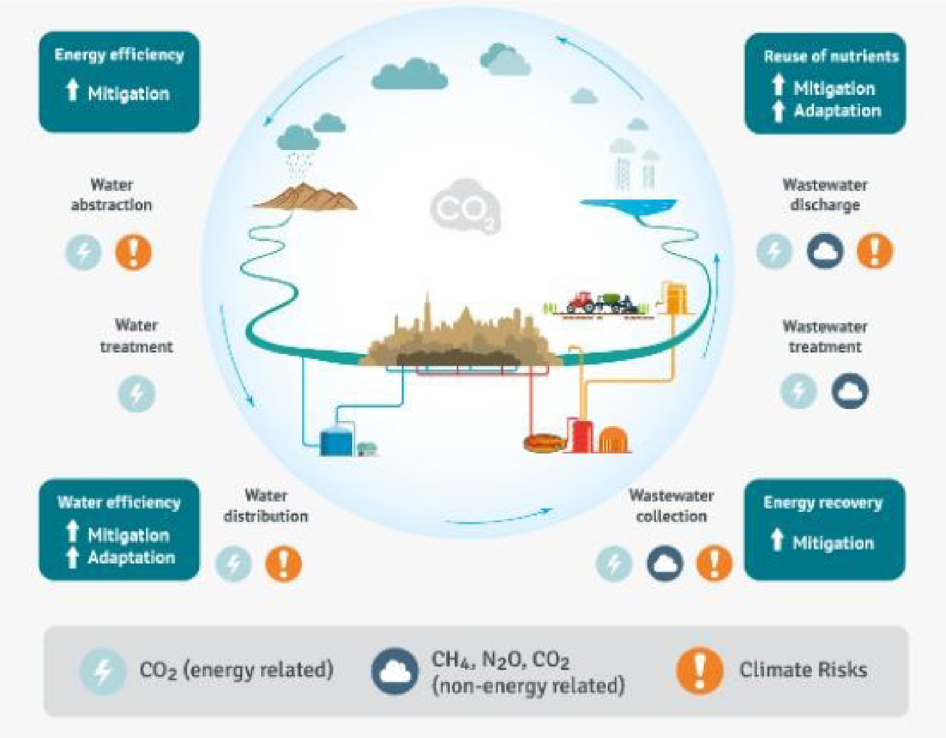
4.5 Calculating GHG emissions for water management (WaCCliM, 2017)

Introduction

The Energy Performance and Carbon Emissions Assessment and Monitoring (ECAM) tool is a web-based tool that is part of the knowledge platform developed by the Water and Wastewater Companies for Climate Mitigation (WaCCliM) project. This Tool offers a solution for utilities to quantify their GHG emissions and contribution to NDCs through reducing indirect and direct emissions from energy use and wastewater management. It is the first of its kind to allow for a holistic approach of the urban water cycle to drive GHG emission reduction in utilities, even those with limited data availability. It promotes transparency, accuracy, completeness, comparability and consistency.

This Tool is a carbon footprint tool for water and wastewater utilities, is a cornerstone of this approach. It also helps utilities understand their overall energy usage and total greenhouse gas emissions at a system-wide level and indicates areas to reduce emissions, considering all components of the urban water cycle, from water supply to wastewater treatment, sludge management and water reuse. The mitigation-focused ECAM Tool integrates well with WaCCliM's activities in support of adaptation, which improve the capacity of utilities to develop climate risk plans, analyse the co-benefits of mitigation and adaptation measures, and prioritise measures for more climate risk-resilient water and wastewater systems.

Figure 4.5: Mitigation and adaptation in the urban water cycle

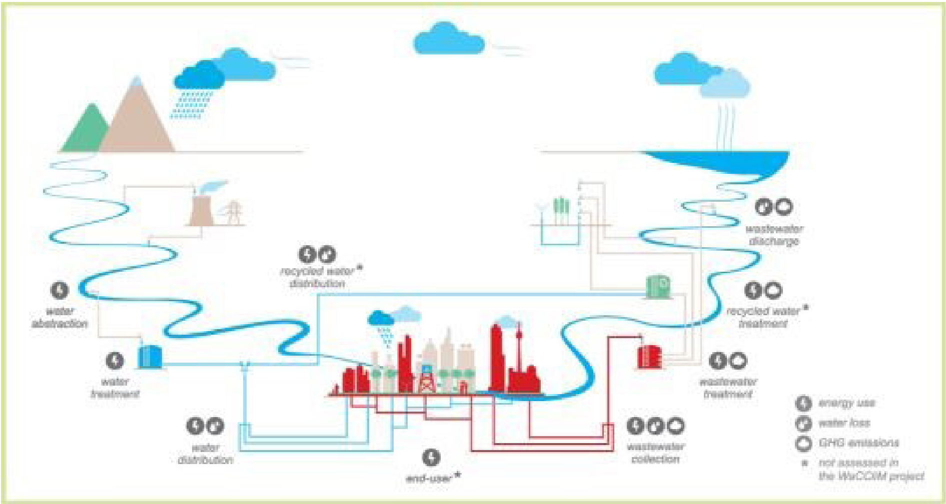


Source: (wacclim)

Holistic Approach

Typically in the water sector, emissions are assessed separately. The ECAM tool however, has been developed to facilitate the assessment of systems via a holistic approach, considering all stages of the urban water cycle and the interlinkages between stages Figure 4.6. The aim is to maintain the overview on the entire urban water cycle in the analysis, to convey the notion that sub-systems are inter-related.

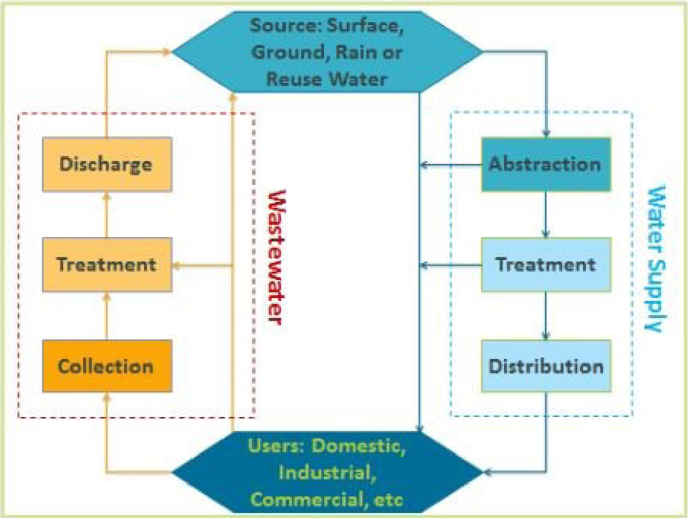
Figure 4.6: Stages of the urban water cycle



Source: (WaCCliM, 2017)

The applied framework of the urban water cycle includes the water supply and wastewater management processes (water abstraction and transmission systems, water treatment, water transport and distribution, wastewater collection, wastewater treatment and wastewater interception and discharge). Figure 4.7 shows the utility boundaries considered in ECAM Tool, the part under the dash lines.

Figure 4.7: System boundary



Source: (WaCCliM, 2017)

In ECAM the user experience starts with Tier A- Initial GHG assessment, which includes the whole water supply and wastewater handling services allowing a user to make a straightforward assessment with back-of-the-envelope calculations. The experience continues with Tier B – Detailed GHG assessment, in which the user can introduce more accurate values to calculate the GHG emissions of the drinking water and wastewater systems and can evaluate Energy Performance within the advanced assessment to identify potential energy savings for the 6 stages of the water cycle (Abstraction, Treatment, Distribution and Collection, Treatment, Discharge) and their individual facilities (pump stations, plants, network divisions) can be characterized. Some of the assessment results are compared with known benchmarks so that inefficiencies can be highlighted, and decision makers can prioritize improvements in the utilities' most promising stages.

The GHG estimation

Two categories of GHG emissions are included in ECAM. GHG emissions associated with electricity use scope 2 – (indirect emissions) and the GHG emissions not related to electricity use, which group the Scope 1 (direct emissions) and scope 3 (other indirect emissions) emissions per the IPCC definitions (see Table 4 2). The "non-electricity related" GHG emissions are associated with activities within the boundary of the utility, or which are a consequence of the services provided outside of the utility boundary.

Table 4.2: GHGs Emission from water and wastewater services

	Water abstraction	Water treatment	Water distribution	Wastewater collection	Wastewater treatment	Wastewater discharge
Scope 1 – Direct emissions						
Emission from the maintenance trucks	○	○	○	○	○	○
CO_2, CH_4 and N_2O emissions from on-site stationary fossil fuel combustion	■	■	■	■	■	■
CH_4 from sewers or biological wastewater treatment				○	■	
N_2O from sewers or biological wastewater treatment				○	○	
Scope 2 – Indirect emissions						
Indirect emissions from electric energy	■	■	■ ••	■ •	■	■ •
Scope 3 –Other indirect emissions						
Emissions from the manufacturing of chemical used		○			○	
Emissions from the construction materials used	○	○	○	○	○	○
CH_4 and N_2O emissions from wastewater discharge without treatment				■		
CO_2, CH_4 and N_2O emissions from sludge transport off-site					■	
N_2O emissions from effluent discharge in receiving waters						■

○ *Emissions not quantified in the ECAM tool, even though they exist* ■ *Emissions quantified in the ECAM tool*

•• *Unless water distribution is gravity (natural) fed* • *Unless wastewater collection/discharge is by gravity*

The energy assessment focuses on electricity consumption at each stage of the utility for process related usage. At each stage of the urban water cycle, the user may enter sub-stages representing the different facilities of that particular stage (e.g. different treatment plants, different pump stages or distribution networks). At the stage level, the energy performance can only be assessed in terms of relative importance of the stage in comparison to the entire water cycle. At sub-stage level, energy performance indicators are calculated to assess if there is a potential to reduce consumption or improve energy production by comparing to benchmark values. These performance indicators (e.g.: standardized pumping energy, treatment energy), when documented at the sub-stage level (i.e.: at the facility level), are then averaged to provide an overview of the overall efficiency of the stage.

4.6 Case Studies

Climate proofing of water and sanitation sector, Surat

Background

Planning for adaptation of Surat's vulnerability to climate change is determined both by its exposure to several climate change threats, including rising temperatures, sea-level rise and devastating floods such as the flood in 1994 and 2006. Surat, an industrial hub also known as the diamond city of India, lies in the southern part of the Indian state of Gujarat, with an approximate area of 326.51 km^2 and unprecedented growth in the post-independence causing strain on the depleting resources. However, Surat has been ranked as the most Climate-Smart City (with the highest five-star ranking) in the Climate Smart Cities Assessment Framework 2.0 of cities in India, announced in June 2021.

CITY PROFILE

SURAT CITY

Geographical Area: 326km^2

Population: 4.47 million

Climate Adaptation Strategies

Climate Adaptation strategies by the Utility

- Energy efficiency cell
- Reuse of treated waste water for industrial use
- Biogas generation
- Renewable energy use for water utilities such as wind power, solar power etc

Objectives of the programs undertaken in Surat

- To reduce the energy utilised in the water supply sector (energy efficiency measures and use of renewable energy)
- To augment reuse of treated wastewater for industrial use

Approach

Surat has been a pioneer city in implementing energy efficiency efforts in the water supply sector. In 1997, a biogas electricity generation pilot project was implemented with support from India's national Ministry of Non-Conventional Energy Sources (MNES), under the UNDP and National Program on Energy Recovery from Urban and Industrial Waste. In 1999, a biogas electricity generation project was implemented at the Anjana Sewage Treatment Plant. To enhance energy efficiency in the water supply sector Energy Efficiency Cell was established in 2001, that reduced energy use significantly strategizing

- energy audits,
- maintaining a database and monitoring,
- specific energy conservation measures at grids for potable water, and
- bill monitoring

Moving towards renewable energy sources such as the biogas plant implementation of 0.5 MWe at Anjana Sewage Treatment Plant of Surat Municipal Council in 2003 and the commissioning of the 3 MW Wind Power Plant, are early initiatives towards reductions in GHGs. In recent years (2019), Surat has become the first city in India to use solar power for meeting energy needs for the city's water supply.

Results

The total energy savings until 2014 was reported as 25,62,79,666 KWH, amounting to Rs. 214 cr. until 2014 with 4,02,310 tonnes of GHG saved.

Lessons learnt

- Rising from a crisis - Continuous learnings from several subsequent floods and extreme events in the city have brought stakeholders together to support SMC in implementing adaptation measures.
- Showcased the ability of wastewater realizing industrial water security without tapping freshwater resources while highlighting the ability of the PPP model.
- Government policies, regulations, and programs. SMC's efforts to build water management infrastructure align with the state government's policy for promoting recycled water for non-potable use and minimizing groundwater withdrawals, although several of these initiatives began even before the Government of Gujrat's Reuse & Recycle of Treated Wastewater Action Plan 2019 was laid. The Action plan supports replication and extension of the reuse in Surat to 70% of total sewage. Support from Government programs such as SBM (Urban), AMRUT, Smart City Mission, 15th Finance Commission have been encouraging.
- Bilateral funds and programs have also played an instrumental role in facilitating innovative solutions towards climate adaptation. Often the implementation of infrastructure projects depends on the availability of funds and technical support. The UNDP/GEF assisted the Sewage Gas Based Power Plant at Anjana Sewage Treatment Plant, (first in the country) in 1999.

Conclusion

Though the water supply and sanitation sector have lower GHG emissions when compared to other economic sectors, water utilities are realising the need for contributing towards reductions in GHG emissions through their low carbon commitments, implementing alternatives to improve their energy efficiency and reduce the GHG emissions. The efforts of Surat in reducing energy consumption in water supply systems consequently contribute towards the national goal of a 33-35% reduction in GHG emissions by 2030. The state of Gujarat emits the highest amount of CO_2 (90MT) which is around 18% of the total emissions in the country.[9]

[9] *https://www.orfonline.org/research/how-indian-states-are-promoting-sustainable-industry/*

Circular economy through reuse of treated wastewater and energy recovery from wastewater sludge, Chennai

Background

With a population of about 7.4 million people, the capital city of Tamil Nadu State produces 830 MLD of water catering to 8,76,891 consumers.

To respond to the rising water crisis and the uncertainties of climate change in the future as against an ever-increasing demand due to urban population growth, supply augmentation for the current Chennai Metro Water Supply and Sewerage Board (CMWSSB) was considered necessary.

Objectives of the programs undertaken in Chennai

- To reduce the energy utilised in the water supply sector (energy efficiency measures and use of renewable energy)
- To augment reuse of treated wastewater for industrial use

Approach

With growing industries, rising urban population and increasing water demand in the background of extreme events that impact water supply, CMWSSB worked towards allocating water resources for industrial use while meeting the rising needs for potable water for households. Recycling and reusing of wastewater for industrial users were initially tried at a small scale which CMWSSB scaled up to two tertiary treatment plants in 2015. The Water Reuse Project with energy-recovery systems, not just helped in augmenting reuse of treated wastewater for industrial osmosis plants of 45 MLD capacity each at two of the existing wastewater treatment plants and supply to industries instead of using freshwater. The main sources of water then included water from reservoirs and groundwater is now replaced by 16% desalination 10% recycled wastewater 65% reservoirs 9% groundwater.

Results

- Reduced cost of operation and reduced risks of water scarcity for industrial users
- Reduced expenses on water purchase for Industries (CPCL, MFL, and MPL) has resulted in annual savings of Rs 164 million.
- Increased sustainability of CMWSSB providing additional revenue for the utility
- Reduced load on freshwater resources
- This means that the use of an equivalent amount of fresh water is being avoided, indirectly augmenting available freshwater to meet the city's increasing water needs.
- Reduced GHG emissions –Installation of energy recovery plants at seven of the twelve WWTPs with a total installed capacity of 7 megawatts (MW) has reduced the dependency on electricity from the city's grid and thereby reduces the emission of GHGs.

Lessons learnt

- The success of the PPP models in ensuring performance and service standards is highlighted. Private participation also encourages contribution to capital and operating costs while assuring financial viability.
- Government support and regulations- The national, state, and municipal legislation and policies provide crucial support. Increased water costs for enterprises, as well as the zero-discharge regulation, have been strong factors for promoting use of treated wastewater. The Water Reuse Plan of CMWSSB and the Greater Chennai Corporation's bylaw mandating all stakeholders to recycle wastewater has played a vital role.
- Proactive planning and Innovative thinking- As a drought proofing measure and for augmentation of water supply to Chennai City, CMWSS Board has set up a 100MLD capacity Seawater Desalination Plant at Nemmeli and Minjur. The Chembarambakkam 530mld Water Treatment Plant has technologies to ensure least water losses from the plant with automated SCADA control and compact plant layout & optimum land usage saving land area.

Conclusion

These results from the case study mark a case of augmentation of water supply in addition to the reduction in greenhouse gas emissions, by CMWSSB's efforts in recycling and reuse between 60 and 75 per cent of the city's wastewater for industrial and indirect potable reuse. This has build resilience in water supply and improved water security supporting climate adaptation. The revenue earned has strengthened the CMWSSB's financial sustainability. The energy recovery system through the biogas power generation from wastewater treatment plants has reduced the electricity demand from the grids and hence contributed towards reduced GHGs.

4.7 Dovetailing climate adaptation strategies in other utilities

Build climate-resilient Water Supply and Sanitation infrastructure.

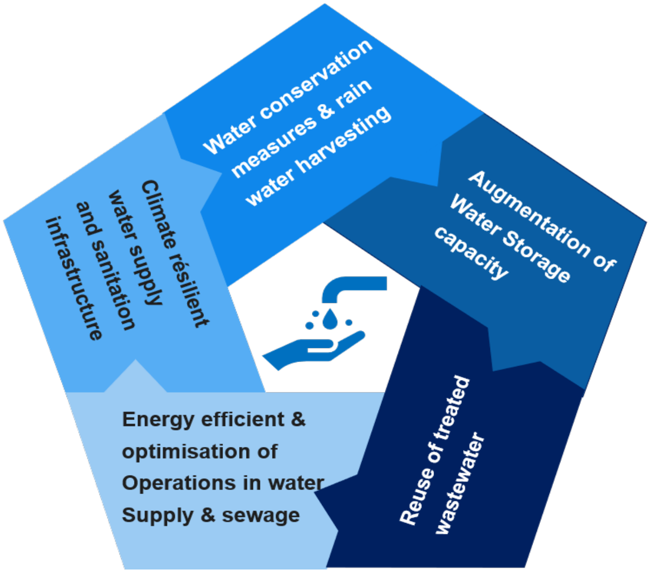
Climate Resilient infrastructure would need to be planned, designed, built and operated for facing climate change events and adapting to the same. For cities to ensure that climate resilience of water and sanitation infrastructure the following aspects are to be covered;

- Risk Assessments for assessing the climate resilience of water and sanitation infrastructure should also include Hazard risk assessments and vulnerability assessments.
- Integrating innovative advanced technologies such as real-time weather forecasting and early warning systems with water supply services
- Strengthening cost-effective approaches to provide potable water supply services during climate extreme events such as floods, cyclones or droughts
- Enhancing exigency planning for hazard events

- Strengthening Water Supply and Sanitation infrastructure based on the risk assessments (such as flood proofing including flood barriers to protect infrastructure etc)
- Integrating Public-Private Partnerships in Climate Resilient Infrastructure for cities

See Climate Resilient Infrastructure Planning in Vishakhapatnam city, https://www.teriin.org/eventdocs/files/Case-Study-Vishakhapatnam.pdf

Figure 4.8: Dovetailing climate adaptation strategies in other utilities



Water conservation measures and Rainwater harvesting

Most Indian cities receive around 900 mm of average annual rainfall and also have several natural water bodies, yet these water resources are not utilised effectively. Conservation of water resources and rainwater harvesting will help utilities bridge the demand supply gap and adapt to drought like scenarios. The Jal Jeevan Mission (JJM) launched for India's Water sector in 2019, not only focussed on functional tap water connections for 100% of households in India, and improving water infrastructure but also brings about a transformative shift from traditional linear water supply delivery to the circular economy of water conservation. The 'Jal Shakti Abhiyan: Catch the Rain' campaign as a Jan Andolan (mass movement) launched for encouraging water conservation at the grassroots level is an important step towards water adaptation. The City Water Balance Plan, the City Used Water/Recycle/Reuse Plan, and the City Aquifer Management Plan under the JJM are noteworthy in the management of water.

Please see the case study on the Revival of Mansagar Lake, Jaipur at *https://smartnet.niua.org/sites/default/files/resources/Doc%203_Revival%20of%20Mansagar%20Lake.pdf*

Augmentation of water storage capacity

Increasing water storage options and enhancing water-saving opportunities is considered one of the most effective climate adaptations measures. Enhancing surface water storage options by rejuvenating lakes and water bodies and increasing the amount of groundwater storage availability promotes adaptive capacity especially to extreme events like droughts and enables meeting the growing water needs.

Refer to the *NITI Ayog, 2017, Selected Best Practices in Water Management* at *http://social.niti.gov.in/uploads/sample/water_index_report2.pdf*

Reuse of treated wastewater

While the Draft National Policy on the Safe Reuse of Treated Wastewater (2020) is under finalisation, there is extensive pressure to reuse treated wastewater especially for industrial use and address the rising water scarcity in the cities. Several states such as Gujrat, Tamil Nadu, Haryana, Karnataka have set mandatory targets for the reuse of wastewater. According to a recent report by the World-Wide Fund, around 30 Indian cities are to face serious water shortage and diversifying water sources early will be immensely useful.

Please see *A Qualitative Framework to Evaluate the Extent of Integrated Urban Water Management in Indian Cities & Applying the Framework to Delhi https://www.niua.org/sites/default/files/NIUA-UNESCO_White%20Paper.pdf5*

Energy Efficiency and optimisation of operations in Water Supply and Sewerage

The highest expenditure on water utilities is for electricity consumption. Energy efficiency measures will save energy costs and make them reduce their carbon footprint. Also, while most utilities are grappling under growing demand and reducing supply, reuse of wastewater, deep well pumping, large scale desalination all demand increased energy. Hence adopting energy-efficient measures and shifting to renewable sources of energy is vital. At the same time wastewater treatment is of grave concern to all cities in India, the amount of GHGs released through the untreated wastewater and sludge can be reduced and cleaner energy is used in the water supply for the utilities.

Please see, *GDI, 2016, Wastewater Systems and Energy Saving in Urban India* at *http://re.indiaenvironmentportal.org.in/files/file/Wastewater%20systems%20and%20energy%20saving%20in%20urban%20India.pdf*

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Chapter 5

Legal Instruments Addressing Climate Change Impacts on Water Resources

Recap

The previous chapter dealt with climate change adaptation measures for utilities in the water sector, choosing flexibility and water energy nexus. The chapter also provides a guide for calculating GHG emissions in the domain of water management.

Training Objectives

- Present an overview of national/state/city level policies and programmes in addressing climate change challenges in water sources management.
- Study the linkages of water and climate change with policy action.
- Review the trends of related policy decisions in India over time.
- Rethink the current policy approaches towards water management in India given the need to act for climate change.

Training Outcomes

- Improved knowledge base and better understanding on the national/state/city level policies and programmes related to water-climate change linkages.
- Participation and inclusion of the public and different stakeholders
- Facilitating review and amendments of water resource management based on monitoring and updates of policy analyses

Chapter Contents

5.1 Introduction

In India, the impacts of climate variability on water resources are likely to affect the key economic sectors of irrigated agriculture, installed power capacity, reduced water flows during the dry season, droughts, floods during the wet season, water supply, urban storm/ flooding, etc. In 2019, water shortage was identified as one of the key reasons for the crisis faced by India's coal-fired energy sector (Woods & Schlissel, 2019). Between 2013 and 2017, water shortage forced the shutdown of 61 coal-fired plants, resulting in nearly 17,000 gigawatt-hours of lost power. Research indicates that water-related challenges are likely to worsen as the impacts of climate change in terms of aggravating the duration and severity of extreme weather events like flooding and drought.

Over the years, various national, state, and municipal level laws and policies have been devised and enforced by the respective Ministries and Departments of the Government of India, State Governments as well as Urban Local Bodies (ULBs) to ensure sustainable management of water resources for combating climate change. In this section, selected four Indian four states (and cities) are in focus. These are Andhra Pradesh (Vijayawada and Guntur), Karnataka (Mysore), Madhya Pradesh (Bhopal), and Rajasthan (Jaipur). In a 2020-study titled 'Climate Vulnerability Assessment for Adaptation Planning in India Using a Common Framework' (DST, GoI, 2020), the states of Rajasthan, Madhya Pradesh, Andhra Pradesh, and Karnataka were categorized as "moderately vulnerable to climate change" and they ranked 14, 15, 17 and 18 respectively in the pan-India assessment (refer Table 51).

Table 5.1: Overview of vulnerability to climate change of select states in India

States	Status of Vulnerability	Key Related Driver(s) of vulnerability
Andhra Pradesh	State-specific assessment: * • *Krishna District (Vijaywada):* Relatively High Vulnerable (0.583) • *Guntur District:* Relatively Low Vulnerable (0.49) All-India district-level assessment • *Guntur:* Vulnerability index (VI): 0.625; Rank: 114th	• Lack of access to an improved drinking water source (in 2 districts in the+ state) • 74.8% of households in Guntur with an improved drinking water source
Karnataka	State-specific assessment: * • Mysore: Relatively Low Vulnerable (0.68) All-India district-level assessment • Mysore: VI: 0.545; Rank: 372nd	• Lack of access to an improved drinking water source (in 11 districts in the state) • 95.6% of households with improved drinking water facilities and 51.28% groundwater depletion in Mysore

States	Status of Vulnerability	Key Related Driver(s) of vulnerability
Madhya Pradesh	State-specific assessment: * • Bhopal: Relatively Very Low Vulnerable (0.43) All-India district-level assessment • Bhopal: VI: 0.531; Rank: 409th	• Low groundwater availability (in 29 districts in the state) • Water-borne diseases (in 2 districts in the state) • 16.5% groundwater availability in Bhopal • 555 cases of water-borne diseases (Diarrhea/Dysentery) per 1,00,000 population reported in Bhopal
Rajasthan	State-specific assessment: * • *Jaipur:* Relatively Low Vulnerable (0.44); All-India district-level assessment • *Jaipur:* VI: 0.506; Rank: 491st	• Water-borne diseases (in 1 district in the state) • 9 water-borne diseases per 1000 population in Jaipur

Source – Adapted from DST, GoI (2020)

** District Level: Relatively High Vulnerable (0.587-665); Relatively Moderate Vulnerable (0.509-0.586); Relatively Low Vulnerable (0.432-0.508)*

5.2 National Policies Addressing Climate Change Challenges

The Government of India launched the National Action Plan for Climate Change (NAPCC), 2008 to mitigate and adapt to the climate change impacts. In 2009, all state governments and Union Territories (UTs) were directed to prepare State Action Plans on Climate Change (SAPCC), based on the strategy outlined in the national plan. The SAPCC of Rajasthan was submitted in 2010, of Andhra Pradesh and Madhya Pradesh in 2012, and Karnataka in 2013. The NAPCC has 8 sub-missions with an aim to fulfil India's developmental objectives on reducing emission intensity. The National Water Mission aims for water conservation by reducing wastage and ensuring equal distribution of water resources across states through integrated management programs. Five goals were identified to attain this objective:

- Comprehensive water database to be shared in public domain and assessment of impacts;
- Promotion of state action for water conservation;
- Focus on vulnerable/overexploited areas;
- Increasing water use efficiency by 20%; and
- Promotion of integrated water resources management.

Two other Missions of the NAPCC focus on water conservation to some extent. The National Mission on Sustainable Habitat focuses on ensuring water supply through making rainwater harvesting mandatory as well as conducting regular water and energy audits. The National Mission on Sustainable Agriculture aims to optimize utilization of water resources for farm management, achieve low-input sustainable agriculture through enhanced water use efficiency, undertake micro-irrigation for efficient use of water (40 MHa), and practice water conservation in 35 MHa of rainfed areas (2009 – 2017).

The National Adaptation Fund for Climate Change (NAFCC), 2015 was created to meet the costs of climate change adaptation projects of States/UTs. The NAFCC prioritises projects that build climate resilience in the areas identified under the National and State Action Plans. The NAFCC also covers vulnerability and climate impact assessment, capacity building of various stakeholders, and effective knowledge management. An account of the NAFCC projects in the four Indian states in focus is given below.

- The project on 'Climate Resilient Interventions in Dairy Sector in Coastal and Arid Areas in Andhra Pradesh' (DoAH, GoAP, 2017) implemented by the State Department of Animal Husbandry aimed to establish community-based shelters for heat/cyclone resilience through provision for rainwater harvesting/ponds for ensuring adequate water availability, and others.
- The project on 'Conservation and management of indigenous varieties of livestock (Cattle and Sheep) in the wake of climate change in Karnataka' (DoAHaVS, GoK, 2016) implemented by the State Department of Animal Husbandry and Veterinary Services aimed to enhance fodder production during the lean period of water flow (to facilitate milk/meat production as well as increase the life span of livestock).
- The project on 'Enhancing Adaptive Capacity to Climate Change through Developing Climate-Smart Villages in three Vulnerable Districts (Sehore, Rajgarh and Satna) of Madhya Pradesh' (UD&ED, GoMP, 2017) focused on water-smart interventions like lined farm ponds and broad bed furrow planting.
- In Rajasthan, the project 'MukhyaMantri Jal Swavlamban Abhiyaan' (MJSA) For Climate Change Adaptation and Water Harvesting in Arthuna, Anandpuri and Sajjangarh blocks of District Banswara (2016-2017)' (RD&PRD, GoR, 2018) was implemented by the State Department of Watershed Development & Soil Conservation in 70 villages. The key objectives were to:
    - Develop 'self-reliant' villages in terms of water requirement;
    - Enhance adaptation and improve resilience;
    - Improve groundwater management;
    - Improve drinking water availability;
    - Increase crop production.

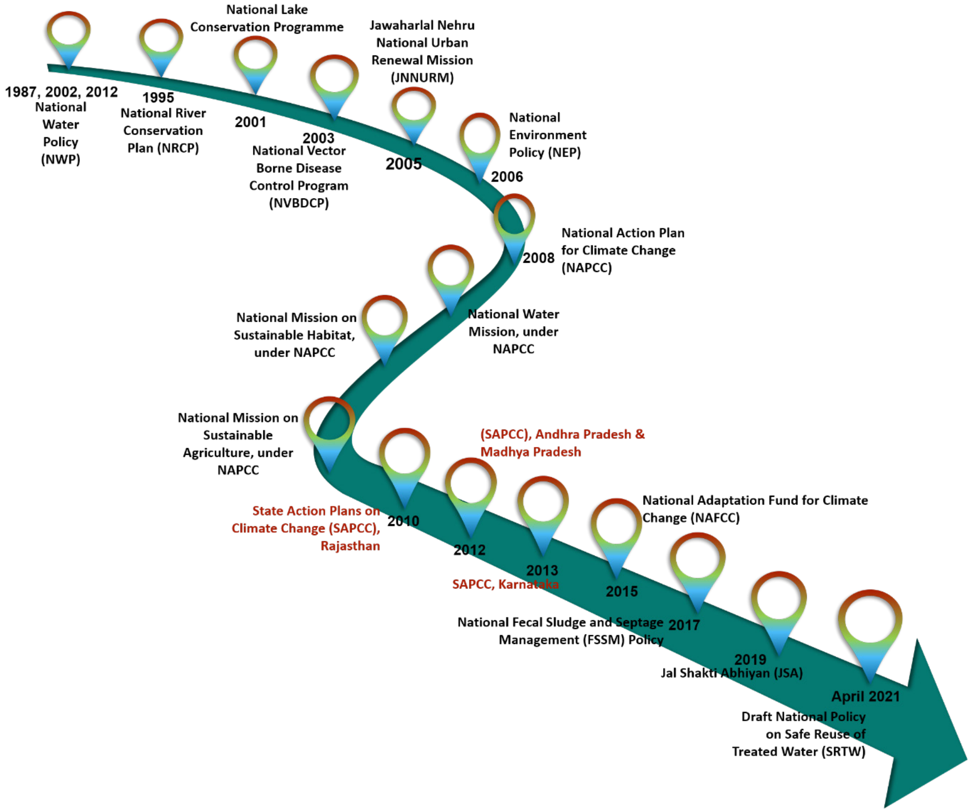
    The main project activities included water conservation and water harvesting along with extensive plantation. The scope of Watershed, Groundwater, Agriculture, Horticulture, Public Health Engineering, Water Resources, Livelihood, and Forest Departments were converged to achieve the objectives of MJSA.

The Draft National Policy on Safe Reuse of Treated Water (SRTW) (April 2021) promotes the management of the hydrological cycle by integrating the existing and proposed policies on sanitation, faecal sludge management, and the reuse of used industrial water. The Draft Policy works on a wider context of river basin planning and relevant actions to address climate change. Ranging from the national to the local level, the Policy mandates the reuse of treated used water for various non-potable uses, creates a mechanism to support SRTW, and proposes a model policy framework for States to develop/modify their policy, regulation and implementation instruments.

Jal Shakti Abhiyan (JSA) is a time-bound water conservation campaign implemented in two phases: the first phase from July 1 to September 15, 2019, for all States and Union Territories; and the second one from October 1 to November 30, 2019, for States and UTs receiving retreating monsoon (including Andhra Pradesh and Karnataka) (MoJS, GoI, 2019). The JSA aimed at making water conservation a Jan Andolan through asset creation and communication. Various target interventions were made in the water-stressed districts (least availability of groundwater): a) Water conservation and rainwater harvesting; b) Renovation of traditional and other water bodies/tanks; c) Reuse/recharge structures; d) Watershed development; and e) Intensive afforestation. Most of these interventions helped address the impacts of climate change on water resources, either directly or indirectly.

National Water Policy (NWP) aims to govern the development of water resources and ensure their optimum utilization. The first National Water Policy was adopted in 1987, was reviewed in 2002 and later in 2012. The NWP 2012 emphasizes climate change stating the need for "mitigation at the micro-level by enhancing the capabilities of community to adopt climate-resilient technological options". The NWP states that coping strategies must be adopted to deal with climate change. References to climate change are made at several places in the policy document. The Policy asserts the need to keep water-related impacts of climate change in mind while taking decisions related to water resources management. The details of this NWP 2012 can be found in the module on Urban Water Management of this series.

Figure 5.1: Relevant National Policies



Source: Author

The National Fecal Sludge and Septage Management (FSSM) Policy, 2017 is to facilitate nationwide implementation of FSSM services in all ULBs to promote 'safe and sustainable sanitation in every urban household in India. In addition, it aims to promote good sanitation habits with improved onsite sanitation services to achieve public health benefits, with a special focus on poor populations. This Policy will thus help to address the climate change impacts on sanitation systems and related FSSM services. The details of this policy can be found in the module on Urban Waste Water and Septage Management of this series.

National Vector Borne Disease Control Program (NVBDCP) is aimed at preventing and controlling six vector-borne diseases (VBDs) including malaria. Such diseases are transmitted through vectors like mosquitos and ticks, could be water-related (though not transmitted by the faeco-oral route). Malaria causing female anopheles mosquito thrives in polluted water bodies, irrigation wells, etc. Therefore, prolonged rains, and stagnant water aid in disease transmission, and hence needs proper management. Climate is one of the key factors that influence the distribution of diseases borne by these vectors that spread pathogens causing illness. Protection and conservation of water bodies can contribute to reducing these Vector-Borne Diseases, and help address the impacts of climate change. Under NVBDCP, an Enhanced Malaria Control Project (EMCP) was implemented in 100 districts of 8 States (including Andhra Pradesh, Madhya Pradesh, and Rajasthan) inhabited by tribal populations that led to a 45% decline in malaria cases. Monitoring and close surveillance under this program will help identify climate-related changes to vector-borne disease trends and bring about corrective action including those related to water resources management.

National Lake Conservation Plan (NLCP) of India aims at the conservation and management of polluted and degraded lakes in urban/peri-urban areas. The key activities include desilting, de-weeding, interception and diversion of sewage entering lakes, etc (MoEFCC, GoI, 2008). It was initiated in 2001 and covered 63 lakes in 14 states. The scheme included six lakes of Rajasthan, 16 in Karnataka and four lakes in Madhya Pradesh. In February 2013, for better coordination and smooth implementation of activities, NLCP was merged with National Wetland Conservation Programme (NWCP). Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) in association with the National Plan for Conservation of Aquatic Ecosystems (NPCA) of the MoEFCC is implementing a project on 'Wetlands Management for Biodiversity and Climate Security' (2018-2022) in 3-4 Ramsar sites (MoEFCC, GoI, 2016) located in the states of Himachal Pradesh, Odisha, and Tamil Nadu, to secure and enhance wetland biodiversity and ecosystem services.

National River Conservation Plan (NRCP), 1995 aimed at preventing river pollution and improving the river water quality. The activities included construction of STPs, riverfront development, low-cost sanitation, afforestation etc. NRCP covered polluted stretches of 33 rivers in 76 towns spread over 15 Indian states. The Ministry of Environment, Forest & Climate Change (MoEFCC) is currently working on pollution abatement of rivers under NRCP, excluding Ganga and its tributaries. The rivers covered under NRCP in the four Indian states in focus are given in Table 5.2.

Table 5.2: Rivers Covered under NRCP in 4 Indian states

State	Rivers covered under NRCP
Andhra Pradesh	Godavari, Krishna, Pennar, Tungabhadra
Karnataka	Bhadra, Cauvery, Pennar, Tunga, Tungabhadra
Madhya Pradesh	Narmada, Tapi, Wainganga
Rajasthan	Ghaggar, Sabarmati

Source - Manda (2021)

The National Environment Policy (NEP), 2006 of the MoEFCC aims at mainstreaming environmental concerns into all developmental activities. It outlines conservation strategies for the existing environmental resources (including water resources) through regulatory reforms as well as promotes intersectoral collaboration and periodic evaluations of the current policies.

Jawaharlal Nehru National Urban Renewal Mission (JNNURM), 2005 is an urban modernization program involving integrated development of infrastructure services in cities related to water supply and sanitation, sewerage, solid waste management, etc. to provide basic services to the urban poor. It also included the provision of wastewater management services related to the recycling of wastewater.

In addition, many states have adopted Demand Side Management Application programs like Drip irrigation systems for increasing water-energy efficiency, which has the potential to reduce the amount of greenhouse gas emissions.

5.3 State Level Policies Addressing Climate Change Challenges

Andhra Pradesh

The Government of Andhra Pradesh has taken several measures for climate change adaptation (especially for the vulnerable sections living below the poverty line), including programs to improve safe water provision, better living conditions, and public health.

Andhra Pradesh State Action Plan for Climate Change 2012 aims to reduce the impact of climate change and achieve environmental sustainability. The key sectors covered under the action plan are Forests and biodiversity, Transportation/ urban development (including water supply system), and Health/Industries/energy. An indicative list of sectoral adaptation/ mitigation interventions related to water resource management is given in Table 5.3.

Table 5.3: Key Recommendations from Andhra Pradesh SAPCC: Interventions for management and sustainability of water resources

Sector	Key interventions
Agriculture	• Development and dissemination of new crop varieties resilient to water stress • Extension program for change of cropping timings and patterns, the efficiency of water use, etc.
Forestry & Biodiversity	• Soil and Water Conservation in forest lands
Energy	• Improve the efficiency of electrical equipment, including water pumping equipment used in agriculture
Industries	• Protection and disaster mitigation activities to reduce risks to industrial areas (e.g., seawalls, improving drainage, alternate water supply sources etc.)
Urban Development	• Safe water supply as per norms for the urban population • Study and remodel existing water supply, sanitation, and sewerage systems to reduce climate change vulnerability • Protection and restoration of existing water bodies in urban areas, creation of new water bodies • Restoring efficiency of drainage network of municipalities to avoid flooding • Mandatory rainwater harvesting systems in Government buildings, larger homes and apartment blocks, commercial establishments, offices, schools/colleges, academic/research establishments, and industrial units • Recovery of phosphates nitrates etc. from wastewater

Source – EPTRI (2012)

In 2017, based on the Model Building Byelaws 2016 of the Government of India, the Municipal Administration and Urban Development of the Government of Andhra Pradesh brought out the Andhra Pradesh Building Rules, 2017 (MA&UDD, GoAP, 2017). This legislation promotes climate-resilient construction mandating water conservation measures like rainwater harvesting and groundwater recharge for improving the environmental conditions for building and construction under Category "A" (5000 sq. m - 20000 sq. m). This State Bylaw applies to both the cities of Guntur and Vijayawada.

The Rajiv Aarogyasri Community Health Insurance (RACHI) in Andhra Pradesh is a social insurance scheme with a private-public partnership model that aims to improve equity of access to healthcare for the poor. It is predicted that there might be increasing demands for this healthcare service resulting from climate-related ill health of the local population. Climate-related illnesses are linked to extreme weather events like heat stress, and the prevalence of water-borne illnesses. It is imperative to monitor these trends as it will enable the authorities to take preventive measures (such as warnings before heatwaves and water stress) to protect public health, especially that of a vulnerable population.

The 'Andhra Pradesh Wastewater Reuse & Recycle Policy', 2017 aims at effective Water Resource Management for ULBs and acts as a mitigation measure for the effects of climate change in the state. It promotes the reuse of treated wastewater in irrigation enabling more freshwater to be used for specific municipal purposes (MA&UDD, GoAP, 2017). The aspects covered in this policy include expanding collection and treatment of wastewater, updating/creating standards, and practices for using treated wastewater in the irrigation and industry sectors. It highlights the importance of increasing surface water utilization and decreasing the use of groundwater for municipal uses.

Karnataka

Climate change impacts are evident in the state of Karnataka. The historical trends show a 6% decline in rainfall between 1951 and 2004, especially in the coastal and north interior districts of the state. Karnataka State Action Plan on Climate Change (SAPCC) entails a comprehensive action plan covering the key sectors and defines about 200 action points to combat climate change; some of the relevant interventions are given in Table 5.4.

Table 5.4: Key Recommendations from Karnataka SAPCC: Interventions for management and sustainability of water resources

Sector	Key interventions
Agriculture	• Reevaluating all agriculture-related policies to integrate climate change issues. • Promotion of Dryland farming • Rendering theft of sprinkler pipes unviable
Water Resources	• Enforcement of Karnataka Groundwater Act • Creation of Policy body for restricting groundwater use • Introduction of a groundwater cess • Introduction of capital subsidy for RWH structures • Integrated water resources management in public buildings • Revision of pricing policy for irrigation water
Coastal zone	• Promotion of effluent treatment plants
Other interventions	• Regional research on climate change • Documentation of adaptation practices • SAPCC updation, as needed

Source – EMPRI (2011)

Karnataka State Water Policy aims at:

- providing drinking water at the rate of 55 litres per capita per day (LPCD) in rural areas, 70 LPCD in towns, 100 LPCD in city municipal council areas and 135 LPCD in city corporation areas;
- creating irrigation potential of 45 lakh hectares under irrigation projects, and an additional 16 lakh hectares by individual farmers using groundwater.

It promotes the creation of a legislative, administrative, and infrastructural environment to ensure equitable distribution and utilization of water resources in the state. The State Policy is in line with the National Water Policy of 2012 in many aspects in terms of recommending interventions such as rainwater harvesting and groundwater recharge. But the State Policy does not refer to issues related to climate change which are featured very prominently in the National Water Policy 2012. In this context, a study was conducted to review the State Water Policy of 2002 and provide recommendations for modifying it in line with the National Water Policy, 2012. These recommendations were needed to address climate change and aspects such as awareness generation, preparedness, coping mechanism, etc. at the state level. In 2019, The new Karnataka State Water Policy was drafted by the Karnataka Jnana Aayoga Task Group. It states that per capita water consumption for domestic use should come down from 135 LPCD to 80-100 LPCD (Karnataka State Water Policy 2019).

The Government of Karnataka's State Urban Wastewater Reuse Policy, 2017 provides a comprehensive framework for wastewater reuse, aiming at cost recovery, equity, and sustainability for urban wastewater management (UDD, GoK, 2017). It focuses on the industrial reuse of treated wastewater for the financial sustainability of ULBs and mitigating water supply risks. The policy covers all Class I and II cities of the state. Reuse of at least 20% secondary treated wastewater (of the total urban wastewater generated) is targeted for identified urban centres by 2020. It advocates the preparation of Integrated Urban Water Management plans by cities.

Karnataka State Fecal Sludge and Septage Management (FSSM) Policy, 2017 recognizes the good practices of treating and disposing of septage/faecal sludge and regulation of the sanitation value chain (GoK, 2017). It aims to achieve 100% coverage of safe sanitation, promotion of non-sewer sanitation models, safe handling/containment of faecal sludge/ septage, scheduled desludging, environmental improvement, better public health, newer employment opportunities and greater institutional capacities for FSSM in the state.

Karnataka Groundwater (Regulation and Control of Development and Management) Act, 2011, through the constitution of an empowered Groundwater Authority, is a key legal instrument for reducing groundwater exploitation. It mandates obtaining permissions for drilling bore wells and drawing water for water-intensive crops in notified areas. It also aims to take necessary steps for rainwater harvesting and identify rainwater-recharge-worthy areas in the state.

To address knowledge deficits in water resources management and for providing a platform for the inclusion of stakeholders in decision processes, the Government of Karnataka established the Karnataka Water Resources Authority under the Ministry for Water Resources in 2008. As mentioned above, an additional Groundwater Authority has been established under the Karnataka Groundwater Act 2011.

Karnataka Drinking Water and Sanitation Policy 2002 is implemented to manage different institutional structures (across departments and institutions) and challenges related to the delivery of drinking water and sanitation services for urban Karnataka, with a likelihood of addressing the related climate change challenges.

The Karnataka Town and Country Planning Act, 1961, and its subsequent amendment in 2004 prescribed the preparation of Master Plans by planning authorities. The prescribed use of solar water heaters and rainwater harvesting systems are two prominent examples where policy decisions were made mandatory through first Structure Plans and then Master Plans.

Water resources are under severe threat in Karnataka. The state is endowed with limited water resources that are stressed and depleting. The State Water Resources Department has initiated comprehensive actions on conservation needs, replenishment, supply and the participation of common people in watershed management.

The State Departments of Agriculture, Horticulture, Animal Husbandry and Krishi Vigyan Kendra had taken up several water conservation measures to address climate change impacts (GWP-India, 2016):

- Soil conservation, rainwater harvesting
- Advising farmers to go for mulching and use of micro-irrigation
- Introducing drought-resistant varieties of crops.
- Awareness of water conservation.
- Increasing green cover area by encouraging area expansion programme of different perennial horticulture crops.
- Creation of water harvesting structures in farmers' fields.

As agriculture is the largest water-consuming sector, the state of Karnataka has been investing a large share of its budget on major, medium, and minor irrigation facilities, large budget funds were invested on such irrigation structures. The state is also promoting the adoption of water-efficient technologies such as drip and sprinkler irrigation techniques to enhance the water productivity and reduce the cost of cultivation.

Madhya Pradesh

Madhya Pradesh SAPCC aims to address concerns and outline strategies for the development of a climate-resilient state. As per Madhya Pradesh SAPCC, the key strategies for adaptation to climate change under the water sector are the increase the water use efficiency for irrigation, domestic and industrial purposes. The strategies and recommendations of the SAPCC will strengthen the developmental planning process of the state with policy-level interventions helping low carbon growth. The strategies and activities pertinent to the key economic sectors are given in Table 5.5.

Table 5.5: Key Recommendations from Madhya Pradesh SAPCC: Interventions for management and sustainability of water resources

Sector	Key interventions
Forests & Biodiversity	• Ensure soil and water conservation measures in forest management • Capacity Building activities for forest officials and communities
Water Resources	• Comprehensive water database (in the public domain) and assessment of the climate change impacts on water resources • Promote surface water development • Water conservation, and augmentation/preservation for areas with heavily depleted groundwater • Increase water use efficiency for irrigation, domestic and industrial purposes • Promote basin level integrated watershed management • Capacity building of professionals from various departments/ organizations/ PRI/ULBs • Building Institutional mechanism for Climate Change Action Plan
Agriculture sector	• Promoting the use of water conservation technologies • Enhancing dissemination of new and appropriate technologies and strengthening further research - Promotion of energy-efficient water pumps • Agriculture information management (water security)
Horticulture	• Soil and water conservation through demonstration of best practices
Animal Husbandry	• Ensuring availability of adequate water for livestock • Ensure adequate housing for livestock to overcome heat stress - Identification and management of dedicated water bodies for the cattle to cool off • Integrate livestock water requirements in watershed management programs • Strengthening fish rearing practices in an integrated manner with the management of reservoirs and watersheds • Make quality fish seeds available to fishers - Promote research on developing fish seeds that are suitable for different waterbodies
Health Sector	• Strengthening support systems for environment management - Identify measures for source reduction for all vector-borne, water-borne diseases • Awareness on Health Issues – Public health education about various vector-borne, water-borne, and other climate-related diseases • Capacity building of rural health activists on vector- & water-borne diseases as well as techniques to purify drinking water
Urban Development & Transport	• Enhancing Energy Efficiency in Residential in-built environment – a) Follow norms related to urban water supply, sewage treatment facility, etc. b) Adoption of energy efficiency measures for urban water supply and sewerage equipment of ULBs • Urban Water Supply – a) Promote water-efficient garden irrigation techniques, reduce leakage in the domestic supply system, water recycling b) Awareness among people about Reduce and Recycle techniques for wastewater • Urban Storm Water Management • Wastewater Management – a) Pilot project for segregation at the household level of black and grey water b) Strengthening institutional and technical capacities of ULBs for effective O&M of sewerage system, and recycling and reuse of wastewater for non-potable uses • Creation and Adoption of benchmarks for sustainable management of water supply, wastewater, stormwater drainage and solid waste management

Sector	Key interventions
Energy	• Undertake demand-side management to improve efficiency and reduce GHG emissions - Promote Energy Efficiency in Street lighting and Water Pumping, Buildings
Industry	• Build strict rules and regulations for upcoming industrial zone keeping in view optimum management of water resources • Devise an integrated water management plan for industrial clusters • Creation of green zones and water harvesting structures in industrial clusters
Rural development	• Promotion of water efficiency in agriculture and other uses • Coordination and integration with the Climate Change action plans of departments like forest water, agriculture, energy and health so that climate resilience of the communities is ensured
Environment	• Improve understanding of climate change at policy level on- water, food security, land-use change, disease transmission, Greenhouse Gas emissions, Clean Development Mechanism etc. in collaboration with relevant institutes/departments

Source – H&ED, GoMP (2014)

Madhya Pradesh State Level Policy for Wastewater Recycle & Fecal Sludge Management, 2017 is to ensure the improved health status of the urban population, especially the underprivileged, through the provision of sustainable sanitation services and protection of the environment. The Policy guides recycling, reuse of treated effluent and safe disposal of sludge, financial management and cost analysis, standards/regulations/quality assurances, legislation and institutional framework, public awareness and IEC & other priority issues (UD&HD, GoMP, 2017).

Madhya Pradesh State Water Policy 2003 addresses the exploitation of groundwater resources for drinking water purposes. The Policy entails maintenance and modernization of key water resources, groundwater development, water allocation priorities, drinking water and quality control, irrigation and land management, rationalization of water rates, the importance of participation in water management, institutional participation including that of non-governmental institutions, the establishment of water zone and watershed management, flood control and management, scarcity area management, science and technology, as well as provision of training and capacity building (GoMP, 2003).

Rajasthan

The state of Rajasthan has the highest climate sensitivity, maximum vulnerability, and lowest adaptive capacity, affected by severe droughts, water shortage, and abrupt rise in surface temperature. The Rajasthan Action Plan on Climate Change aims to enhance resilience in the state by addressing current and likely impacts of climate change on key sectors, enhance adaptive capacities of the vulnerable communities, and tap potential opportunities for mitigation. The key interventions for water resource management identified in the Rajasthan SAPCC are given in Table 5.6.

Table 5.6: Key Recommendations from Rajasthan SAPCC: Interventions for management and sustainability of water resources

Sector	Key interventions
Water Resources	• Groundwater management with focused attention on overexploited areas • Enhancing preparedness for drought monitoring, drought mitigation and development of early warning system • Enhancing Water Conservation Measures • Improving Water Use Efficiency • Developing a comprehensive water database for assessment of climate change impacts on water resources
Agriculture & Animal Husbandry	• Enhancing the productivity of crops and livestock - Development of climate-hardy cultivars which are tolerant to droughts, thermal extremes, and are less water consumptive.
Human health	• Research-based prioritization of vulnerable regions/populations for targeted health interventions - Study the regional pattern of climate-sensitive diseases & disease outbreaks including waterborne diseases • Strengthen disaster management plan specific to the health sector - for management of sanitation, water, etc.
Forests & Biodiversity	• Measures to address land degradation and desertification including water resources management
Enhanced energy efficiency and use of renewable energy	• Demand-side measures including energy efficiency – Waste-to-energy- Greenhouse gases from municipal solid waste disposal, domestic wastewater disposal, and industrial wastewater disposal. • Reduction of transmission and distribution losses - providing tariff concession on solar water heaters
Urban Governance and Sustainable Habitat	• Urban stormwater drainage infrastructure improvement related to an increase in frequency and intensity of extreme rainfall • Restrict/control land use in areas prone to flash-flood • Preparedness and Mitigation Plan – community participation through awareness programs on extreme weather events, good practices to avoid the spread of water-borne diseases and training on monitoring river water levels to prevent future disasters • State directive (to ULBs) to incorporate water harvesting and wastewater treatment and dual water supply for other uses than drinking, in building by-laws for a reduction in mean annual rainfall in some areas • Amendments to existing urban policies to incorporate water conservation and harvesting principles • Calculation of water footprint, linking with tax rebates for business owners and individuals • Promoting green buildings as a mitigation strategy – procurement of water-saving equipment
Strategic Knowledge on Climate Change	• Climate change vulnerability assessment and strategies for better preparedness - Hydrology and water resources is a key sector • Dissemination and Capacity Building on climate change for government officials including Department of Water Resources & Irrigation • Technical capacity building for the advancement of research on climate change - Hydrological Modeling (of groundwater, surface water and basin hydrology).

Source – TERI (2010)

To overcome water shortage in the state, Rajasthan State Sewerage and Wastewater Policy, 2016 promotes the use of potable water only for drinking purposes, and reuse of water (of a certain standard after proper treatment) for non-potable uses. It also aims to achieve scientific disposal of waste to ensure 100% sanitized cities. It is to be noted that only 2% of the population of Jaipur is provided with partial sewerage coverage. The Policy takes into consideration various national and state legislations like the Effluent Quality Guidelines for health protection measures in aquaculture use of wastewater and Quality Guidelines for health protection in using human wastes for aquaculture.

Rajasthan State Water Policy, 2010 proposes an integrated approach to planning, development, and sustainable management of water resources. The policy focuses on Integrated Water Resources Management, with a holistic and bottom-up approach. It addresses issues related to water supply and development, sustainable irrigation, water resources infrastructure, water conservation, water quality, environmental management, water pricing, legal support, capacity building, research, monitoring and evaluation of water policy and action plans. Rajasthan State Water Resource Planning Department (RSWRP) is the implementing organization. Water Resource Vision 2045 has been prepared to highlight the short term (up to 2015) and long term (up to 2045) thrust areas and action plans which are the pre-requisites for successful implementation of the State Water Policy and Plan.

Rajasthan State Environment Policy, 2010 is in line with the objectives and underlying principles of the National Environment Policy, 2006, and addresses state-specific specific issues related to the key sectors like agriculture, animal husbandry, mining, industry, tourism, energy, and basic urban services and infrastructure, most of which are linked to climate change impacts.

Rajasthan Farmers Participation in Management of Irrigation System Act 2000 aims to promote and secure distribution of water among its users, sustenance of the irrigation system, efficient utilization of water to optimize agricultural production, and environmental protection. It encourages the involvement of farmers by promoting a sense of ownership for irrigation. It specifies a water budget and operational plan for the implementation of these activities.

5.4 City-Level Policies/Programs Addressing Climate Change Challenges in Water Sources Management

Mysore

Mysore City Sanitation Plan 2011 is a key planning tool and vision document for achieving city-wide sanitation. It aims at improving water supply services that are likely to provide resilient solutions for the challenges of diminishing water sources and impacts of climate change.

Mysore Urban Development Authority Master Plan 2031 envisions a balanced and equitable urban growth for Mysore through suggested interventions for new land use plans and zonal regulations. The plan mandates rainwater harvesting for all plots that are more than 200 sq m. in extent. It also calls for conservation and preservation of open spaces including water bodies of the city.

Rockefeller Foundation's Asian Cities Climate Change Resilient Network (ACCCRN) program aims at improving climate resilience and enables local governments to assess climate risks related to urbanization, poverty and vulnerability and formulate resilience strategies. Under ACCRN, the Mysore City resilience strategy was developed (CDIA, 2015). Following the strategy document, a resilient, integrated, stormwater drainage project was adopted for the city of Mysore. This project was aimed to increase the capacity of urban drainage and address drainage problems (caused by solid waste disposal and untreated sewage discharge into open drains), thereby reducing the negative impacts of increased floods linked to climate change.

Jaipur

Jaipur Development Authority (JDA) developed Building By-Laws for Rainwater Harvesting & Recycling applicable for all plot sizes measuring 300 Sqm or more in their plot (JDA, 2013). JDA constructed RWH structures in all their office buildings, residential buildings, community centres, etc. This initiative is likely to address the challenge of depleting groundwater and address climate change impacts in the city of Jaipur.

Vijayawada-Guntur

The 'Cities and Climate Change' initiative of the International Development Research Centre (IDRC), Canada has piloted a comprehensive integrated rural-urban water management for climate-based adaptations (IAdapt) program in the city of Vijayawada (Athena Infonomics, 2018). Athena Infonomics is the implementing partner of the project. The city of Vijayawada is being showcased as a model city at the national level as a "replicable and scalable model".

A bottom-up stakeholder-centric rural-urban platform has been established. A Decision Support Tool is used to simulate and predict climate adaptation scenarios for its effective integration into water resource programs; in other words, to move from conventional water management approaches to an 'Integrated Approach' based on the principles of IWRM and IUWM. The essence of the program lies in establishing a connection between the main stakeholders and facilitate scientific and inclusive decision making. The end objective is to replicate activities at the state level culminating into policy framework, the first-of-its-kind in India.

Bhopal

Under the Bhopal Smart City Program, Rainwater Harvesting (RWH) System will be installed for city buildings. Bhopal Municipal Corporation (BMC) is one of the 98 smart cities of the Government of India under the National Smart Cities Mission. As per the plan for Bhopal, Area Based Development plans have adapted the Sustainable Urban Drainage System Strategy. All buildings should have an RWH System with Storm Water Detention Capacity to reduce peak run-off that will be utilized by the building itself to meet its water needs (Saha, 2017).

Climate change is all a global, regional, national, and local challenge. The policy instruments discussed in this section are extremely relevant in this ever-changing world. The social and economic challenges of the ongoing COVID-19 pandemic were further compounded by the climate disasters like Cyclone Amphan in 2020 and Cyclone Yaas in 2021 (Climate Action Tracker, 2020). Research indicates that with the currently implemented policies, India can achieve its Nationally Determined Contribution target. Under policy projections, greenhouse gas emissions (excluding Land Use, Land-Use Change and Forestry, LULUCF) was likely to reach a level of 2.8-2.9 GtCO2e in 2020 and 3.8–4.1 GtCO2e in 2030. The economic standstill is due to the pandemic is leading to sharp reductions in greenhouse emissions in the short term, but they will start increasing again at an earlier rate unless India develops a focused and sustainable COVID-19 recovery strategy. Water management entailing sustainable management of quality and quantity of water resources plays a key role in achieving the national targets. With an accelerating population and economy and rapidly changing climate, India needs to pay importance and address its challenges related to water resources to ensure a long-term supply of safe water for all concerned.

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Glossary

Adaptation – It is the adjustment in natural or human systems to climate change (including climate variability and extremes) is known as adaptation. It is the process sought to cope with the consequences of climate change.

Climate – Climate refers to the average weather, in terms of the mean, and its variability over a certain time span and area.

Climate Change – The change in the state of the climate that can be ascertained by changes in the mean and/or the variability of its properties, and that lasts for extended period of time.

Climate-proofing – These are the actions taken to improve the resilience and resistance of infrastructure to climate change impacts, risks, hazards, and climate extremes.

Greenhouse Gases – GHG are chemical compounds found in the Earth's atmosphere, such as carbon dioxide, methane, water vapor, and other human-made gases, that allow much of the solar radiation to enter the atmosphere, where the energy strikes the Earth and warms the surface.

Mitigation – Mitigation refers to an action aimed towards reduction or prevention of greenhouse gas emissions. It can also include developing and deploying new technologies, using renewable energies like wind and solar, or making older equipment more energy efficient etc.

Resilience – Resilience is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization and the capacity to adapt to stress and change.

Sensitivity – Sensitivity is the degree to which a a system (natural or human) is affected to change in climate.

Vulnerability – Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.

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