DECEMBER 2025

# GANGA RIVER BASIN MANAGEMENT PLAN 2.0

## (GRBMP 2.0)

## FRAMEWORK


Prepared by

cGanga

Centre for Ganga River Basin
Management and Studies
Indian Institute of Technology Kanpur

## National Mission for Clean Ganga (NMCG)

NMCG is the implementation wing of National Ganga Council which was setup in October 2016 under the River Ganga Authority order 2016. Initially NMCG was registered as a society on 12th August 2011 under the Societies Registration Act 1860. It acted as implementation arm of National Ganga River Basin Authority (NGRBA) which was constituted under the provisions of the Environment (Protection) Act (EPA) 1986. NGRBA has since been dissolved with effect from the 7th October 2016, consequent to constitution of National Council for Rejuvenation, Protection and Management of River Ganga (referred to as National Ganga Council).
www.nmcg.in

## Centre for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this it is also responsible for introducing new technologies, innovations and solutions into India.
www.cganga.org


## Acknowledgment

This report is a collective effort of many experts, institutions and organisations, in particular team cGanga, IIT Kanpur & NMCG, Jal Shakti Ministry, GoI.

## Suggested Citation

cGanga & NMCG, 2025, Framework: Ganga River Basin Management Plan (GRBMP 2.0)



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*Framework*

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# Preface

Rivers have shaped India's civilisation, culture, ecology, and economy for millennia. Yet today, the lifelines that sustain nearly half of our population face unprecedented stress. Rapid urbanisation, declining groundwater, intensive agriculture, shrinking floodplains, untreated effluents, and the impacts of climate change together threaten the health of the Ganga River Basin, one of the world's largest and most densely populated. Meeting these challenges requires more than isolated interventions; it demands a unified, scientific, and administratively workable framework to guide coherent national action.

The Ganga River Basin Management Plan (GRBMP), prepared in 2015 by the Consortium of seven IITs, established the foundational philosophy and long-term vision for rejuvenating the Basin. Since then, the declaration of the National Mission for Clean Ganga (NMCG) as an authority and the launch of Namami Gange Programme have significantly advanced national understanding and commitment. As NMCG's knowledge partner, cGanga has been mandated to continually evolve this framework in response to new scientific insights, administrative experience, and emerging environmental realities.

GRBMP 2.0 has been developed within this mandate. It synthesises advances in science with lessons from national missions, district-level experiences, and CAMP assessments undertaken by leading institutions. The updated framework expands the original basin-scale vision into a structured architecture that integrates hydrology, ecology, soils, agriculture, geomorphology, wetlands, groundwater, climate resilience, pollution management, and governance into a single coherent system. A central contribution of GRBMP 2.0 is its ability to bridge natural (ecological) boundaries with administrative ones by enabling district-level implementation through District River Management Plans (DRMPs).

This document presents GRBMP 2.0 as India's first fully integrated blueprint for basin governance, anchored in digital monitoring, adaptive management, ecological restoration, and accountability. It recognises that river rejuvenation must extend beyond pollution control to restoring ecological flows, improving sediment and nutrient balance, reviving wetlands and natural buffers, strengthening soil health, and building resilient rural-urban water cycles. By aligning with national missions and the Sustainable Development Goals (SDGs), GRBMP 2.0 provides a pathway for convergence across departments and levels of government.

Developed by cGanga with support from NMCG and contributions from experts across disciplines, this framework aims to guide basin-scale planning, state coordination, and district implementation. The aspiration is to empower policymakers, administrators, scientists, and communities to work collectively to safeguard the Ganga Basin, ensuring that as the river leaves each administrative boundary, its ecological condition is preserved and progressively improved.

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## Framework

# GANGA RIVER BASIN MANAGEMENT PLAN (GRBMP 2.0)

## Summary

### 1. Purpose & Vision

GRBMP 2.0 provides a comprehensive, basin-wide framework to restore the Ganga and its tributaries by integrating hydrology, ecology, agriculture, urban systems, governance, digital tools, climate resilience, and Arth Ganga (green livelihood systems). It shifts river management from fragmented interventions to a harmonised, science-driven, community-led and economically sustainable model.

The long-term vision is a Nirmal (clean), Aviral (continuous), and ecologically vibrant Ganga Basin, where healthy rivers, wetlands, floodplains, and aquifers support resilient communities, sustainable economies, and cultural heritage.

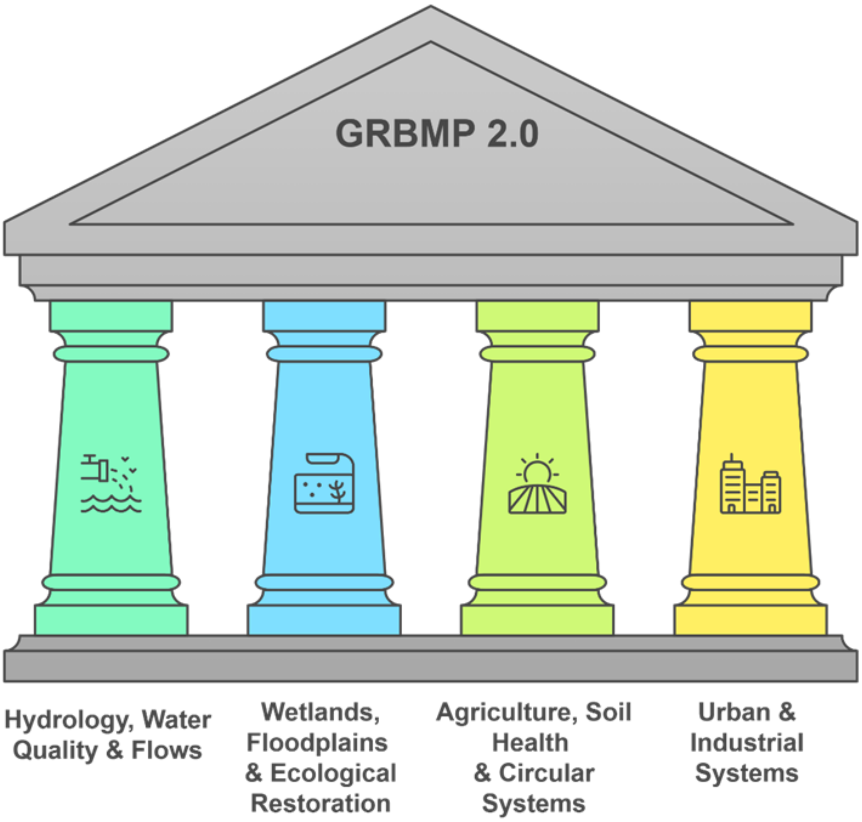
### 2. Core Principles

1. Integrated River Basin Management (IRBM) — connect land, water, biodiversity, and economic systems across the basin.
2. District River Management Plans (DRMPs) operating as ground-level engines of rejuvenation, updated annually and integrated with district administration.
3. Nature-Based Solutions as well as wetlands, floodplains, riparian forests, and soil systems form the backbone of hydrological and ecological restoration.
4. Closing the Water, C-N-P Loop at appropriate scale using treated wastewater, biomass, soil nutrients, and agriculture function within circular cycles.

Presents a basin-wide roadmap that unifies scattered projects into one ecological, hydrological and economic recovery program, defining success as clean, perennial rivers, restored wetlands and aquifers, climate resilience and green livelihoods under Arth Ganga.

5. Digital Governance — sensors, GIS, drones, remote sensing, and unified dashboards enable real-time monitoring and transparency.
6. Community Stewardship involving Jal Mitras, SHGs, farmers, youth clubs and citizen science play central roles.
7. Practicing Arth Ganga, realizing both spirit and economy, linking river restoration with livelihoods, green enterprises, and economic resilience.
8. Adaptive Management: Refine decisions through continuous monitoring, evaluation, and data-driven revision.

## 3. Key Components of GRBMP 2.0




### *A. Hydrology, Water Quality & Flows:*

- Restore perennial flows through decentralised STPs, treated wastewater discharge, wetland replenishment, and aquifer recharge.
- Improve Nirmal Ganga by appropriately treating sewage, industrial waste, and agricultural runoff using decentralised treatment, CETP upgrades, and nature-based systems.

- Maintain ecological flows using gauging stations, release protocols, and upstream–downstream coordination.

### *B. Wetlands, Floodplains & Ecological Restoration:*

- Wetlands act as natural treatment plants, flood buffers, recharge zones, and biodiversity hotspots.
- Floodplains are reconnected to rivers through hydrological restoration, channel revival, desilting, and riparian buffers.
- Biomass harvesting prevents eutrophication and forms a raw material for compost and biochar industries.

### *C. Agriculture, Soil Health & Circular Systems:*

- Promote regenerative agriculture: crop diversification, micro-irrigation, mulching, agroforestry, soil carbon enhancement.
- Reduce nutrient leakage into rivers through Integrated Nutrient Management (INM), buffer strips, soil management, and wetland-linked nutrient cycles.
- Transform biomass from drains/wetlands into compost, biochar, fish feed, and green products.

### *D. Urban & Industrial Systems:*

- Hybrid wastewater systems: sewers + d-STPs + polishing wetlands.
- Stormwater–sewage separation with minimal additional large sewer network and green urban infrastructure reduce flooding and pollution.
- Industrial compliance through CETPs, ETP modernisation, real-time monitoring, and hazardous waste regulation.
- Urban lake and drain rejuvenation improve water quality, biodiversity, and microclimate.

## 4. Governance & Institutional Architecture

- NMCG provides strategy, funding, standards, and basin oversight.
- cGanga anchors science, technology, frameworks, and tools.
- State Ganga Committees ensure convergence across departments.
- District Ganga Committees (DGCs) serve as implementation hubs, managing DRMPs and coordinating all sectors.
- ULBs & Panchayats execute ground-level restoration, sanitation, and wetlands/pond management.

- Community groups monitor conditions, maintain wetlands, operate compost units, and support enforcement.

## 5. Digital Systems & Monitoring

- Unified digital architecture includes GIS maps, IoT sensors, remote sensing, drone surveys, early warning systems (EWS), and AI-based analytics.
- Dashboards integrate water quality, flows, groundwater, wetland status, industrial compliance, and project progress.
- Citizen-facing apps support crowd-reporting and transparency.
- Digital systems allow GRBMP to function as a living, adaptive platform.

## 6. Climate Resilience & Disaster Management

- Flood mitigation through wetlands, floodplains, improved stormwater systems, and early warnings.
- Drought resilience through aquifer recharge, treated wastewater irrigation, soil moisture conservation, and crop diversification.
- Climate-smart agriculture and climate-proof infrastructure support long-term stability.

## 7. Arth Ganga: Green Livelihoods & Economic Regeneration

- Green enterprises: compost, biochar, biomass products, nurseries, fish farming, ecotourism, handicrafts, cultural tourism, riverfront amenities.
- SHGs, youth groups, cooperatives, and micro-enterprises drive local economies.
- Navigation, river-based tourism, craft clusters, and heritage circuits support broader economic revival.

## 8. Financial Sustainability

- Multi-source finance: NMCG, state budgets, municipal funds, national schemes, CSR, PPPs, green bonds, blue bonds, and impact funds.
- Convergence with MGNREGA, SBM, JJM, PMKSY, CAMPA, Smart Cities Mission, etc.
- O&M sustainability through lifecycle costing, user charges, and revenue-generating eco-economies.
- Carbon credits and ecosystem services valuation support long-term financial autonomy.

## 9. Monitoring, Evaluation & Adaptive Cycles

- Comprehensive monitoring tracks hydrology, water quality, biodiversity, agriculture, groundwater, and climate risks.
- Annual DRMP renewals ensure continuous improvement.
- Mid-term basin reviews (every 5 years) recalibrate priorities and update GRBMP versions.
- Adaptive management ensures long-term resilience against emerging threats.

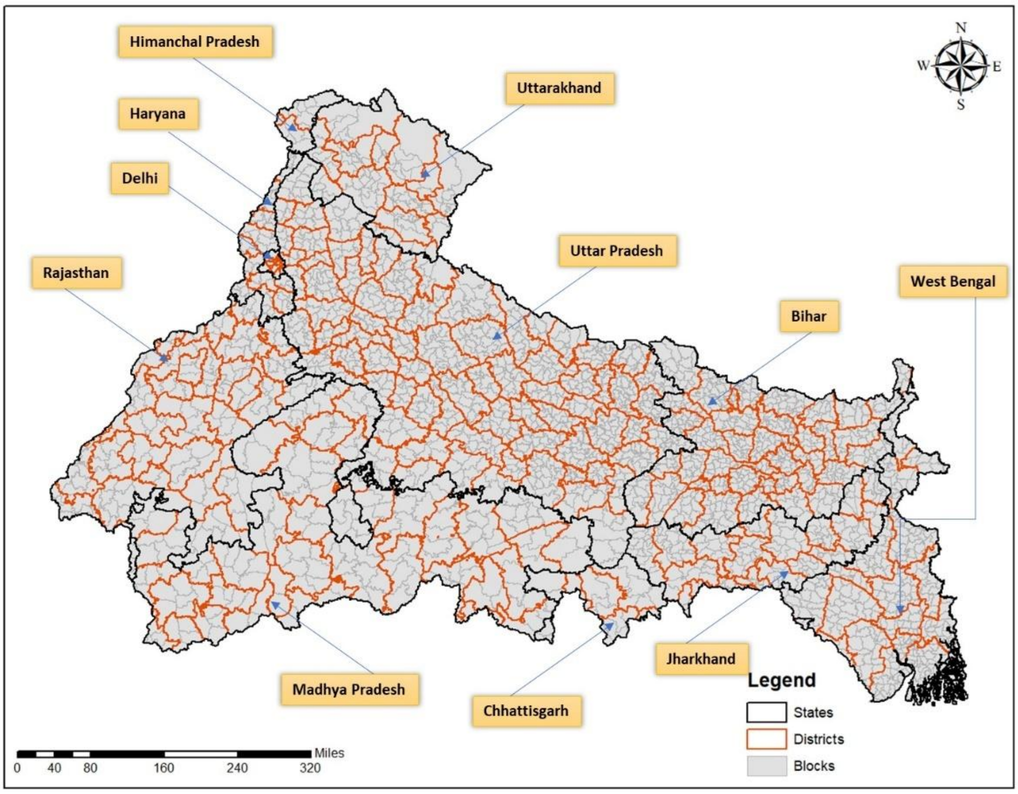
## 10. Long-Term Vision

GRBMP 2.0 envisions the Ganga Basin transformed into a self-repairing ecological system, a resilient hydrological network, and a vibrant eco-economy. It unifies science, governance, communities, and technology to create a globally exemplary model of sustainable river basin management.

## 1. Introduction

The Ganga Basin, covering ~1.09 million km$^2$, is one of the world's most complex socio-ecological systems. It sustains:

- 520+ million people
- 273 districts
- 11 states
- Multi-tributary hydrology with 50+ key rivers
- Thousands of drains and wetlands
- The world's largest alluvial aquifer system




GRBMP 1.0 introduced a scientific basis and policy philosophy. But new challenges that include rapid urbanisation, climate variability, groundwater decline, wetland loss, industrial intensification, floodplain encroachment, and ecosystem fragmentation require an action-oriented, cyclic, district-driven GRBMP 2.0.

### GRBMP 2.0 aligns with modern frameworks:

- **Samarth Ganga** (Aviral, Nirmal, Jan, Gyan, Arth Ganga)
- **DRMP** (District River Management Plans)
- **RHMP** (River Health Monitoring Program)
- **Integrated soil–water–biomass metabolism**
- **Arth Ganga economic pathways**
- **Digital governance** (GBIC/VGKC)

It provides a basin-wide yet district-operational blueprint.

GRBMP 2.0 establishes a comprehensive, science-based, and operational blueprint for rejuvenating the Ganga Basin through hydrological restoration, ecological regeneration, socio-economic integration, and district-level execution. The introduction defines the basin as a living ecological system whose health is shaped by multiple interacting components: rivers, tributaries, wetlands, drains, aquifers, soils, forests, agriculture, industries, floodplains, and settlements. The chapter presents river rejuvenation as a basin-wide responsibility requiring decentralised planning through District River Management Plans (DRMPs), supported by real-time monitoring under the River Health Monitoring Program (RHMP). The introduction lays out the need for integrated water quantity and quality management, nature-based treatment systems, wetland restoration, sustainable agriculture, groundwater security, and socio-cultural engagement. It frames GRBMP 2.0 as a shift from isolated engineering interventions to a holistic, multi-sectoral strategy aligned with Namami Gange, Arth Ganga, Jal Jeevan Mission, AMRUT, and other national programs.

## 1.1 Background

The Ganga Basin faces persistent pressures from population growth, urban expansion, industrial intensification, agricultural nutrient loading, declining groundwater levels, wetland degradation, and climate-related variability. GRBMP 1.0 provided the initial scientific foundation for basin planning, including ecological flow concepts, pollution load modelling, and conservation principles. Over the past decade, new data and insights have emerged on hydrological connectivity, soil–water–biomass cycles, managed eutrophication, wetland metabolism, and district-level governance. River management now requires deeper integration across sectors, real-time datasets, nature-based solutions, and decentralised operational structures. Basin governance has matured with the creation of NMCG, District Ganga Committees, and national missions. The background establishes the context for GRBMP 2.0 as an upgraded, implementable framework that unifies scientific advances, policy evolution, administrative experience, and community participation.

## 1.2 Need for GRBMP 2.0

Untreated sewage inflows, industrial discharge, agricultural runoff, and solid waste continue to degrade river stretches and tributaries, while groundwater depletion and wetland loss weaken natural hydrological buffers. Climate variability has altered rainfall patterns, reduced base flows, intensified floods, and increased drought frequency. Urban centres generate rising wastewater loads, and rural sanitation gaps persist. Restoring river health requires a basin-wide strategy that integrates hydrology, ecology, agriculture, industry, and socio-economic systems. GRBMP 2.0 provides a unified framework connecting decentralised wastewater treatment, wetland-based natural purification, soil restoration, biomass management, agricultural nutrient control, groundwater recharge, floodplain preservation, and economic linkages. District-level DRMPs become the operational units of implementation, supported by RHMP monitoring, digital dashboards, and multi-tier governance. The need for GRBMP 2.0 arises from the demand for actionable, scalable, and adaptive solutions grounded in contemporary science and field realities.

## 1.3 Scope of GRBMP 2.0

GRBMP 2.0 covers the full hydrological, ecological, socio-economic, and governance dimensions of the Ganga Basin across all 273 districts and 11 basin states. The plan includes characterisation of rivers, tributaries, drains, wetlands, floodplains, ponds, reservoirs, aquifers, soils, and land use systems. It embeds water quality and water quantity management, ecological flow assurance, decentralised wastewater treatment, wetland-based natural purification, industrial compliance, rural sanitation, agricultural nutrient optimisation, and groundwater recharge within a single, coherent framework. The scope extends to biodiversity conservation, soil restoration, biomass harvesting, climate resilience, disaster-risk reduction, and economic revitalisation under Arth Ganga. GRBMP 2.0 integrates district-level plans (DRMPs), river health monitoring (RHMP), and basin governance through command centres and data platforms. Its scope is basin-wide in vision but district-operational in execution, ensuring alignment of natural boundaries with administrative structures.

## 1.4 Structure of the Document

The GRBMP 2.0 document progresses from foundational concepts to operational strategies through a layered structure. It begins with basin overview, hydrological characterisation, ecological principles, and socio-economic context. This is followed by thematic chapters covering water quality management, wastewater treatment, ecological flows, tributary rehabilitation, groundwater governance, wetland and floodplain rejuvenation, soil–water–biomass integration, agricultural transformation, industrial regulation, and climate resilience. Later chapters describe the DRMP framework, including district methodologies, project clusters, monitoring systems, and governance models. The document concludes with implementation roadmaps, finance models, evaluation metrics, and annexures containing technical standards, templates, and operational protocols. Each chapter builds logically on the previous ones, linking basin-level science with district-level planning and project execution. The structure ensures coherence, clarity, and ease of adoption by policymakers, technical agencies, administrators, and communities.

# 2. Vision & Objectives

The vision and objectives chapter establishes the overarching direction for GRBMP 2.0, defining outcomes for hydrology, ecology, water quality, socio-economic systems, culture, and governance. The vision emphasises a perennial, pollution-free, ecologically functional, culturally vibrant, and economically productive Ganga Basin. Objectives include restoring environmental flows, ensuring zero untreated discharge, regenerating wetlands and floodplains, reducing industrial and agricultural pollution, stabilising groundwater, enhancing biodiversity, and shifting to decentralised and nature-based water management systems. The chapter integrates Samarth Ganga's pillars—Aviral, Nirmal, Jan, Gyan, and Arth Ganga—into basin planning. Another objective is strengthening multi-tier governance through DRMPs, RHMP, district Ganga committees, and basin command centres. The objectives guide all sector-specific and district-level interventions and provide a unified lens for evaluating progress and adaptive management.

## 2.1 Vision Statement

A self-sustaining Ganga Basin with continuous and adequate ecological flows, clean water that supports aquatic life, resilient ecosystems across rivers, tributaries, wetlands, and floodplains, and a harmonious balance between human development and natural processes. The basin thrives through restored hydrological connections, protected floodplains, revitalised wetlands, healthy soils, and sustainable aquifer systems. Communities across urban and rural landscapes participate actively in river stewardship, supported by scientific knowledge, cultural reverence, and river literacy. Economic activities, including agriculture, fisheries, tourism, and biodiversity-based enterprises, align with ecological health under the Arth Ganga model. Governance structures ensure transparency, accountability, data-driven decision-making, and coordinated action across districts and states. The vision reflects a long-term commitment to safeguarding the ecological integrity, hydrological stability, cultural heritage, and economic vitality of the Ganga Basin for future generations.

## 2.2 Objectives

Achieve uninterrupted environmental flows across all major rivers and tributaries; eliminate untreated sewage and industrial effluent discharge; integrate decentralised wastewater treatment with wetland-based natural purification; regenerate wetlands, ponds, lakes, and floodplains; restore and protect riparian zones and aquatic habitats; reduce nutrient and pesticide pollution from agriculture through soil health improvement and runoff management; ensure groundwater recharge and sustainable extraction; create nature-based infrastructure for flood management; promote biodiversity conservation and biomass-based ecological maintenance; strengthen river-centred livelihoods through Arth Ganga; empower communities as custodians of river systems; establish real-time water quality and flow monitoring through RHMP; institutionalise

DRMPs as district-level hydrology–ecology–governance frameworks; mainstream climate resilience and disaster preparedness into basin planning; align national schemes with basin priorities; and ensure adaptive management through periodic reviews and scientific updates.

### 2.3 Guiding Principles

River systems function as interconnected ecological continua, requiring integrated management across surface water, groundwater, soils, biota, wetlands, and floodplains. Planning must align natural hydrological boundaries with administrative governance through district-led DRMPs. Nature-based solutions—wetlands, floodplains, riparian buffers, soil carbon enhancement, and biomass management—form the foundation of sustainable restoration. Water quality improvement hinges on source reduction, decentralised treatment, reuse, and nutrient recycling. Socio-cultural values and traditional practices enrich river stewardship, while scientific monitoring ensures accountability. Climate resilience, disaster-risk reduction, equity, and livelihood security guide all interventions. Economic instruments under Arth Ganga create incentives for conservation and sustainable enterprise. Decision-making must be transparent, participatory, and data-driven, supported by digital river basins observatories. The principles ensure ecological integrity, hydrological stability, adaptive governance, and long-term sustainability.

### 2.4 Alignment with National Policies and Missions

GRBMP 2.0 aligns with Namami Gange, Jal Jeevan Mission, Swachh Bharat Mission, AMRUT, National Wetlands Rules, National Water Policy, Atal Bhujal Yojana, National Mission for Clean Ganga, National River Conservation Plan, Smart Cities Mission, and climate adaptation frameworks. It integrates the ecological flow mandates of the National Ganga Council, water-use efficiency targets, groundwater recharge protocols, sanitation and wastewater norms, and urban stormwater guidelines. The plan supports national ambitions for circular economy, green growth, and nature-based infrastructure. Convergence pathways include: d-STPs under AMRUT; rural greywater under SBM-G; aquifer recharge under Atal Bhujal; wetland restoration under MoEFCC; biodiversity programs under Forest Departments; and livelihoods under NRLM and MSME schemes. This alignment ensures resource pooling, policy coherence, and efficient implementation across all basin districts.

## 3. Basin Characterisation & Natural Boundary Delineation

The chapter presents the physical, hydrological, ecological, and socio-economic features of the Ganga Basin as the foundation of GRBMP 2.0. It describes the basin's geological origin, climatic zones, river morphology, drainage density, aquifer systems, soil distribution, wetlands, floodplains, land use patterns, and demographic distribution. Basin delineation is based on natural hydrological units, including major rivers, sub-basins, tributaries, micro-watersheds, and groundwater provinces, ensuring planning coherence. The chapter includes spatial mapping of rivers, canals, natural drains, lakes, reservoirs, ponds, oxbow lakes, and infiltration zones such as the Tarai–Bhabar belt. It documents water quantity and quality patterns, sediment regimes, ecological sensitivity zones, biodiversity hotspots, and areas affected by encroachments and pollution. Basin characterisation supports tributary prioritisation, flow modelling, vulnerability analysis, and district-level DRMP design. It ensures GRBMP reflects natural boundaries rather than administrative boundaries.

## 3.1 Basin Delineation

Basin delineation divides the Ganga Basin into hydrologically coherent units including the mainstem Ganga, its major tributaries (Yamuna, Ramganga, Gomti, Ghaghara, Gandak, Kosi, Sone, Damodar), and hundreds of sub-basins. Natural boundary delineation uses watershed divides, Digital Elevation Models, flow accumulation pathways, aquifer contours, and wetland systems. The delineation captures key hydro-geomorphic zones such as the Himalayas, Shivaliks, Tarai–Bhabar infiltration belts, alluvial plains, doab regions, and deltaic stretches. This subsection identifies sub-basin boundaries for river restoration and assigns districts to their corresponding natural drainage units, enabling DRMP alignment. Basin delineation supports ecological flow modelling, sediment transport analysis, pollution source attribution, and flood vulnerability assessment. It forms the spatial backbone of all planning frameworks, linking basin science to administrative execution.

### 3.1.1 Basin–Sub-Basin–DRA Hierarchy

This section presents the hierarchical structure for organising the basin into progressively smaller hydrological units: Basin → Sub-Basin → District River Areas (DRAs) → District River & Water Body Areas (DRWBAs). The hierarchy enables planning at scales appropriate for different processes—basin-level flow modelling, sub-basin level tributary assessment, district-level project planning, and micro-catchment level implementation. Each DRA encompasses all rivers, drains, wetlands, floodplains, ponds, canals, reservoirs, and aquifers falling naturally within a district's hydrological footprint. DRWBAs add smaller water bodies, recharge areas, and ecological nodes. This structure allows GRBMP 2.0 to maintain hydrological integrity while enabling district-led execution through DRMPs. It also supports cumulative impact analysis, prioritisation frameworks, and basin-wide monitoring under RHMP.

### 3.1.2 River & Tributary Network

This subsection maps the entire river network within the Ganga Basin, classifying basins from Level 1 – Ganga Basin to Level 2, Level 3 ........Basins. It documents major tributaries and sub-tributaries such as Yamuna, Ramganga, Gomti, Tons, Kali, Hindon, Ghaghara, Gandak, Kosi, Sone, Damodar, and their drainage areas. The mapping includes flow pathways, confluence points, barrages, embankments, distributaries, and key hydrological disruptions. The section highlights ecologically significant tributaries, stressed tributaries with declining flows or polluted reaches, and those influencing wetland systems and aquifer recharge. River network mapping provides the basis for ecological flow assessments, tributary restoration strategies, pollution load distribution analysis, and alignment of district plans with basin hydrology. It emphasises the need for integrated tributary–mainstem management.

### 3.1.3 Drainage Systems (Natural Drains, Nalas, Canals)

The drainage system includes natural stormwater drains, seasonal streams, perennial nalas, and manmade canals that discharge into tributaries and the Ganga. This section lists major and minor drains by district, categorises them by flow regime, pollution load, land use influences, and connectivity to wetlands and ponds. Natural drains act as hydrological arteries that convey monsoon flows, sediment, nutrients, and treated wastewater for perennialisation. The section identifies drains that are fully natural, drains altered by urbanisation, and canalised drains receiving sewage. It highlights drains requiring interception, in-stream treatment, wetland linkage, or perennialisation. This mapping is critical for wastewater management, decentralised treatment planning, flood mitigation, and wetland restoration. It supports the DRMP framework, where each district must rationalise and restore its drainage system.

## 3.2 Climate & Hydrometeorology

This subsection summarises rainfall patterns, temperature regimes, evapotranspiration rates, and monsoon dynamics influencing basin hydrology. The basin experiences significant spatio-temporal variability, including heavy Himalayan precipitation, intense monsoon rains, and extended dry periods in the plains. Climate data inform hydrological modelling, e-flow requirements, drought–flood cycles, and reservoir operations. Trends such as increased extreme rainfall events, shifting monsoon onset, prolonged dry spells, and rising temperatures impact river flows, groundwater recharge, agricultural demand, and water quality. Climate-risk hotspots include Himalayan zones vulnerable to glacial melt, Tarai regions susceptible to waterlogging, and urban centres prone to flooding. This section outlines the need for climate-adaptive planning, nature-based buffers, and resilient infrastructure within GRBMP 2.0.

## 3.3 Geology & Geomorphology

This section describes the geological framework of the Ganga Basin, extending from the Himalayan orogeny in the north to the alluvial plains and deltaic formations downstream. The basin comprises young alluvial deposits, unconsolidated sediments, clay–sand layers, gravel beds, and deep aquifers. Geomorphological features include floodplains, paleo-channels, oxbow lakes, terraces, meandering belts, natural levees, foothill fans, and alluvial cones. These formations influence river behaviour, groundwater storage, soil fertility, erosion patterns, and flood dynamics. Regions such as the Tarai–Bhabar zone show strong infiltration and shallow aquifers, whereas central plains hold deep multi-aquifer systems. Geomorphology shapes natural drainage, wetland distribution, sediment transport, and floodplain functions. Understanding these features is essential for wetland protection, river restoration, channel reconfiguration, sediment management, and groundwater recharge strategies in GRBMP 2.0.

## 3.4 Hydrogeology & Aquifer Systems

This section characterises the basin's groundwater systems, including shallow and deep aquifers, confined and unconfined layers, recharge and discharge zones, and hydraulic connectivity with rivers and wetlands. The Tarai–Bhabar belt exhibits high infiltration and shallow aquifers, while central plains host thick alluvial aquifers with significant storage. Hydrogeological mapping identifies groundwater recharge areas, over-exploited blocks, declining water levels, and zones with fluoride, arsenic, nitrate, or salinity concerns. River–aquifer interactions, especially base-flow contributions, influence dry-season flows. Anthropogenic pressures include excessive abstraction for irrigation, urban extraction, declining recharge due to urbanisation, and contamination from sewage, industry, and agriculture. GRBMP 2.0 integrates hydrogeology with river restoration, treated wastewater reuse, MAR structures, wetland rejuvenation, and irrigation efficiency to stabilise groundwater.

## 3.5 Land Use/Land Cover (LULC)

This subsection summarises basin-wide land use categories: agriculture, forests, wetlands, urban areas, industrial zones, pastureland, barren land, and water bodies. Agriculture occupies the largest share, influencing nutrient runoff, groundwater extraction, and soil health. Urban expansion converts permeable land into impervious surfaces, reducing recharge and increasing runoff and pollution. Wetlands and ponds have reduced significantly due to encroachment and drainage alteration. Forest cover affects watershed stability, sediment loads, and infiltration. LULC mapping identifies high-risk zones for erosion, flooding, pollution hotspots, and ecological fragmentation. Integrating LULC with hydrology is essential for designing wetlands, recharging aquifers, restoring riparian zones, and managing agricultural pressures under GRBMP 2.0.

## 3.6 Soils & Agro-Ecological Zones

The basin hosts a variety of soil types—sandy loam, clay loam, alluvium, peat soils, calcareous soils—distributed across agro-ecological regions. Soil properties determine infiltration, runoff generation, nutrient retention, organic carbon content, and susceptibility to erosion. Intensive agriculture has depleted soil organic carbon, increasing fertilizer demand and nutrient leaching into drains and rivers. Soil degradation contributes to declining groundwater recharge, higher irrigation requirements, and greater vulnerability to droughts. This section links soils to agricultural water management, sewage reuse for soil moisture improvement, compost and biochar integration, and nutrient budgeting. Agro-ecological zones help design crop diversification, horticulture, agroforestry, and low-chemical farming suited to regional soil and climate.

## 3.7 Wetlands, Lakes & Floodplain Systems

This section maps natural and manmade wetlands, oxbow lakes, floodplain ponds, marshes, jheels, reservoirs, and riverine wetlands. Wetlands function as natural water storage, groundwater recharge zones, biodiversity habitats, and nutrient sinks. Floodplains regulate flood peaks and maintain ecological flows. Many wetlands have been lost or degraded due to encroachment, siltation, drainage alterations, nutrient overload, and disconnected hydrology. This subsection documents wetland–drain–tributary linkages crucial for natural treatment and perennialisation. GRBMP 2.0 integrates wetland restoration into wastewater polishing, base-flow augmentation, biodiversity enhancement, and climate buffering.

## 3.8 Biodiversity & Riverine Ecology

The Ganga Basin hosts diverse aquatic and terrestrial species, including fish, macroinvertebrates, plankton, birds, amphibians, reptiles, and riparian vegetation. Riverine ecology depends on flow regimes, water quality, sediment supply, habitat heterogeneity, and connectivity with wetlands and floodplains. Key ecological zones include river confluences, oxbow lakes, shallow riffles, deep pools, sandbars, and riparian forests. Biodiversity patterns reflect hydrological gradients—from Himalayan cold-water streams to warm alluvial rivers. Pressure factors include habitat fragmentation, reduced flows, pollution, sand mining, agricultural chemicals, hydropower structures, and wetland loss. Sensitive and endangered species serve as biological indicators of ecological health. GRBMP 2.0 emphasises ecological flow maintenance, restoration of habitat diversity, wetland protection, pollution reduction, and reconnection of rivers with natural buffers to ensure long-term ecological resilience.

## 3.9 Demography & Socio-Economic Context

The Ganga Basin sustains nearly half of India's population across rural and urban settlements. The region's economy is dominated by agriculture, small-scale industries, services, and cultural-tourism activities. Rapid urbanisation and population growth increase water demand, sewage generation, solid waste, and pressure on drains, wetlands, and aquifers. Rural communities depend heavily on irrigation, fisheries, and riparian agriculture, while urban areas exert industrial and domestic pollution pressures. The basin contains diverse cultural landscapes, including pilgrimage centres, riverfront heritage, and traditional livelihoods. Socio-economic patterns influence water use, agricultural practices, sanitation, and land cover. GRBMP 2.0 integrates demographic projections into water budgeting, pollution management, livelihood strategies, and public participation frameworks under Jan Ganga and Arth Ganga.

### 3.10 Summary of Basin Characteristics

The Ganga Basin is defined by Himalayan-fed rivers, extensive alluvial plains, monsoon-driven hydrology, deep aquifer systems, rich biodiversity, vast agricultural lands, and dense human settlements. The basin's physical and socio-economic complexity demands integrated, multi-scale planning. Key challenges include declining flows, pollution from domestic and industrial sources, agricultural nutrient runoff, wetland degradation, groundwater depletion, climate variability, and habitat fragmentation. The natural resource base is also a driver of cultural identity, livelihoods, and economic productivity. These characteristics underscore the need for a basin-wide, district-operational plan linking hydrology, ecosystems, agriculture, soil health, governance, and socio-economics — the central mandate of GRBMP 2.0.

## 4. River System Assessment (Aviral Ganga)

The chapter assesses the status of flows across the Ganga and its tributaries, documenting seasonal variations, dry-season flow collapse, flow modifications due to barrages and canals, and base-flow contributions from groundwater. It evaluates hydrological alterations arising from climate variability, glacier retreat, land-use changes, and groundwater over-extraction. Flow continuity is analysed through discharge data, Environmental Flows (E-Flows) requirements, and river segmentation based on ecological sensitivity. Hydraulic barriers, diversions, embankments, and channel alterations are identified as major constraints. The chapter provides flow regime characterisation essential for determining restoration needs, floodplain reconnection, reservoir operations, and perennialisation strategies. It presents the foundation for ensuring Aviral Ganga by restoring flows at all spatial scales.

### 4.1 Present Flow Regime

This subsection summarises discharge patterns across major tributaries and the mainstem for monsoon and non-monsoon seasons. Many rivers stretches, especially in plains and heavily abstracted regions, experience low or near-zero flows in lean months. Flow disruptions include diversion to canals, groundwater abstraction reducing base flows, and blocked tributary pathways. Reduced flows exacerbate pollution, hinder sediment transport, decrease aquatic habitat quality, and weaken ecological functions. Flow monitoring data identifies critical stretches requiring E-Flows support, perennialisation of tributaries, treated wastewater augmentation, and improved catchment infiltration. The present flow regime provides baseline information for ecological flow modelling and restoration design under GRBMP 2.0.

## 4.2 Flow Variability & Seasonality

Flow variability is driven by monsoon-dominated rainfall, snowmelt contributions, local runoff, groundwater discharge, and regulated releases from reservoirs and barrages. Monsoon flows bring high discharge and sediment loads, while non-monsoon flows depend heavily on groundwater interactions, wetland storage, and upstream releases. Increasing climate variability has altered seasonal flow patterns—shorter, intense rainfall events; longer dry periods; and greater interannual fluctuation. Seasonal flow collapse affects navigation, fisheries, biodiversity, floodplain connectivity, and water quality. GRBMP 2.0 incorporates seasonal flow profiles to design perennialisation, recharge interventions, and reservoir release protocols, ensuring ecological stability across seasons.

## 4.3 Environmental Flow Requirements

Environmental Flows (E-Flows) represent the water quantity needed to sustain riverine ecological functions, sediment transport, water quality, fisheries, and cultural uses. This subsection identifies E-Flows requirements for major Ganga Basin rivers using hydrological, ecological, and geomorphological criteria. E-Flows recommendations support habitat maintenance, species migration, spawning cycles, and wetland connectivity in addition to incidental dilution of pollutants. Many rivers fail to meet E-Flows in lean seasons due to excessive abstraction and upstream regulation. GRBMP 2.0 integrates E-Flows mandates into river management, reservoir operations, and district-level planning, ensuring compliance through monitoring, policy instruments, and coordinated water-use efficiency measures across sectors.

## 4.4 River Hydraulics & Sediment Transport

This subsection examines sediment dynamics, channel morphology, erosion–deposition patterns, sediment sources, and impacts of hydraulic structures. Himalayan rivers contribute high sediment loads, critical for maintaining floodplain fertility, channel stability, and delta formation. Barrages, dams, and embankments disrupt sediment continuity, causing reservoir siltation, downstream channel incision, loss of sandbars, and habitat degradation. Reduced sediment supply alters river depth, width, meandering patterns, and floodplain functions. GRBMP 2.0 addresses sediment continuity through catchment treatment, floodplain reconnection, controlled releases, dredging where necessary, and nature-based sediment distribution mechanisms. This section forms the basis for geomorphic river restoration.

### 4.5 River–Floodplain Connectivity

River–floodplain connectivity is essential for groundwater recharge, biodiversity, sediment distribution, nutrient exchange, and flood mitigation. Floodplains act as natural sponges absorbing monsoon flows and sustaining base flows during dry periods. Urbanisation, embankments, agriculture encroachment, and infrastructure have severed these connections. Many floodplain wetlands no longer receive seasonal flooding, diminishing ecological services. GRBMP 2.0 promotes restoring channels to natural alignments, reactivating floodplain wetlands, removing barriers, and ensuring controlled seasonal inundation. River–floodplain reconnection enhances resilience to climate extremes, reduces flood risk, and improves ecological productivity across the basin.

### 4.6 River Morphology & Channel Stability

This section documents channel forms—straight, meandering, braided—and analyses their stability based on discharge, sediment load, slope, and geomorphology. Human interventions such as embankments, sand mining, land reclamation, and flow diversions destabilise channels, causing erosion or aggradation. Channel instability affects riverbank settlements, agriculture, wetlands, and aquatic habitats. GRBMP 2.0 emphasises geomorphic restoration through riparian buffers, sediment balancing, natural bank stabilisation, meander reconnection, controlled sediment releases, and channel reconfiguration where necessary. Stable channels maintain ecological functions, reduce flood risks, and support river-dependent livelihoods.

### 4.7 River Water Quality Status

River water quality varies widely across the basin due to sewage inflow, industrial effluents, agricultural runoff (mostly only during monsoon), solid waste dumping, non-point source pollution, and inadequate wastewater treatment. Monitoring data indicate high BOD, COD, ammonia, nutrients, pathogens, and heavy metals in several tributaries and urban river stretches. Pollution hotspots correspond to dense urban centres and industrial clusters. Water quality degradation affects drinking water sources, aquatic life, agriculture, and cultural uses. GRBMP 2.0 integrates decentralised treatment, drain interception, wetland polishing, agricultural nutrient management, and industrial regulation to restore Nirmal Ganga. Continuous monitoring under RHMP supports adaptive management.

## 5. Water Quality Management (Nirmal Ganga)

This chapter defines the basin-wide strategy for restoring and maintaining water quality across the Ganga and its tributaries. It consolidates pollution diagnostics, wastewater treatment pathways, natural purification systems, and monitoring frameworks into a unified plan. Key elements include eliminating untreated sewage through decentralised treatment, tapping polluted drains, upgrading STPs, integrating wetland-based polishing, controlling industrial discharges, managing rural greywater, and reducing agricultural nutrient loads. The chapter emphasises that improving water quality requires a **source-to-river** approach—intervening at households, farms, industries, drains, wetlands, and rivers simultaneously. Nature-based solutions including bio-remediation, constructed wetlands, riverbank vegetation, and perennialisation are central. Water quality management is linked with RHMP for continuous monitoring and with DRMPs for district-level implementation. The chapter positions Nirmal Ganga as essential for ecological health, groundwater protection, human use, and cultural value of the river.

## 5.1 Pollution Sources & Load Assessment

Pollution sources include municipal sewage, industrial effluents, agricultural runoff (mostly only during monsoon), livestock waste, solid waste leachate, legacy contamination, stormwater flush loads, and diffuse non-point sources. Sewage contributes the largest organic and microbial loads, while industries add heavy metals, toxic chemicals, and high-COD effluents. Agricultural runoff carries nitrogen, phosphorus, pesticides, and sediments into drains and tributaries essentially during monsoonal flows. Unlined drains and dumping sites release leachate into groundwater that eventually enters rivers in non-monsoon base flows. This subsection quantifies pollutant loads using monitoring data, modelling, and district-level assessments. Hotspot mapping identifies priority drains, tributaries, and river stretches requiring urgent action. Pollution load assessment forms the basis for designing treatment systems, wetland restoration, enforcement strategies, and district pollution abatement plans.

## 5.2 Sewage & Wastewater Management

Wastewater management focuses on reducing untreated discharge through decentralised treatment systems, in-situ bio-remediation, small STPs (1–10 MLD), and drain-based treatment. The approach shifts from large centralized STPs requiring long sewer networks to modular, distributed systems located at drain nodes, enabling efficient interception. Treatment pathways include anaerobic units, FAB reactors, MBBR systems, planted gravel filters, polishing wetlands, and nature-based solutions. The chapter integrates sewage mapping, identification of no-network zones, interim solutions for unsewered areas, reuse planning, and operation and maintenance protocols. Rural sanitation gaps are addressed through soak pits, phytoremediation channels, and community treatment units. Wastewater becomes a resource for perennialising drains, wetlands, and ponds under controlled conditions, reducing groundwater abstraction.

## 5.3 Industrial Pollution Control

This subsection addresses pollution from industrial clusters, including food processing units, tanneries, distilleries, textile and chemical industries, metal-plating units, paper mills, and small-scale enterprises. Key measures include strengthening CETPs and ETPs, enforcing pre-treatment norms, regulating hazardous waste, controlling illegal discharge points, and monitoring effluent flow and quality through telemetry. Cluster-specific action plans focus on segregating industrial drains, preventing mixing with domestic sewage, and creating dedicated zero-liquid-discharge facilities where feasible. Industrial zoning and relocation of high-risk units away from riverbanks are recommended. The section integrates compliance monitoring with SPCBs, periodic audits, satellite surveillance of hotspots, and penalty frameworks. Cleaner production technologies, water recycling, and waste minimisation enhance long-term sustainability.

## 5.4 Solid Waste & Plastic Waste Management

Solid waste mismanagement contributes significantly to river pollution through open dumping, littering, stormwater wash-off, and illegal disposal along floodplains and drains. This subsection outlines district-level interventions including door-to-door collection, segregation at source, decentralised composting, MRF-based sorting, scientific landfills, and remediation of legacy waste. Plastic waste management integrates extended producer responsibility (EPR), regular clean-up drives, drain screens, floating booms, and community engagement. Waste hotspot mapping identifies high-risk zones near drains and ghats. Floodplain regulation restricts dumping and promotes buffer zone restoration. Integration with DRMP ensures that ULBs and Panchayats embed waste management in river protection strategies.

## 5.5 Agricultural Runoff & Non-Point Pollution

Agricultural runoff introduces nitrogen, phosphorus, pesticides, herbicides, sediments, and organic matter into surface water, mostly only during monsoon. This subsection presents interventions such as vegetated buffer strips, contour bunding, controlled fertilizer application, integrated nutrient management, micro-irrigation, mulching, crop diversification, and soil organic carbon enhancement. Wetland and pond revitalisation improves nutrient retention. Agrochemical monitoring identifies hotspots of nitrate and pesticide contamination. Farmer training programmes promote eco-friendly practices and discourage overuse of chemicals. Runoff mitigation is coordinated through agriculture departments, ATMA, KVKs, and community groups. Integration with treated wastewater reuse reduces dependency on groundwater and enhances soil moisture, reducing runoff loads.

## 5.6 Rural Sanitation & Greywater Management

Rural households generate greywater that often flows untreated into lanes, drains, ponds, and wetlands, degrading water quality. This subsection introduces low-cost, decentralised greywater management solutions such as soak pits, twin-pit systems, planted gravel filters, community-level bio-remediation units, and household-level drainage improvements. Panchayats identify hotspots for intervention, especially near schools, anganwadis, markets, and densely populated habitations. Livestock waste management through biogas plants, cattle-sheds, and composting is included to minimise direct drain contamination. Integration with Swachh Bharat Mission (SBM-G) ensures toilet coverage and safe disposal. Rural greywater is repurposed after filtration to irrigate horticulture and plantations. Greywater management is tied into DRMP at village level, forming the rural equivalent of wastewater management in urban areas.

## 5.7 Stormwater Management

Stormwater systems in urban and rural areas are often clogged, encroached, or integrated with sewage flows, exacerbating pollution during monsoon. This subsection outlines stormwater master planning including drain desilting, green drains, bio-swales, pervious pavements, infiltration trenches, retention ponds, recharge zones, and flood mitigation structures. Urban Local Bodies (ULBs) adopt integrated stormwater–sewage separation, minimise mixing, and develop GIS-based mapping of stormwater networks. Natural storm drains are restored as ecological corridors with native vegetation. Rooftop rainwater harvesting and recharge pits reduce peak runoff and enhance groundwater. Proper stormwater management controls erosion, protects wetlands, and improves river water quality.

## 5.8 In-Situ Treatment & Drain-Based Treatment

This subsection describes techniques for treating sewage and polluted flows within existing drains without constructing large sewer networks. In-situ systems include microbial bioremediation, aeration, floating wetlands, constructed wetland channels, phytoremediation, silt traps, trash barriers, and oxidation zones. These systems improve BOD, COD, nutrient loads, and pathogen reduction while maintaining ecological functions. Drain-based treatment is crucial for immediate mitigation in districts lacking full sewerage. Treatment nodes are positioned based on pollution severity, flow volume, and downstream water body sensitivity. Integrating in-situ treatment with decentralised STPs creates a layered purification strategy across the basin.

## 5.9 Natural Treatment Systems (Wetlands, Ponds, Green Corridors)

This subsection focuses on harnessing natural ecosystems for water purification, storage, nutrient removal, and biodiversity enhancement. Wetlands, ponds, oxbow lakes, and floodplains act as natural filters and buffers. Restoration includes de-silting, bank stabilisation, revegetation, inlet–outlet management, and controlled perennialisation using treated wastewater. Green corridors along drains enhance aeration, trap sediments, and reduce pollutants. Constructed wetlands near STPs and drain confluences provide tertiary treatment. Pond networks store treated water for reuse, groundwater recharge, and ecological support. Natural treatment systems offer low-cost, climate-resilient solutions for sustained water quality improvement.

## 5.10 Drain Management & Interception Strategies

Drain management focuses on mapping, categorising, and restoring natural and urban drains to improve hydrological and ecological functions. Interception strategies prevent untreated sewage from entering major drains and tributaries by capturing flows at upstream nodes and diverting them to decentralised treatment units. Drains are desilted, reshaped, and lined with vegetative buffers to stabilise banks and enhance ecological processes. Trash racks, screens, and sediment traps are installed at strategic points. Priority drains with high pollution loads receive treatment wetlands, aeration systems, and flow regulation structures. Continuous drain monitoring using RHMP supports adaptive management. Drain management is central to eliminating pollution at source.

## 5.11 Integration with Wetland Systems

Drains, wetlands, ponds, and lakes are reconnected to form functional hydrological and purification networks. Treated wastewater is directed into wetlands for natural polishing and seasonal storage. Wetlands absorb nutrients, support biodiversity, and attenuate floods. Integration strategies include linking drains to upstream and downstream wetlands, restoring natural channels, and ensuring controlled flow exchange. Wetland–drain systems improve water quality, stabilise groundwater, and support agriculture and fisheries. They convert restored wetlands into multi-functional assets under DRMP.

## 5.12 Summary of Water Quality Strategy

The water quality strategy integrates decentralised wastewater treatment, natural purification, drain interception, industrial compliance, rural greywater management, stormwater systems, agricultural nutrient reduction, and wetland rejuvenation. The multi-layered approach ensures pollution reduction at the household, village, urban, industry, drain, and tributary levels. Water quality data from RHMP informs prioritisation and adaptive management. The strategy shifts focus from end-of-pipe treatment to holistic, landscape-scale restoration that reconnects water, soil, wetlands, aquifers, and ecology.

# 6. Ecological Restoration & Biodiversity Conservation

This chapter presents a comprehensive ecological strategy to restore the Ganga Basin's natural functions, biodiversity, and habitat connectivity. It recognises rivers, tributaries, wetlands, floodplains, riparian zones, and soils as integrated ecological systems. Restoration focuses on improving habitat heterogeneity, ensuring species migration pathways, enhancing nutrient cycling, and stabilising ecological processes through revived flows, clean water, and healthy riparian buffers. The chapter integrates wetland rejuvenation, floodplain restoration, channel re-naturalisation, riparian plantation, removal of invasive species, and biomass-based eutrophication management. Biodiversity enhancement is linked with habitat restoration—riffles, pools, sandbars, backwaters, and oxbow lakes. Ecological restoration also creates nature-based livelihoods such as fisheries, wetland-based agriculture, and ecotourism. Monitoring includes tracking macroinvertebrates, fish assemblages, vegetation patterns, and ecological flow compliance. The chapter frames ecological restoration as both a conservation imperative and an economic opportunity under Arth Ganga.

## 6.1 Ecological Zones & Habitat Types

The Ganga Basin comprises a diverse mosaic of ecological zones—Himalayan headwaters, Shivalik foothills, Tarai wetlands, alluvial plains, doab regions, and deltaic estuaries. Each zone supports distinct habitat types shaped by flow regimes, geomorphology, soil composition, and climatic conditions. Key habitats include fast-flowing mountain streams with cold-water species, braided channels with sandbar ecosystems, deep pools supporting large fish, shallow riffle zones rich in macroinvertebrates, floodplain wetlands with high productivity, and oxbow lakes serving as fish nurseries. Riparian forests, reedbeds, mudflats, and marshes provide ecological connectivity and refuge for birds, amphibians, and reptiles. Understanding these habitats is essential for designing restoration strategies, identifying critical biodiversity hotspots, and prioritising interventions. Ecological zoning ensures interventions match the natural dynamics of each habitat type, strengthening resilience across the basin.

## 6.2 Ecological Degradation & Threats

Major ecological threats include flow reduction, pollution, habitat fragmentation, wetland loss, floodplain encroachment, invasive species spread, sand mining, overfishing, hydropower disruptions, and climate-driven hydrological changes. Urbanisation and agriculture have altered natural drainage, converted wetlands, and reduced habitat complexity. Industrial effluents and sewage degrade water quality, affecting fish, plankton, and dissolved oxygen levels. Channel straightening and embankments sever river–floodplain connectivity. Excessive nutrient loads create eutrophication, algal blooms, and oxygen crashes. Invasive species such as water hyacinth outcompete native vegetation. Climate variability increases extreme floods and droughts, destabilising ecological processes. These threats compromise biodiversity, ecological flows, and ecosystem services. GRBMP 2.0 addresses them through integrated river–wetland–floodplain restoration, pollution abatement, controlled sand mining, riparian protection, and biomass management.

## 6.3 Ecological Restoration Framework

The ecological restoration framework integrates hydrological, geomorphological, biological, and socio-economic principles to rebuild river health. Key components include restoring natural flow regimes, reconnecting tributaries and wetlands, re-establishing channel features like meanders and pools, and improving water quality. Riparian buffers stabilise banks and provide habitat. Habitat structures (woody debris, fish refuges) enhance diversity. Wetland rejuvenation supports nutrient retention and biodiversity. Floodplain reconnection enables seasonal inundation and ecological productivity. Restoration incorporates managed eutrophication: harvesting biomass to maintain ecological balance while supporting livelihoods. The framework is adaptive, relying on monitoring data from RHMP and community observations. Restoration actions are prioritised based on ecological sensitivity, degradation extent, and socio-economic benefits.

## 6.4 Riparian Zone Restoration

Riparian zones—vegetated corridors along riverbanks—regulate water quality, stabilise banks, filter sediments, and support diverse flora and fauna. Degraded riparian strips lead to erosion, habitat fragmentation, reduced shading, and higher water temperatures. Restoration involves planting native species suited to local hydrology, creating multi-layer vegetation belts, and establishing buffer zones to prevent encroachment. Riparian vegetation also mitigates pollution by absorbing nutrients and intercepting runoff from agricultural and urban areas. Controlled grazing, removal of invasive plants, and community stewardship strengthen riparian recovery. Riparian corridors act as biodiversity highways, connecting wetlands, oxbow lakes, and upland habitats. Restored riparian areas also enhance cultural and aesthetic values along ghats and riverfronts.

## 6.5 Wetland Restoration & Management

Wetland restoration focuses on reviving hydrological functions, biodiversity, and natural purification processes. Interventions include desilting, removing encroachments, reconnecting wetlands with drains and tributaries, creating inlet–outlet structures, managing hydroperiods, planting native vegetation, and enhancing water retention. Wetlands serve as nutrient sinks, flood buffers, fish nurseries, and migratory bird habitats. Restored wetlands support groundwater recharge, improve water quality, and strengthen climate resilience. Management includes assigning community stewardship groups, regulating land use around wetlands, implementing buffer zones, and monitoring water levels and vegetation. Wetlands integrated with treated wastewater function as natural biofilters, reducing treatment costs and enhancing ecological health. Wetland networks form the backbone of nature-based river restoration.

## 6.6 Floodplain Restoration

Floodplains moderate floods, recharge aquifers, enable nutrient cycling, and support rich biodiversity. Restoration requires mapping historical floodplain boundaries, removing encroachments, opening blocked channels, restoring wetlands, reconnecting oxbow lakes, and designing controlled seasonal inundation regimes. Agroforestry, riparian plantations, and wet meadows enhance ecological productivity. Sand mining restrictions protect geomorphological stability. Floodplain-based nature reserves promote habitat continuity. Restored floodplains reduce flood peaks, enhance groundwater recharge, and maintain dry-season flows. Floodplain zoning under GRBMP 2.0 integrates regulation, community use, green buffers, and sustainable agriculture, ensuring long-term hydrological and ecological benefits.

## 6.7 River Habitat Improvement

Habitat improvement enhances in-channel diversity by re-establishing structural features—riffles, pools, runs, sandbars, backwaters, and woody debris. Healthy habitats support different life stages of fish, macroinvertebrates, and aquatic plants. Mechanical measures include installing boulder clusters, artificial riffles, flow deflectors, and fish shelters. Natural measures involve restoring channel sinuosity, reconnecting side channels, and reactivating floodplain wetlands. Habitat improvement must align with ecological flows and sediment supply. This approach strengthens resilience to hydrological variability, supports fisheries, and improves ecological indicators. Habitat restoration also increases recreational and cultural value, creating opportunities under Arth Ganga.

## 6.8 Aquatic Biodiversity Conservation

Aquatic conservation focuses on protecting native fish, macroinvertebrates, reptiles, amphibians, and plankton communities. Conservation zones include confluences, deep pools, oxbow lakes, headwater streams, and unique habitat niches. Measures include protecting spawning grounds, restoring migration pathways, regulating fishing pressure, monitoring water quality, and removing invasive species. Fish ladders or bypass channels may be required at key barriers. Biodiversity mapping informs priority conservation areas. Wetland–river connectivity supports bird populations and fish breeding. Conservation is integrated with sustainable fisheries, ecotourism, and community stewardship models, ensuring ecological and economic benefits. RHMP bio-monitoring tracks recovery.

### 6.9 Invasive Species Management

Invasive species such as water hyacinth, parthenium, and predatory exotic fish disrupt native ecosystems by competing for nutrients, altering habitats, and hindering water flow. Management requires mechanical harvesting, biological control agents, manual removal by community groups, and restoration of native vegetation. Biomass from invasive plants is repurposed for composting, biochar, biogas, or handicrafts. Preventive measures include controlling nutrient inflows, maintaining flow regimes, and monitoring water bodies for early detection. Integrated management ensures ecological balance and reduces maintenance burdens.

### 6.10 Biomass & Eutrophication Management

This subsection introduces a scientific and livelihood-based approach to managing eutrophication through periodic harvesting of aquatic biomass—algae, hyacinth, and macrophytes. Harvesting physically removes nutrients and prevents oxygen crashes, fish kills, and stagnation. Mechanical harvesters and manual labour networks support removal operations. Biomass conversion into compost, vermicompost, biochar, cattle bedding, and handicrafts creates green livelihoods under Arth Ganga. Wetlands, ponds, and drains benefit from regulated biomass cycles that maintain ecological balance. Treated wastewater use increases nutrient inflows; hence biomass management becomes essential to prevent eutrophication in restored water bodies. This approach complements pollution reduction and supports long-term ecological health.

### 6.11 Fisheries & Livelihood Enhancement

Restored rivers, wetlands, and floodplains provide opportunities for sustainable fisheries and aquatic livelihoods. Interventions include improving habitat quality, maintaining flow variability, stocking native fish, creating fish refuges, and controlling invasive species. Community-based fisheries cooperatives manage harvest levels and breeding seasons. Integrated aquaculture–wetland models enhance productivity. Value chains for fish processing, marketing, and cold-storage support income diversification. Fisheries promote food security and supplement rural incomes while encouraging community participation in river stewardship. Training and financial support strengthen local enterprises under Arth Ganga.

### 6.12 Ecotourism & Cultural Heritage Restoration

Ecotourism leverages restored riverine landscapes, wetlands, birding sites, riparian forests, and cultural heritage to generate sustainable income. This subsection outlines developing nature trails, birdwatching zones, interpretation centres, riverfront parks, and heritage walks. Ghats and sacred sites are revived through ecological landscaping and improved sanitation. Cultural circuits linking temples, festivals, and ghats enhance visitor engagement. Eco-sensitive infrastructure, community guides, homestays, and local crafts promote responsible tourism. Ecotourism enhances awareness, supports conservation funding, and strengthens the emotional connection between people and rivers under Jan Ganga and Arth Ganga pillars.

### 6.13 Summary of Ecological Strategy

The ecological strategy integrates hydrological restoration, habitat enhancement, wetland and floodplain rejuvenation, riparian plantation, invasive species control, biomass harvesting, and biodiversity conservation into a unified framework. Restoration actions reconnect rivers with their natural buffers, improve water quality, stabilise groundwater interactions, enhance ecological flows, and promote sustainable livelihoods. Ecological recovery supports fisheries, ecotourism, agriculture, and climate resilience. Monitoring under RHMP ensures adaptive management. The strategy shifts from purely engineering-based solutions to holistic ecological regeneration central to GRBMP 2.0.

## 7. District River Management Plan (DRMP) Framework

The DRMP framework operationalises GRBMP 2.0 at the district level by integrating hydrology, ecology, governance, infrastructure, agriculture, industry, and community participation into an actionable district plan. Each district prepares a DRMP covering both the **urban river management plan (URMP)** and the **rural river management plan (RRMP)**, unified under the District Magistrate and District Ganga Committee. DRMP includes: mapping all rivers, drains, wetlands, ponds, aquifers, and floodplains; assessing water quality and flow status; identifying pollution sources; designing decentralised treatment systems; restoring wetlands and floodplains; improving rural sanitation and agricultural practices; regulating industrial pollution; and ensuring groundwater recharge. The DRMP also includes project prioritisation, implementation schedules, DPR templates, budgets, institutional roles, convergence with government schemes, monitoring systems, and a five-year cyclic revision mechanism. DRMP ensures that every district contributes to basin outcomes through coordinated, hydrologically coherent actions.

### 7.1 DRMP Architecture

The DRMP architecture consists of interconnected modules covering hydrology, water quality, wastewater management, rural sanitation, agriculture, groundwater, wetlands, floodplains, biodiversity, industry, solid waste, climate resilience, and governance. It starts with **baseline diagnostics**, followed by **gap analysis**, **project cluster development**, **block-level plans**, and **implementation frameworks**. Each district is divided into DRWBA (District Rivers & Water Bodies Area) and hydrological units for targeted planning. The architecture embeds Samarth Ganga pillars—Aviral, Nirmal, Jan, Gyan, Arth Ganga—by linking scientific assessments with community-led action. GIS-based mapping, RHMP monitoring nodes, dashboards, and decision-support tools guide real-time planning. Institutional responsibilities are distributed across departments but coordinated by the DGC. The architecture ensures alignment with national missions and basin-level priorities.

## 7.2 DRMP Preparation Methodology

DRMP preparation begins with strengthening the District Ganga Committee, establishing a technical cell, and collecting all relevant datasets: river/drain maps, STP status, wetland inventory, groundwater data, agriculture practices, industry clusters, and socio-economic profiles. Field surveys identify pollution hotspots, drain outfalls, wetland conditions, groundwater recharge points, and rural sanitation gaps. Water quality and flow data are compiled from RHMP and district laboratories. A gap analysis identifies deficiencies in wastewater management, water supply, groundwater status, wetland linkage, industrial discharge, and agricultural runoff. Project clusters are developed based on hydrological needs, ecological restoration opportunities, and socio-economic priorities. DPR templates define cost, scope, timeline, and institutional roles. Stakeholder consultations validate project selection. The final DRMP includes phased implementation, monitoring plans, O&M protocols, and integration with state and national programs.

## 7.3 DRMP Components

A DRMP includes the following components:

- **Urban Water Management:** Sewerage, decentralised STPs, reuse, stormwater, and urban drains.
- **Rural Water & Sanitation:** Greywater treatment, livestock waste management, village drains, and hamlet-level ecosystems.
- **Agriculture & Soil Management:** Nutrient budgeting, low-chemical farming, buffer strips, runoff reduction.
- **Groundwater Management:** Recharge structures, regulation, MAR, well monitoring.
- **Wetlands & Floodplains:** Restoration, buffer creation, hydrological linkage.
- **Industrial Management:** CETPs, hazardous waste regulation, effluent segregation.
- **Ecology & Biodiversity:** Riparian zones, habitat improvement, biomass management.
- **Climate & Disaster Resilience:** Flood risk, drought mitigation, early warning.
- **Monitoring & Governance:** RHMP nodes, dashboards, community scouts, DRMP revision cycles.

These components form a unified hydrology–ecology–governance planning matrix.

## 7.4 DRMP Data Requirements

Each district must compile high-resolution datasets including river and drain shapefiles, groundwater level data, water quality parameters, land use/land cover, wetland inventory, rainfall data, soil health cards, agricultural inputs, livestock density, industrial discharge information, STP/ETP performance, demographic maps, sanitation coverage, solid waste data, flood and drought history, and climate projections. Satellite imagery, DEMs, and GPS-based ground surveys support precise mapping. Data from Jal Nigam, ULBs, irrigation departments, agriculture departments, SPCBs, groundwater boards, and panchayats is integrated into a central database. Historical trends are analysed to identify shifts in hydrology, pollution, and land use. Data requirements ensure scientific rigour, accuracy in project location selection, and measurable outcomes.

## 7.5 DRMP Diagnostics

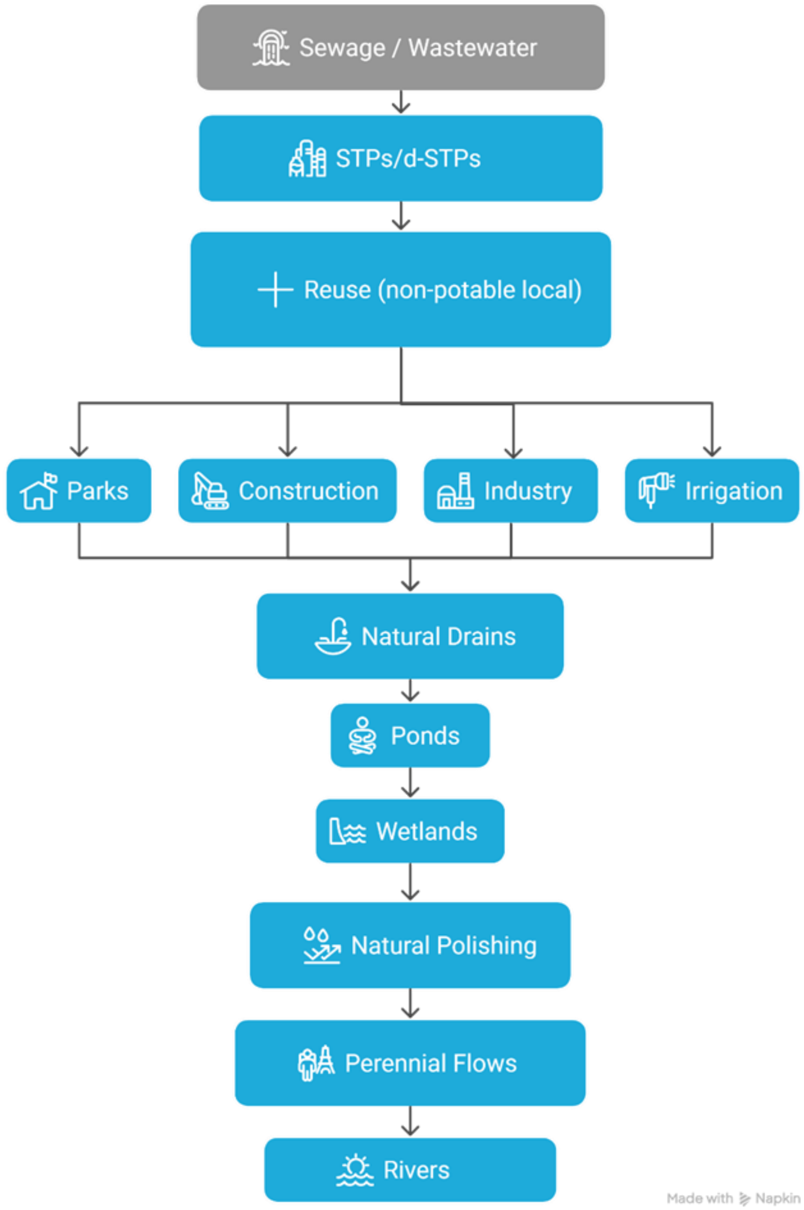
Diagnostics identify existing conditions, challenges, and opportunities in the district's hydrology and ecology. These include pollution source mapping (sewage, industry, agriculture), quantification of untreated flows, drain condition assessment, groundwater decline zones, wetland degradation, floodplain encroachment, biodiversity hotspots, soil fertility issues, and climate vulnerability. Diagnostics also evaluate the performance of existing infrastructure—STPs, ETPs, drains, and rainwater systems. Gaps in governance, data availability, institutional capacity, and community involvement are noted. Diagnostics form the factual basis for shaping project clusters and prioritising investment. Each diagnostic theme is linked to basin-wide indicators of river health.

## 7.6 DRMP Gap Analysis

The gap analysis compares district diagnostics with the DRMP standards required for basin rejuvenation. It identifies missing sewerage coverage, insufficient decentralised treatment, non-functional or overloaded STPs, drains with untreated discharge, polluted tributaries, impaired wetlands, inadequate rural sanitation, excessive agricultural chemical use, weak groundwater recharge, industrial non-compliance, poor stormwater systems, limited biodiversity protection, and insufficient monitoring. Institutional gaps include lack of coordination, limited technical capacity, overlapping responsibilities, and inconsistent data reporting. The analysis informs the design of targeted interventions that close these gaps, aligning district actions with basin-level goals.

## 7.7 DRMP Projectisation

Projectisation converts gaps and opportunities into executable projects grouped under specific clusters. Each project is assigned a title, scope, location, rationale, lead agency, partner departments, estimated cost, timeline, and technical specifications. Projects include decentralised treatment units, wetland restoration, groundwater recharge structures, buffer plantation, industrial drain segregation, biomass management units, solid waste facilities, and agricultural runoff mitigation. Projectisation ensures each district generates a DPR-ready pipeline of interventions. Priority ranking uses criteria such as pollution impact, ecological importance, population served, cost-effectiveness, and feasibility. This forms the operational heart of the DRMP.



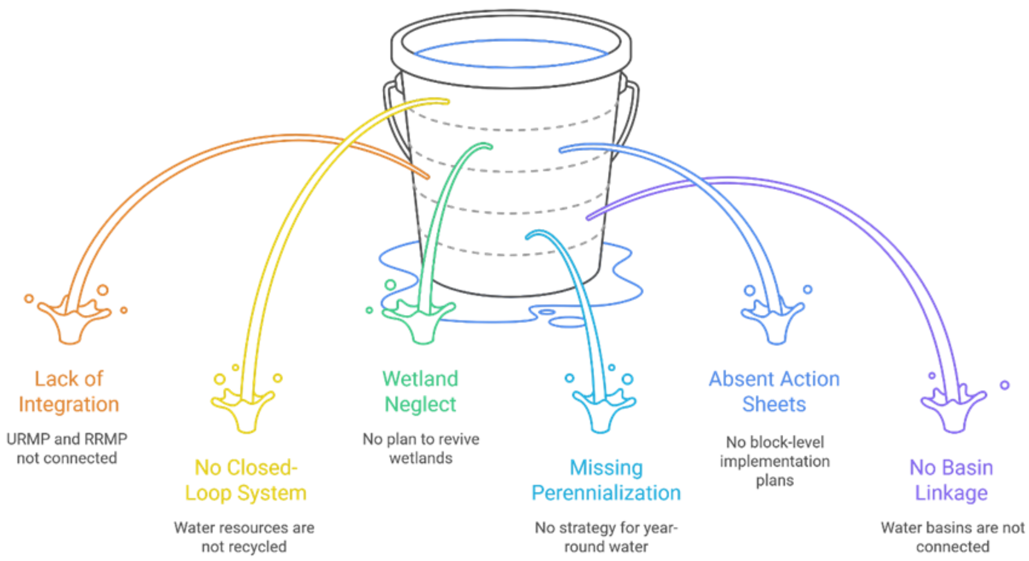

## 7.8 DRMP Project Clusters

Project clusters organise district interventions into coherent categories such as:

- Urban Water Loop (U-series)
- Rural Water & Agriculture (R-series)
- Drainage & Perennialisation (D-series)
- Wetlands & Floodplains (W-series)
- Industrial Pollution Control (I-series)
- Groundwater Security (G-series)
- Monitoring & Governance (M-series)
- Ecology & Biodiversity (E-series)

Each cluster includes a suite of standardised project types tailored to local hydrology and socio-economic conditions. Clusters ensure that interventions are not isolated but integrated into a holistic water–ecology–economy system. They facilitate budgeting, institutional coordination, and cross-district comparison.

Missing Elements in DGP

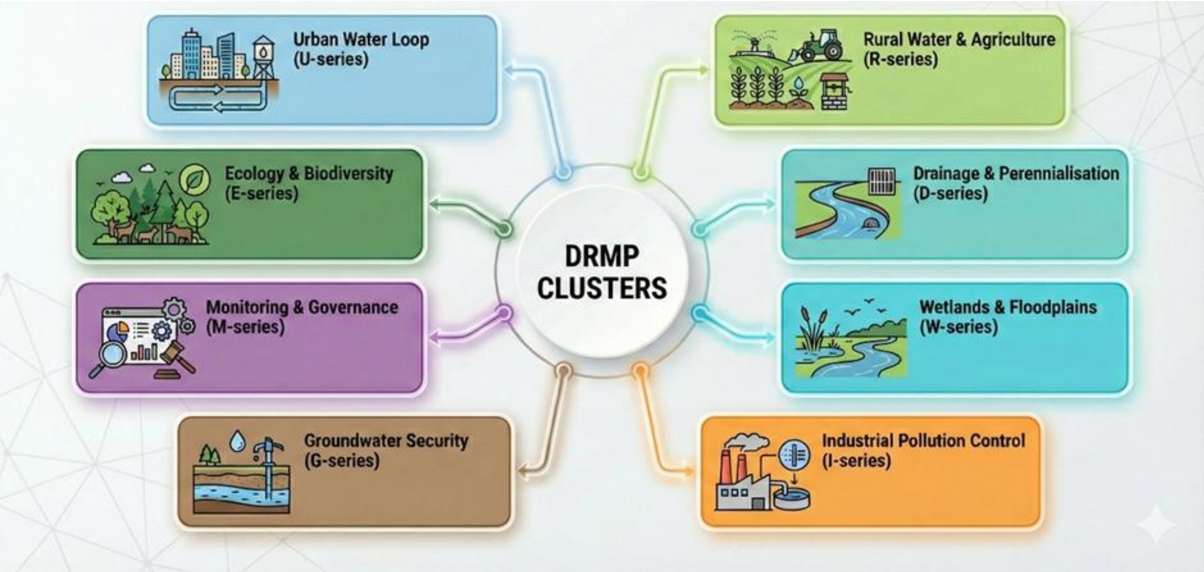



## 7.9 Block-Level DRMP Planning

Block-level planning translates district strategies into geographically specific actions. Each block is assessed for hydrological features, dominant land uses, river/drain networks, groundwater status, agricultural patterns, wetland presence, flood risk, and socio-economic characteristics. Projects are assigned at the block scale—village greywater systems, recharge ponds, agricultural run-off control, wetland revival, riparian planting, industrial regulation, and community-led monitoring. Block plans reflect micro-level constraints and opportunities, ensuring that DRMP actions are locally relevant and hydrologically coherent. This planning level ensures that river restoration is grounded in on-the-ground realities.

## 7.10 DRMP Implementation Framework

The implementation framework outlines roles, timelines, and action pathways. District Ganga Committees coordinate all activities, while line departments execute sectoral projects. Annual action plans specify yearly targets, procurement, monitoring schedules, community engagement activities, and cross-department convergence. State Project Management Units (SPMUs) provide technical assistance. National-level guidelines ensure alignment. Implementation integrates funding from Namami Gange, JJM, SBM, AMRUT, MGNREGA, Atal Bhujal, and other schemes. Mid-course corrections are made using RHMP data. The framework ensures that the DRMP becomes a living operational document.




## 7.11 Institutional Roles & Governance

Institutional roles are distributed across national (NMCG), state (SGAs, SPMUs), district (DGC, DRMP Cell), and local levels (ULBs, Panchayats). NMCG sets basin strategy, standards, and monitoring protocols. SGAs coordinate state-level implementation and data integration. Districts serve as the execution centre, DGCs steer all planning, while line departments deliver projects. Panchayats and ULBs manage local systems such as drains, wetlands, sanitation, and solid waste. Community groups (Jal Mitras, River Scouts) support monitoring and stewardship. Clear governance mandates prevent overlap, build accountability, and promote participatory river management.

## 7.12 DRMP Monitoring & Evaluation

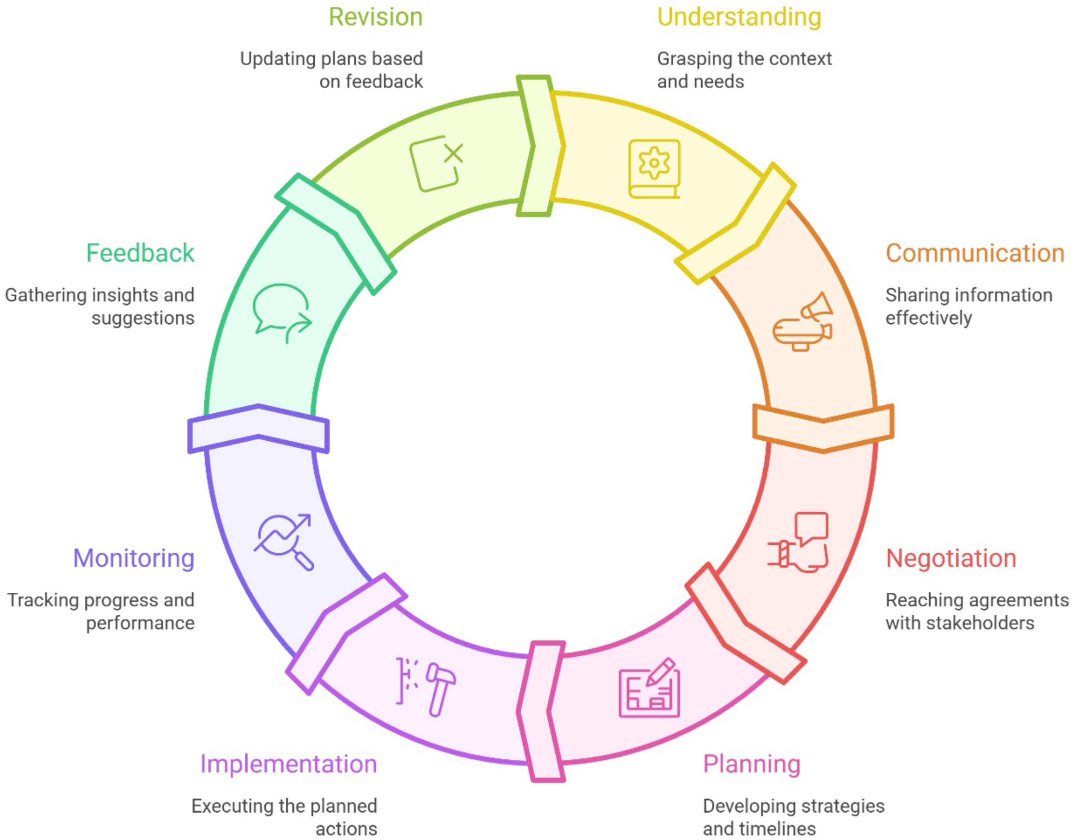
Monitoring combines RHMP sensors, citizen reporting, satellite imagery, and departmental data. Indicators include water quality parameters, flow levels, wetland health, groundwater trends, agricultural chemical usage, STP performance, drain discharge, and biodiversity metrics. Evaluation includes quarterly reviews by DGCs, annual district river health reports, and mid-term progress assessments. Monitoring ensures transparency, corrects project deviations, and strengthens adaptive management. A feedback loop links monitoring results to DRMP revisions.

## 7.13 DRMP Cyclic Planning (5-Year Revision)

The DRMP is revised every five years based on monitoring data, changing hydrology, socio-economic trends, climate impacts, and new technologies. Annual updates refine project progress, budget allocations, and emerging needs. The cyclic process follows: **Understand → Communicate → Negotiate → Plan → Implement → Monitor → Feedback → Revise**. This ensures dynamic, responsive management rather than static planning. The revision cycle aligns district priorities with evolving basin objectives under GRBMP 2.0.

### 7.14 Summary of DRMP Framework

The DRMP framework transforms districts into primary execution units of river basin restoration. It unifies diagnostics, gap analysis, project clusters, governance structures, block-level plans, monitoring systems, and cyclic revision into a single operational plan. DRMP ensures decentralised, data-driven, environmentally sustainable, socially inclusive, and economically viable river rejuvenation. It translates GRBMP 2.0 principles into actionable district interventions.




## 8. Tributary Management

Tributary management focuses on restoring the hydrological and ecological health of the Ganga's major and minor tributaries, which collectively determine basin water quality, flow continuity, sediment dynamics, and biodiversity. Many tributaries suffer from flow collapse, sewage and industrial pollution, agricultural runoff, wetland disconnection, channel encroachment, and groundwater depletion. This chapter outlines a comprehensive approach that includes source control of pollution, perennialisation through treated wastewater, channel re-naturalisation, wetland linkages, groundwater–surface water integration, and catchment restoration. Tributary rejuvenation follows the same principles as the main river but tailored to local hydrology, geology, and socio-economic pressures. Tributary management is executed through DRMPs, ensuring district-led action for each stream segment. This chapter forms the backbone of restoring basin-wide river health under GRBMP 2.0.

## 8.1 Tributary Classification Framework

This section categorises tributaries based on hydrology, geomorphology, pollution load, flow regime, ecological sensitivity, and socio-economic importance. Tributaries are grouped into:

- **Himalayan snow-fed rivers** (e.g., Bhagirathi, Alaknanda)
- **Rainfall-fed rivers** (e.g., Ramganga, Gomti)
- **Groundwater-fed rivers** (e.g., Saryu, Sai)
- **Urbanised tributaries** (e.g., Hindon, Kali East/West)
- **Agriculture-dominated tributaries**
- **Industrial belt tributaries**
- **Forest-linked tributaries**

Classification informs restoration strategies—Himalayan rivers require flow and sediment protection; urban tributaries need drain interception and treatment; agricultural tributaries need nutrient management. Prioritisation ensures resources focus on tributaries with the greatest ecological and hydrological leverage.

## 8.2 Priority Tributaries

Priority tributaries are selected based on ecological degradation, pollution load, human exposure, flow collapse, and strategic importance to the Ganga Basin. Examples include Sahibi River (now referred as Najafgarh drain in Delhi), Shahadara, Hindon, Kali East, Kali West, Ramganga, Assi, Varuna, Gomti, Damodar, Saryu, Sai, Kanh, Kshipra and numerous regional streams. Urban tributaries near large cities are high-priority due to their high pollutant loads and human health impacts. Tributaries serving as major recharge channels or linked to wetlands also receive high priority. GRBMP 2.0 assigns each priority tributary a restoration plan covering pollution control, flow augmentation, habitat improvement, and governance mechanisms. Prioritisation allows phased investment while ensuring cumulative ecological benefits.

## 8.3 Tributary Pollution Diagnostics

Diagnostics include mapping major and minor drains, quantifying untreated sewage, analysing industrial discharge points, identifying agricultural runoff hotspots, and measuring water quality parameters (BOD, COD, nutrients, pathogens, heavy metals).

Many tributaries receive mixed sewage–industrial loads, leading to severe degradation. Urban centres discharge directly into tributaries without treatment. Agricultural belts contribute nutrient spikes during monsoon. Legacy contamination and dump sites contribute chronic toxicity. Diagnostics also evaluate seasonal variations—monsoon dilution and dry-season stagnation. The insights guide targeted actions such as drain interception, CETP upgrades, natural treatment systems, and catchment interventions.

## 8.4 Tributary Flow Status

Most tributaries experience significant flow variability and dry-season flow collapse due to groundwater over-extraction, upstream diversions, reduced base-flow contributions, and insufficient catchment infiltration. Flow assessments include measuring discharge at multiple locations, analysing seasonal patterns, mapping perennial versus seasonal stretches, and modelling groundwater–river interactions. Flow collapse affects water quality, biodiversity, drinking water availability, and ecological functions. GRBMP 2.0 addresses flow decline through treated wastewater augmentation, wetland networks, recharge structures, aquifer protection, and controlled releases from upstream reservoirs where applicable.

## 8.5 Tributary–Wetland–Floodplain Connectivity

Tributaries form hydrological and ecological corridors linked to wetlands, ponds, oxbow lakes, marshes, and floodplains. Many tributaries have lost their wetland linkages due to channelisation, embankments, encroachment, and altered hydrology. This subsection outlines strategies to reconnect tributaries with wetland systems through channel opening, flow restoration, treated wastewater diversion to wetlands, and de-silting of link channels. Floodplain reconnection improves nutrient cycling, recharges groundwater, enhances fish spawning, and buffers floods. Tributary–wetland networks become natural treatment systems, ecological habitats, and livelihood sources.

## 8.6 Tributary Restoration Measures

Restoration measures include drain tapping, decentralised treatment, constructed wetlands, riparian plantation, flow augmentation, channel re-naturalisation, removal of obstructions, bank stabilisation with bioengineering, desilting, and habitat improvement. For ecologically sensitive tributaries, interventions emphasise nature-based solutions. Urban tributaries require multi-layer pollution control and stormwater systems. Agricultural tributaries require nutrient management, vegetative buffers, and erosion control. Industrial tributaries require CETP/ETP strengthening and effluent segregation. Measures are prioritised based on pollution severity and hydrological significance.

## 8.7 Tributary Perennialisation

Perennialisation involves restoring year-round flow using treated wastewater, wetland-fed base flows, channel deepening, aquifer recharge, and removal of flow obstructions. Treated water from d-STPs is discharged into tributary headwaters or midstream sections to maintain minimum ecological flows. Wetlands act as natural storage and buffers for monsoon and dry seasons. Recharge interventions restore base-flow pathways. Perennialised tributaries improve water quality, aquatic habitat, navigation, and groundwater stability. This approach is vital for tributaries affected by dry-season collapse.

## 8.8 Tributary Sediment & Geomorphology Management

Tributary sediment regimes are shaped by catchment erosion, land use changes, sand mining, and hydraulic structures. Excessive sedimentation causes channel choking, wetland infilling, and habitat loss; sediment deficit leads to incision and bank erosion. Management includes catchment treatment, check-dams in uplands, erosion control measures, regulated sand mining, floodplain protection, and controlled sediment releases. Geomorphic restoration re-establishes pools, riffles, and natural meanders. Sediment management stabilises tributary morphology and enhances ecological functions.

## 8.9 Governance & Institutional Mechanisms

Tributary governance involves coordination across districts, states, irrigation departments, pollution control boards, ULBs, and panchayats. DGCs oversee tributary restoration within districts, while inter-district committees manage shared tributaries. Regulatory instruments include effluent norms, floodplain regulations, land use policies, and industrial compliance enforcement. Monitoring frameworks under RHMP track water quality and flow along tributary stretches. Citizen groups support observation and reporting. Governance ensures accountability and equitable sharing of restoration responsibilities.

## 8.10 Monitoring & Evaluation

Monitoring tracks water quality improvements, flow augmentation, ecological recovery, wetland connectivity, sediment balance, and performance of treatment units. Automated sensors, satellite imagery, biological indicators (fish, macroinvertebrates), and community observations form the monitoring system. Evaluation uses before–after comparisons, seasonal patterns, and compliance assessments. Results inform adaptive management and tributary-specific DRMP revisions. Monitoring & Evaluation ensures transparency and long-term sustainability.

### 8.11 Summary of Tributary Strategy

Tributary restoration is central to basin recovery. The strategy combines pollution control, perennialisation, wetland linkage, geomorphic stabilisation, catchment treatment, nature-based solutions, and governance reforms into a unified framework. It ensures that each tributary functions as a hydrological, ecological, and livelihood-supporting system. DRMPs implement tributary strategies at district scale, turning basin vision into local action.

## 9. Groundwater Management & Aquifer Health

This chapter presents a comprehensive approach to stabilising and restoring the Ganga Basin's groundwater systems, which are vital for base flows, irrigation, drinking water, and ecosystem integrity. Groundwater depletion across many districts threatens river flows, causes declining water tables, and reduces dry-season discharge. Over-extraction reduced infiltration due to urbanisation, pollution from sewage and industry, and agricultural intensification further stress aquifers. GRBMP 2.0 integrates groundwater with river management through recharge enhancement, regulation, demand reduction, treated wastewater use, and aquifer–river reconnection. The chapter introduces Managed Aquifer Recharge (MAR) systems, recharge ponds, infiltration trenches, percolation tanks, check dams, subsurface dykes, and wetland-fed recharge mechanisms. Groundwater quality issues (arsenic, fluoride, nitrates, salinity) are addressed through source control and monitoring. The chapter links groundwater governance to DRMPs, ensuring localised planning and monitoring for sustainable groundwater futures.

### 9.1 Groundwater Status in the Ganga Basin

Groundwater levels show significant depletion across large parts of the basin, especially in urban centres, agricultural belts, and over-exploited blocks. Water tables have declined due to excessive pumping for irrigation, reduced recharge from declining wetlands and floodplains, and sealing of permeable surfaces in cities. In some areas, seasonal groundwater fluctuations exceed several metres. Aquifer stress is highest in western UP, Haryana–Delhi areas, parts of Bihar, and urban zones across the basin. Hydrographs indicate long-term declining trends. Groundwater depletion reduces base flows into rivers, leading to dry season collapse in tributaries. GRBMP 2.0 prioritises recharge enhancement, demand management, and treated wastewater reuse to reverse these trends.

### 9.2 Aquifer Typology & Recharge Dynamics

The basin hosts diverse aquifer types: Tarai–Bhabar high-infiltration aquifers, multi-layer alluvial aquifers in the plains, weathered rock aquifers in southern regions, and shallow-dug wells in rural belts. Recharge occurs through rainfall infiltration, river seepage, floodplain inundation, wetland percolation, canal seepage, and artificial recharge systems. Urbanisation and soil compaction reduce natural recharge. Over-extraction disrupts pressure gradients, reducing river–aquifer connectivity. Aquifer typology informs suitable recharge interventions. For example, Tarai regions require floodplain protection, while alluvial plains benefit from ponds and percolation tanks. Understanding recharge dynamics is essential for designing district-specific groundwater strategies.

## 9.3 Groundwater Over-Extraction

Excessive pumping for irrigation, domestic use, and industry has rendered many blocks semi-critical, critical, or over-exploited. Over-extraction lowers the water table, dries shallow wells, increases pumping costs, and reduces river base flows. In agricultural belts, high-Yield tube wells withdraw more than recharge. Urban centres face growing demand from population and industry. Over-extraction also leads to land subsidence in certain areas. GRBMP 2.0 integrates demand-side measures such as micro-irrigation, crop diversification, water pricing pilots, groundwater metering, treated wastewater substitution, and community water budgeting. Supply-side interventions include recharge structures and wetland rejuvenation.

## 9.4 Groundwater Contamination

Groundwater in the basin faces contamination from natural and anthropogenic sources. Arsenic and fluoride occur naturally in many districts, while nitrates arise from agricultural fertilisers and sewage infiltration. Industrial pollutants, heavy metals, and leachate from waste sites contaminate aquifers near urban centres. Pathogen contamination from leaking septic tanks is common in rural areas. Contaminated aquifers compromise drinking water safety and agricultural productivity. GRBMP 2.0 introduces source control (sewer networks, lined drains), treatment interventions, pollution hotspot mapping, safe drinking water alternatives, and recharge with clean water. Monitoring wells track trends in contamination and guide mitigation.

## 9.5 Managed Aquifer Recharge (MAR)

MAR enhances groundwater storage by directing water to infiltration structures. Techniques include recharge ponds, percolation tanks, recharge shafts, injection wells, check dams, infiltration galleries, and channel-spreading interventions. MAR solutions are tailored to local geological and hydrological conditions. Treated wastewater from decentralised STPs is used to recharge aquifers through wetlands and recharge ponds. MAR stabilises water tables, supports base flows, and mitigates drought impacts. GRBMP 2.0 promotes combining MAR with catchment restoration, wetland revival, and floodplain reconnection to maximise natural infiltration. MAR becomes a major DRMP project cluster at district and block levels.

## 9.6 Restoration of River–Aquifer Interactions

Healthy rivers depend on aquifer contributions during dry seasons. Over-extraction disrupts this relationship, causing rivers to lose water to aquifers rather than gaining it. Restoration requires enhancing recharge upstream, reducing pumping near riverbanks, reconnecting rivers to floodplains, and revitalising wetlands that feed aquifers. Treated wastewater supports base flows, reducing aquifer dependence. Riverbed deepening and de-silting in some areas improve hydraulic connectivity. Integrated hydrogeology and river restoration allow aquifers to recover and sustain ecological flows. This reconnective approach is fundamental to Aviral and Nirmal Ganga.

## 9.7 Groundwater Regulation & Governance

Groundwater governance requires coordinated regulation of extraction, improved monitoring, and enforcement of sustainable usage rules. District and state groundwater authorities track abstraction through meters, well registration, permits, and audits. Policies encourage limiting extraction in critical blocks and incentivise alternative water sources such as treated wastewater. Panchayats develop water budgets and enforce local rules on extraction. Urban regulations mandate rainwater harvesting and dual plumbing. Community monitoring ensures transparency. Governance integrates Atal Bhujal Yojana guidelines and aligns with DRMP structures for district-wide coordination.

## 9.8 Groundwater Monitoring & Digital Platforms

Monitoring networks include piezometers, observation wells, automated level recorders, water quality sensors, and community monitoring stations. Real-time groundwater dashboards integrate RHMP, remote sensing, and GIS layers. Monitoring identifies trends, seasonal variability, contamination zones, and recharge impacts. Integration with irrigation pumping data and STP discharge data supports water budgeting. Transparent digital platforms assist administrators, stakeholders, and the public in understanding groundwater status. Data informs policy revisions and DRMP updates.

## 9.9 Agriculture–Groundwater Linkages

Agriculture consumes most of the groundwater in the basin. High water-demand crops (sugarcane, paddy) exacerbate depletion. Runoff carries agrochemicals into aquifers and drains. Linkages include promoting micro-irrigation, crop diversification, soil organic carbon enhancement, mulching, and controlled fertilizer application. Treated wastewater use reduces groundwater dependency and enhances soil moisture. Agricultural advisory services and KVKs promote water-efficient farming. Integration of soil and aquifer management supports sustainable agriculture under Arth Ganga.

### 9.10 Urban–Groundwater Linkages

Urban areas rely heavily on groundwater for drinking and industrial use. Over-extraction, impermeable surfaces, and poor stormwater systems reduce recharge. Leaking sewers and solid waste leachate contaminate aquifers. Strategies include rainwater harvesting, permeable pavements, recharge parks, greywater recycling, dual plumbing, treated wastewater substitution, and strict regulation of borewells. Urban planning integrates groundwater maps into zoning. Wetland protection enhances natural recharge. These linkages are crucial for sustainable cities.

### 9.11 Groundwater Resilience & Climate Adaptation

Climate change intensifies groundwater stress through erratic rainfall, increased evapotranspiration, and altered recharge patterns. Groundwater resilience requires diversified recharge, enhanced storage, reduced dependency, and improved soil moisture. Nature-based recharge systems and resilient farming practices help maintain aquifer levels. Floodplain restoration improves infiltration. Climate-adaptive irrigation scheduling and water budgeting reduce vulnerability. Robust monitoring and risk assessments prepare districts for drought cycles.

### 9.12 Summary of Groundwater Strategy

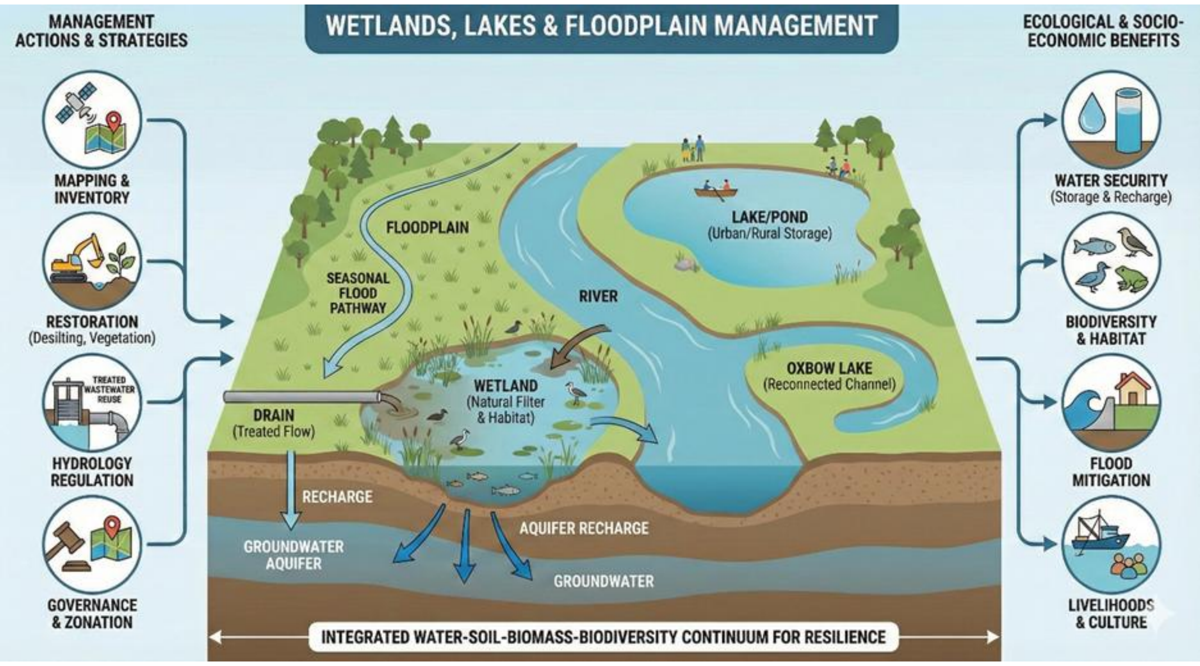
The groundwater strategy integrates recharge enhancement, demand reduction, pollution control, river–aquifer reconnection, governance reform, and monitoring. It ensures aquifer sustainability, supports ecological flows, stabilises drinking water supplies, and underpins agriculture. Groundwater becomes central to basin rejuvenation, linking hydrology, ecology, and livelihoods

## 10. Wetlands, Lakes & Floodplain Management

This chapter outlines a basin-wide framework for rejuvenating wetlands, lakes, ponds, oxbow lakes, marshes, and floodplain systems, recognising them as vital for hydrology, ecology, water quality, climate regulation, and livelihoods. Wetlands store monsoon water, recharge aquifers, regulate flows, and host diverse flora and fauna. Floodplains act as natural buffers that spread and slow floodwaters, enhance infiltration, support nutrient cycling, and sustain fish breeding habitats. Urbanisation, siltation, encroachment, drainage modifications, and pollution have degraded these systems. GRBMP 2.0 introduces hydrological restoration, de-silting, vegetation management, inlet–outlet regulation, buffer zone creation, pollution interception, perennialisation using treated wastewater, and integration with DRMPs. The chapter embeds wetlands and floodplains within the water–soil–biomass–biodiversity continuum, ensuring long-term ecological and socio-economic benefits.

### 10.1 Mapping & Inventory of Wetlands and Floodplain Systems

This subsection compiles spatial inventories of wetlands, lakes, ponds, oxbow lakes, marshes, and floodplain water bodies across all basin districts. Mapping uses satellite imagery, GIS layers, cadastral maps, and field validation. Attributes recorded include area, depth, hydroperiod, connectivity to tributaries and drains, vegetation type, pollution status, encroachments, and biodiversity indicators. Seasonal changes are documented to identify inactive or ephemeral wetlands. Floodplain boundaries are delineated using DEMs, historical flood maps, and geomorphic signatures. The inventory supports prioritisation of wetlands for restoration, understanding hydrological networks, and linking wetlands to tributary and river rejuvenation. This dataset becomes part of the DRMP and RHMP systems.




## 10.2 Wetland Hydrology & Hydroperiod Management

Wetland hydrology depends on seasonal inflows, groundwater interactions, rainfall, and connectivity with rivers and drains. Many wetlands have lost their hydroperiod due to channelisation, encroachment, siltation, and reduced flow. Restoring hydroperiod involves controlled inflow management, spillway design, wetland inlet–outlet regulation, reconnection to natural drains, and use of treated wastewater during dry seasons. Ensuring appropriate hydroperiod supports biodiversity, prevents stagnation, and maintains ecological resilience. Hydroperiod modelling helps determine optimum water levels across seasons. This subsection emphasises hydrological-based wetland rejuvenation rather than cosmetic beautification.

## 10.3 Wetland Biodiversity & Ecological Functions

Wetlands support fish nurseries, migratory birds, amphibians, reptiles, macroinvertebrates, aquatic plants, and riparian species. They enhance ecological productivity through nutrient cycling, organic matter decomposition, and sediment trapping. Biodiversity depends on hydroperiod, water quality, habitat heterogeneity, and connectivity with other water bodies. Ecological functions include flood buffering, pollutant removal, groundwater recharge, and carbon sequestration. Degradation leads to biodiversity loss, eutrophication, and habitat fragmentation. GRBMP 2.0 promotes habitat restoration (reedbeds, marsh zones, open-water pockets), invasive species removal, and ecological monitoring using indicator species.

### 10.4 Floodplain Hydrology & Geomorphology

Floodplains are dynamic extensions of river channels shaped by lateral flows, sediment deposition, erosion, and seasonal inundation. They absorb floodwaters, store sediments, recharge groundwater, and support agriculture and biodiversity. Floodplain geomorphology includes natural levees, backswamps, meander belts, paleo-channels, and oxbow lakes. Encroachment, embankments, and land use changes have disrupted these natural processes. GRBMP 2.0 encourages restoring floodplain hydrology through reconnection of old channels, regulated seasonal flooding, erosion control, desilting, and establishing riparian buffers. Floodplain restoration enhances ecological flows, reduces flood peaks, and stabilises soil moisture regimes.

### 10.5 Wetland Restoration & Revitalisation Strategies

This section details interventions for full ecological revitalisation of wetlands, including:

- Desilting to restore depth and storage
- Clearing encroachments and securing boundaries
- Reconnecting wetlands to drains/tributaries
- Creating inlet–outlet structures
- Planting native aquatic vegetation
- Developing buffer zones
- Dewatering and refilling cycles to disrupt invasive species
- Creating bird islands and fish habitats
- Controlled perennialisation using treated wastewater

Wetlands become multi-functional: improving water quality, supporting fisheries, enhancing biodiversity, and serving as climate buffers. Community stewardship ensures long-term maintenance.

### 10.6 Wetlands as Natural Water Treatment Systems

Wetlands naturally remove pollutants through sedimentation, microbial degradation, plant uptake, and sunlight-driven pathogen reduction. Constructed wetlands can be integrated with STPs and drain-based treatment units for tertiary treatment. Natural wetlands receiving treated wastewater improve BOD, COD, nutrients, and pathogens before water enters rivers. Wetlands also reduce peak flows, trap sediments, and stabilise hydrology. This subsection promotes using wetlands as cost-effective, low-energy, sustainable treatment systems that complement decentralised wastewater treatment in urban and rural landscapes.

### 10.7 Wetlands & Groundwater Recharge

Wetlands contribute significantly to groundwater recharge, especially in Tarai–Bhabar zones and alluvial plains. Permeable soils and extended ponding allow water to infiltrate, replenishing aquifers. Rejuvenated wetlands improve base flows in downstream rivers and enhance water security. Recharge depends on hydroperiod, soil type, vegetation, and connectivity to floodplains. GRBMP 2.0 integrates wetland restoration with Managed Aquifer Recharge (MAR) systems, recharge ponds, and infiltration trenches. Wetland–aquifer linkages are mapped and incorporated into DRMPs for sustainable groundwater strategies.

### 10.8 Floodplain Restoration & Reconnection

Restoring floodplains requires removing or modifying obstructions, reactivating old channels, rejuvenating oxbow lakes, stabilising banks with bioengineering, and creating controlled flood pathways. Seasonal inundation enhances fish breeding, nutrient cycling, and sediment deposition. Reconnected floodplains reduce downstream flooding by dispersing peak flows. Riparian corridors, agroforestry buffers, and green belts strengthen ecological linkages. Floodplain zoning regulations restrict incompatible land use, ensuring long-term ecological integrity.

### 10.9 Wetland & Floodplain Zonation

Zonation identifies core ecological areas, buffer zones, controlled-use zones, and community-use areas. Core zones protect vulnerable habitats, migratory bird areas, and fish nurseries. Buffer zones stabilise water quality and prevent encroachment. Controlled-use zones allow regulated livelihoods (fisheries, horticulture, reed harvesting). Community-use zones support recreational and cultural activities. Zonation integrates ecological priorities with socio-economic needs, ensuring balanced use and conservation.

### 10.10 Wetland–River–Drain Integration

This subsection connects wetlands, rivers, and drains into a functional hydrological and ecological network. Drains feed wetlands with treated wastewater; wetlands polish and store water; rivers receive improved flows; groundwater gets recharged. Integration requires mapping link channels, enhancing flow pathways, constructing weirs or regulators, and preventing cross-contamination. Integrated systems improve water quality, biodiversity, flood mitigation, and overall ecological health. Such linkages are central to DRMP planning.

### 10.11 Urban & Peri-Urban Lakes Management

Urban lakes suffer from sewage inflow, solid waste dumping, encroachment, and siltation. Restoration includes intercepting sewage, installing decentralised treatment, aeration, desilting, native landscaping, pathway creation, and setting up surveillance. Peri-urban lakes are revitalised to serve as recharge zones, recreational spaces, and biodiversity nodes. Treated wastewater perennialises lakes, improving aesthetic and ecological value. Community involvement ensures upkeep and monitoring.

### 10.12 Traditional Water Bodies (Talabs, Pokhars, Johads)

Traditional water bodies serve as cultural, ecological, and hydrological assets. Many have been encroached or neglected. Restoration strategies include de-silting, reviving catchment channels, reconstructing embankments, and enhancing storage. Traditional designs are combined with modern hydrology—percolation zones, filtration trenches, and controlled inflows. These water bodies support cultural practices, village water security, livestock use, and small-scale irrigation. Integrating traditional knowledge strengthens DRMPs.

### 10.13 Wetland & Floodplain Governance

Governance involves Wetland Management Committees, District Ganga Committees, Panchayats, Forest Departments, and ULBs. Policies regulate land use, encroachment, waste discharge, and resource extraction. Community-based wetland stewardship enhances compliance and ownership. Monitoring includes water levels, biodiversity indicators, pollution inflows, and biomass accumulation. Governance ensures wetlands and floodplains function as long-term ecological infrastructure.

### 10.14 Summary of Wetland–Floodplain Strategy

The strategy integrates wetland rejuvenation, floodplain reconnection, hydrological regulation, biodiversity protection, groundwater recharge, and treated wastewater utilisation. It positions wetlands and floodplains as nature-based solutions central to hydrological stability and ecological resilience. This approach enhances river health, supports livelihoods, mitigates floods, and builds climate resilience.

## 11. Agriculture, Soil Health & Sustainable Land Management

Land management under GRBMP 2.0 integrates soil conservation, water efficiency, nutrient recycling, and landscape-level ecological planning. Healthy soils increase infiltration, reduce runoff, enhance groundwater recharge, and improve crop productivity. Sustainable practices reduce pressure on rivers, wetlands, and aquifers. The chapter aligns agricultural transformation with basin hydrology, climate resilience, and rural livelihoods. It connects farmers with natural-resource based economies under the Arth Ganga initiative, promoting circular agriculture through compost, biochar, and wastewater reuse. The approach ensures long-term food security, ecological stability, and economic viability.

## 11.1 Agricultural Water Demand & Efficiency

Agriculture accounts for 70–80% of total water withdrawals in the Ganga Basin, primarily through groundwater pumping. High water-demand crops (paddy, sugarcane) increase stress on aquifers and reduce base flows to rivers. GRBMP 2.0 promotes micro-irrigation (drip, sprinkler), laser land levelling, deficit irrigation, and irrigation scheduling. Treated wastewater becomes an alternative water source for peri-urban agriculture, reducing groundwater extraction. Water-efficient cropping systems, including pulses, oilseeds, and millets, reduce water demand. Community-based irrigation management ensures equitable distribution. Digital water budgeting and soil moisture sensors optimise irrigation. Reducing agricultural water demand is essential for restoring river flows.

## 11.2 Soil Degradation & Organic Carbon Loss

Soils in the basin suffer from declining organic carbon due to intensive cultivation, excessive tillage, chemical overuse, and removal of crop residues. Soil degradation reduces fertility, increases erosion, lowers water-holding capacity, and contributes to nutrient runoff into drains and rivers. GRBMP 2.0 promotes adding organic matter through compost, green manure, mulching, agroforestry, and biomass-based soil amendments. Soil carbon restoration improves infiltration, reduces irrigation demand, supports groundwater recharge, and enhances nutrient retention. Soil health cards guide farmers in balanced fertilizer application. Linking biomass harvesting from wetlands and drains to compost production creates a circular nutrient economy.

## 11.3 Fertiliser & Nutrient Management

Excessive fertilizer use leads to nitrate contamination of groundwater, nutrient runoff into drains, and eutrophication in ponds and wetlands. Integrated Nutrient Management (INM) promotes balanced fertiliser dosing based on soil tests, split applications, slow-release fertilisers, fertigation, and biofertilisers (Rhizobium, Azotobacter, PSB). Nutrient budgeting at village and block levels aligns agricultural inputs with crop requirements. Compost and biochar reduce reliance on chemical inputs. Buffer strips and vegetated drainage lines intercept nutrient runoff. Policies incentivise low-nutrient-footprint farming. These practices reduce nutrient loading in waterways and improve soil fertility.

## 11.4 Crop Diversification & Climate-Resilient Agriculture

Crop diversification reduces water demand, mitigates climate risks, and improves income stability. GRBMP 2.0 encourages transitioning from water-intensive crops to drought-resistant and climate-resilient varieties—millets, pulses, oilseeds, horticulture crops, and fodder grasses. Diversified farms reduce groundwater extraction, improve soil structure, and allow for integrated systems like agroforestry, apiary, and livestock-based farming. Crop diversification also reduces nutrient runoff by minimising excessive fertiliser use. Extension services, KVKs, and farmer field schools promote diversification, enabling climate-adaptive agriculture across the basin.

## 11.5 Agroforestry & Silvipastoral Systems

Agroforestry integrates trees with crops and livestock to enhance ecological resilience. Trees improve infiltration, stabilise soil, sequester carbon, and provide shade for livestock. Agroforestry systems reduce soil erosion, improve micro-climate, and diversify income through fruit, timber, fodder, and NTFPs. Riparian agroforestry buffers protect riverbanks from erosion. Silvipastoral systems improve pasture productivity and reduce grazing pressure on riparian and forest areas. Agroforestry is aligned with government schemes like PMKSY, CAMPA, and MNREGA. It strengthens the ecological foundation of agriculture while enhancing livelihoods.

## 11.6 Erosion Control & Sediment Management

Soil erosion contributes to sediment overload in rivers and drains, reducing channel capacity, choking wetlands, and degrading aquatic habitats. Erosion control measures include contour bunding, terracing, vegetative barriers, mulching, check-dams, gully plugs, and watershed treatment. Riverbank erosion is controlled through bioengineering—vetiver grass plantation, bamboo spurs, and riparian buffers. Catchment treatment in upland areas reduces sediment inflow to tributaries. Sediment management maintains channel stability, improves water quality, and supports ecological restoration. These measures reinforce basin-wide geomorphic and hydrological resilience.

## 11.7 Integrated Farming Systems

Integrated farming combines crops, livestock, fisheries, horticulture, agroforestry, and waste recycling in a synergistic manner. This reduces input costs, enhances productivity, diversifies income, and optimises resource use. Livestock waste is converted to manure or biogas; crop residues feed livestock; fishponds use nutrient-rich water; agroforestry provides shade and leaf litter. Integrated systems reduce pressure on groundwater and chemical fertilisers and improve soil health. They align with Arth Ganga by creating local circular economies. Integrated systems are particularly valuable for small and marginal farmers.

### 11.8 Biomass-Based Soil Amendments (Compost, Biochar, Vermi-compost)

Biomass harvested from drains, wetlands, and floodplains—algae, hyacinth, macrophytes—is processed into compost, vermicompost, and biochar. These amendments improve soil organic carbon, water retention, nutrient availability, and microbial activity. Compost enhances soil structure; biochar increases cation exchange capacity and long-term carbon storage; vermicompost enriches soil biology. Biomass utilisation reduces disposal costs, generates green livelihoods, and closes nutrient loops between water and agriculture. Application of these amendments reduces synthetic fertiliser use and mitigates eutrophication by exporting nutrients from water bodies to soils.

### 11.9 Sustainable Rural Livelihoods through Soil–Water Integration

Soil–water integration creates new livelihood opportunities: composting enterprises, nursery development, agroforestry products, fish farming in restored ponds, and eco-friendly agriculture. Community groups manage biomass harvesting, compost units, and wetland maintenance. Treated wastewater supports peri-urban agriculture and horticulture. Soil carbon markets provide incentives for regenerative agriculture. These livelihood models strengthen the rural economy while contributing to basin health. Linking water restoration with rural development is central to Arth Ganga.

### 11.10 Agriculture–Wetland–Drain Linkages

Agriculture affects wetlands and drains through nutrient runoff, pesticides, and soil erosion. Conversely, restored wetlands supply moisture, support fisheries, and recharge groundwater. Treated wastewater directed into wetlands enhances soil–water cycles. Vegetated buffers and filter strips reduce agricultural pollution entering wetlands. Controlled irrigation from restored ponds supports horticulture. Integrating agriculture with the wetland–drain network creates a closed-loop system that minimises nutrient loss and improves productivity.

### 11.11 Climate-Resilient Land Use Planning

Climate-resilient land use includes drought-resistant crops, flood-tolerant varieties, soil moisture conservation, diversified farming, and agroforestry. Land zoning prevents cultivation on erosion-prone slopes and riverbanks. Recharge zones, wetlands, and floodplains are protected as climate buffers. GIS-based land use planning aligns agriculture with water availability, ecosystem services, and climate forecasts. Climate-resilient land use reduces water stress, enhances soil health, and safeguards livelihoods against extreme weather.

### 11.12 Summary of Agricultural Strategy

The agricultural strategy integrates water efficiency, soil carbon restoration, nutrient management, crop diversification, agroforestry, erosion control, integrated farming, biomass-based amendments, and climate-resilient land use. It reduces pressure on groundwater and rivers, improves soil fertility, strengthens rural livelihoods, and enhances ecological stability. Agriculture becomes a partner—not a pressure—on basin health.

## 12. Urban & Industrial Systems

This chapter addresses the pressures urbanisation and industrialisation exert on rivers, wetlands, groundwater, and floodplains. Urban areas generate concentrated sewage, stormwater, solid waste, and industrial effluents, which often enter drains untreated. Unplanned expansion increases impervious surfaces, reduces infiltration, and intensifies flooding. Industrial clusters contribute heavy metals, toxic chemicals, and high-COD loads. GRBMP 2.0 integrates decentralised wastewater treatment, stormwater separation, solid waste management, industrial compliance, urban lake rejuvenation, and green infrastructure into a single urban river management framework. Smart mapping, zoning, and urban hydrology planning reduce ecological footprints. The chapter aligns urban development with river health through ecological riverfronts, urban wetlands, dual plumbing, treated wastewater reuse, and climate-resilient city planning. Industrial regulation focuses on effluent segregation, CETP modernisation, zero-liquid-discharge zones, and real-time monitoring.

### 12.1 Urbanisation Trends & River Health

Urban populations in the Ganga Basin have grown rapidly, increasing demand for water, sanitation, and infrastructure. Expansion often encroaches on drains, wetlands, and floodplains, disrupting natural hydrology. Urban sewage contributes the majority of the basin's BOD load. Industrial clusters near cities add toxic pollution. Urban heat islands alter microclimates and intensify water demand. These pressures reduce flow, degrade water quality, and fragment habitats. GRBMP 2.0 advocates compact urban planning, land-use zoning, ecological buffers, green infrastructure, and restoration of natural drainage networks to balance growth with river health. Integrating river and urban development plans ensures sustainable urbanisation.

### 12.2 Urban Wastewater Collection & Conveyance

Many urban areas lack full sewerage networks, leading to direct discharge of wastewater into drains and tributaries. Even where networks exist, they often fail due to broken pipes, illegal connections, insufficient pumping, and inadequate capacity. GRBMP 2.0 promotes a hybrid wastewater conveyance model combining conventional sewers with decentralised conveyance at the drain-neighbourhood level. Mapping of sewer networks identifies gaps and priorities for repair. Low-cost conveyance technologies (shallow sewers, simplified sewers) supplement main systems. Interception chambers capture waste before entering drains. Proper conveyance is essential for ensuring that wastewater reaches decentralised STPs or treatment wetlands without leaking into groundwater or storm drains.

## 12.3 Decentralised Wastewater Treatment (d-STPs, Modular Units)

Decentralised treatment is a cornerstone of GRBMP 2.0, reducing dependence on large STPs and long sewer networks. Modular units (1–10 MLD) located at drain junctions treat sewage near the source. Technologies include MBBR, FAB reactors, anaerobic filters, constructed wetlands, and bio-remediation systems. Decentralised systems ensure flexibility, low O&M cost, rapid deployment, and scalability. These systems feed treated water into drains, ponds, or wetlands for perennialisation and natural polishing. d-STPs are integrated into DRMPs and linked with reuse networks for parks, industries, and agriculture. They reduce pollution loads in rivers while conserving groundwater.

## 12.4 Citywide Water Recycling & Reuse

Urban reuse strategies involve using treated sewage for non-potable applications such as landscaping, construction, industrial cooling, horticulture, and lake rejuvenation. GRBMP 2.0 favours a **restore-first, reuse-second** approach: treated water is first used to perennialise drains, wetlands, and lakes, ensuring hydrological and ecological benefits; only then is excess water distributed for reuse. Localised reuse points near STPs reduce the need for long pipelines. Dual plumbing in institutional and industrial buildings promotes reuse. Integrated reuse planning reduces groundwater extraction, enhances soil moisture, and supports climate resilience. Public awareness and regulatory support ensure safety and adoption.

## 12.5 Stormwater Systems & Urban Flooding

Urban stormwater drains are often clogged, encroached, or combined with sewage lines, causing monsoon flooding and polluting rivers. GRBMP 2.0 promotes separate stormwater and sewage networks, desilting, drain widening, and green infrastructure such as bio-swales, rain gardens, detention ponds, and permeable pavements. GIS-based stormwater master plans identify bottlenecks and redesign flow pathways. Wetland restoration supports stormwater detention and infiltration. Floodplain zoning prevents construction in high-risk areas. Improved stormwater systems reduce pollution wash-off, enhance recharge, and mitigate urban flood risks.

## 12.6 Urban Solid Waste Systems

Urban solid waste, especially plastics and organic waste, often ends up in drains, wetlands, and rivers. GRBMP 2.0 integrates door-to-door collection, waste segregation, composting, biomethanation, MRF operations, sanitary landfills, and legacy waste remediation. Floating trash barriers and nets intercept waste before it reaches rivers. Behavioural change campaigns reduce littering. Policies enforce bans on dumping along riverbanks and floodplains. Plastic waste is recycled through authorised vendors. Clean, functional waste systems are vital to Nirmal Ganga.

### 12.7 Urban Riverfront Development (Ecological & Cultural Lens)

Riverfronts are revitalised as ecological, cultural, and public spaces. Interventions include riparian plantation, natural embankments, ghat restoration, public walkways, biodiversity parks, wetlands, and clean access points for rituals. Ecological riverfronts prioritise natural hydrology and habitat protection rather than concrete-heavy designs. Cultural heritage—temples, ghats, festivals—is integrated with ecological restoration. Community involvement ensures maintenance and cultural continuity. Riverfront improvement enhances tourism, recreation, and stewardship under Jan and Arth Ganga.

### 12.8 Industrial Cluster Mapping & Pollution Control

Industrial clusters are mapped according to location, pollution risk, effluent quality, and connectivity to drains. High-risk industries (tanneries, distilleries, chemical units) are prioritised for strict regulation. CETPs are upgraded with modern processes (ozonation, MBR, advanced oxidation). Effluent pipelines are strengthened to prevent mixing with sewage. Hazardous waste disposal is regulated through authorised facilities. Compliance is monitored using real-time sensors. Cluster-level zero-liquid-discharge or closed-loop recycling is promoted where feasible. Industrial mapping enables targeted interventions that significantly reduce toxic inputs to tributaries and rivers.

### 12.9 CETPs, ETPs & Industrial Compliance

Centralised Effluent Treatment Plants (CETPs) and individual ETPs are essential for treating industrial wastewater. Many units operate below capacity or lack adequate treatment. GRBMP 2.0 mandates modernisation of CETPs, strict monitoring, and penalty mechanisms for non-compliance. Pre-treatment at unit level prevents toxic shocks to CETPs. Sludge must be scientifically disposed of. Real-time online monitoring systems track pH, COD, TDS, ammonia, and metals. Incentives are provided for recycling treated industrial water. Enforcement ensures industries do not pollute drains and tributaries.

### 12.10 Industrial Hazardous Waste & E-Waste Management

Hazardous waste from tanneries, metal plating units, chemical factories, and e-waste recyclers contaminates wetlands and floodplains. GRBMP 2.0 outlines strict regulation, formalisation of recycling units, scientific storage, and safe disposal. E-waste clusters near rivers are relocated. Authorised recycling centres with pollution control systems replace informal dumping and burning. Hazardous waste tracking systems ensure accountability. Public–private partnerships support recycling infrastructure. Managing hazardous waste reduces toxic contamination and ecological risks.

### 12.11 Urban Biodiversity & Green Spaces

Urban biodiversity enhances ecological connectivity, air quality, and temperature regulation. Green spaces—parks, green corridors, riparian buffers, urban wetlands—act as micro-refugia for birds, pollinators, and aquatic species. Native species plantations, butterfly parks, and biodiversity gardens increase ecological value. Tree canopy enhances infiltration and reduces stormwater runoff. Urban biodiversity initiatives contribute to community well-being and river health. Linking green spaces with drains and wetlands creates ecological corridors across cities.

### 12.12 Urban Groundwater Recharge & Natural Infrastructure

Recharge in urban areas is hindered by impervious surfaces and stormwater mismanagement. GRBMP 2.0 promotes recharge wells, percolation parks, trench systems, and restored lakes. Rooftop rainwater harvesting is mandated in institutional and commercial zones. Green roofs and permeable pavements enhance infiltration. Restored wetlands serve as major recharge hubs. Reduced dependence on groundwater through treated wastewater reuse complements recharge measures. Sustainable urban water systems depend on integrated recharge planning.

### 12.13 Climate-Resilient Urban Planning

Urban planning integrates climate risks—extreme rainfall, flooding, heatwaves, droughts—into city design. Measures include flood-safe zoning, blue–green infrastructure, resilient drains, surge storage ponds, heat-resilient materials, and shaded pedestrian corridors. Wetlands, lakes, and urban forests moderate microclimates. Drainage networks are redesigned for high-intensity rainfall. Climate modelling guides infrastructure planning. Resilient cities support water security, ecological health, and community well-being.

### 12.14 Summary of Urban & Industrial Strategy

The strategy integrates decentralised wastewater treatment, stormwater reform, solid waste management, industrial regulation, riverfront restoration, green infrastructure, groundwater recharge, climate resilience, and urban biodiversity. Urban–industrial systems transition from river-stressing to river-supporting models. This chapter ensures that cities and industries become partners in Nirmal and Aviral Ganga.

## 13. Soil & Biomass Management

This chapter establishes soil and biomass as core resources for river rejuvenation under GRBMP 2.0. Healthy soils increase infiltration, support groundwater recharge, reduce runoff, improve agricultural productivity, and reduce sediment and nutrient flows into rivers. Biomass—including crop residue, aquatic vegetation, algae, hyacinth, and organic waste—plays a key role in nutrient cycling and soil health when managed properly. Mismanaged biomass contributes to pollution, choking drains and wetlands. GRBMP 2.0 introduces circular systems where biomass harvested from wetlands, drains, ponds, and floodplains is converted into compost, vermicompost, and biochar, forming a nutrient loop from water to soil. Soil carbon enhancement, regenerative farming, and erosion control reduce chemical dependence and improve resilience.

## 13.1 Soil Organic Matter & Carbon Enhancement

Soil Organic Matter (SOM) drives fertility, water retention, nutrient cycling, and microbial activity. Declines in SOM across the Ganga Basin reduce productivity, increase runoff, and exacerbate groundwater depletion. GRBMP 2.0 promotes adding organic residues, compost, green manure, mulching, agroforestry litter, and biochar to rebuild SOM. Restoring carbon improves infiltration, reducing the burden on rivers by preventing sediment and nutrient wash-off. Increased SOM also improves soil structure, reduces irrigation demand, and enhances climate resilience. Soil carbon enhancement links directly with Arth Ganga through compost and biochar enterprises. Monitoring SOM becomes a key indicator within DRMPs and is integrated with soil health cards.

## 13.2 Erosion Control & Sediment Trapping

Unchecked soil erosion contributes to river siltation, loss of agricultural productivity, wetland choking, and altered river morphology. This subsection promotes contour bunding, terracing, check-dams, brushwood barriers, vetiver grass plantations, and riparian buffers to trap sediment. Gully plugs and watershed treatment in upland areas reduce sediment loads entering tributaries. Silt traps and desilting cycles in wetlands restore depth and ecological function. Sediment trapping protects downstream channels from aggradation and helps maintain flood-carrying capacity. These soil conservation measures are incorporated into block-level DRMPs, ensuring hydrological coherence between agricultural landscapes and river systems.

## 13.3 Biomass Harvesting (Wetlands, Drains, Floodplains)

Aquatic biomass—algae, water hyacinth, macrophytes—accumulates in wetlands, ponds, and drains due to nutrient inflow. If unmanaged, it causes eutrophication, restricts flow, triggers oxygen collapse, and blocks channels. GRBMP 2.0 introduces systematic biomass harvesting using mechanical cutters, floating booms, manual teams, and community-based Jal Mitras. Harvesting removes nutrients physically, preventing excessive algal growth and improving water quality. Regular biomass cycles stabilise wetland hydrology, support fish habitat, and maintain ecological balance. This harvested biomass becomes a raw material for compost, biochar, handicrafts, and biogas. Biomass management is a core project cluster within DRMPs.

## 13.4 Composting & Soil Amendment Systems

Biomass from wetlands and drains, along with crop residues and organic waste, is converted into compost and soil amendments through decentralised units. Composting enhances soil fertility, reduces synthetic fertiliser use, and improves soil structure. GRBMP 2.0 promotes co-composting systems near wetlands, village-level compost pits, vermicompost units, and municipal compost yards. Compost is applied to agricultural fields, horticulture, and riparian buffers. It reduces nutrient leakage into water bodies, closing the nutrient loop. Soil amendment systems support local enterprises and strengthen circular economies under Arth Ganga.

## 13.5 Biochar Production from Biomass

Biochar produced through pyrolysis of harvested biomass improves soil health by enhancing cation exchange capacity, increasing water retention, reducing fertiliser demand, and sequestering carbon long-term. Biochar also binds contaminants in soil, reducing nutrient leaching into groundwater and drains. GRBMP 2.0 promotes small-scale decentralised biochar units near biomass-rich wetlands. Biochar provides economic opportunities for rural entrepreneurs. Biochar-amended soils become more resilient to drought and heavy rainfall. This strategy links eutrophication management with soil restoration and climate mitigation.

## 13.6 Nutrient Recycling & Circular Economy

Nutrient recycling transforms waste inputs such as biomass, organic waste, treated wastewater into productive resources for soil and agriculture. Wetlands become nutrient sinks and biomass factories; compost and biochar return these nutrients to soils; treated wastewater irrigates fields; and agricultural produce supports rural economies. This closed-loop system reduces pollution, enhances soil fertility, and decreases dependence on chemical fertilisers. Nutrient recycling aligns with Arth Ganga by generating green livelihoods and reducing environmental costs. Circularity strengthens basin-wide ecological resilience.

## 13.7 Soil–Water–Biomass Integration

Healthy soils, restored wetlands, perennialised drains, and biomass cycles create a holistic ecological system. Soil captures nutrients and increases infiltration; wetlands buffer floods and polish water; biomass converts excess nutrients into economic products; and drains maintain flow continuity. Integration enhances hydrological stability, reduces pollution loads, and creates livelihoods. DRMPs implement soil–water–

biomass integration through coordinated multi-sector planning. This integrated approach ensures long-term ecological regeneration across the basin.

### 13.8 Soil Health Monitoring & Indicators

Monitoring tracks soil organic carbon, nutrient balance, microbial activity, infiltration rate, erosion status, and salinity. Soil Health Cards are upgraded with indicators aligning with river health: nutrient runoff risk, soil erosion vulnerability, and water retention capacity. Community soil labs and digital soil mapping support data-driven farming. Soil health monitoring feeds into DRMP diagnostics and guides adaptive land management. Monitoring ensures accountability and helps measure the impact of regenerative agriculture.

### 13.9 Summary of Soil & Biomass Strategy

This strategy transforms degraded soils and unmanaged biomass into ecological assets. It reduces nutrient flows to rivers, enhances infiltration, stabilises groundwater, improves crop productivity, and creates circular livelihoods. Soil and biomass form a unified ecological economy under GRBMP 2.0, driving sustainable river rejuvenation.

## 14. Climate Resilience & Disaster Risk Reduction

This chapter integrates climate adaptation and disaster preparedness into basin planning. The Ganga Basin faces rising temperatures, erratic monsoon patterns, extreme rainfall, glacial retreat, droughts, and severe flooding. These events threaten water security, infrastructure, agriculture, and ecosystems. GRBMP 2.0 enhances resilience through hydrological buffers (wetlands, floodplains), nature-based solutions, resilient agriculture, drought-proofing, flood-safe infrastructure, and early warning systems. District-level climate-risk assessments are integrated into DRMPs. Climate resilience focuses on reducing vulnerability, building adaptive capacity, and ensuring long-term sustainability of river rejuvenation efforts.

### 14.1 Climate Risks in the Ganga Basin

The basin is vulnerable to heavy monsoon rainfall, flash floods, glacial lake outburst floods (GLOFs), prolonged dry spells, heatwaves, and stormwater surges. Urban areas experience frequent flooding, while agricultural belts face drought and groundwater stress. Rising temperatures accelerate evaporation and alter river hydrology. Himalayan regions see reduced snowmelt predictability. These risks affect drinking water supply, agriculture productivity, infrastructure stability, and ecological functions. GRBMP 2.0 identifies climate hotspots across districts to prioritise adaptation.

## 14.2 Drought Susceptibility & Response

Drought-prone districts experience declining rainfall, rapid groundwater depletion, and soil moisture stress. Response strategies include recharge structures, treated wastewater irrigation, drought-resistant crops, mulching, soil carbon enhancement, and efficient irrigation. Village-level water budgeting and contingency planning improve resilience. Rejuvenated wetlands and floodplains improve local microclimates and provide drought-cycle buffers. GRBMP 2.0 embeds drought resilience into agricultural and hydrological planning.

## 14.3 Flood Vulnerability & Management

Floods arise from intense rainfall, river overflow, encroached floodplains, clogged drains, and loss of wetlands. This subsection outlines strategies for flood zoning, early warning systems, stormwater reform, wetland restoration, channel desilting, and river–floodplain reconnection. Nature-based flood mitigation—wetlands, riparian forests, detention basins—reduces peak flows and protects communities. Flood-safe infrastructure planning ensures long-term resilience. Flood vulnerability maps guide DRMP priorities.

## 14.4 Climate-Smart Agriculture

Climate-smart agriculture adapts cropping systems to changing rainfall and temperature patterns. Techniques include drought-tolerant crops, improved sowing windows, micro-irrigation, mulching, integrated farming, agroforestry, and weather-based advisory services. Soil carbon enhancement improves moisture retention and reduces irrigation needs. Climate-smart agriculture stabilises livelihoods and reduces stress on rivers and aquifers. It is central to basin-level climate adaptation.

## 14.5 Blue–Green Infrastructure for Climate Resilience

Blue–green infrastructure combines natural and engineered systems—wetlands, ponds, green corridors, rain gardens, bio-swales, recharge parks, and urban forests—to buffer climate extremes. This infrastructure reduces flood risk, enhances groundwater recharge, cools urban temperatures, filters pollutants, and increases biodiversity. GRBMP 2.0 promotes blue–green networks across cities and rural landscapes as a core climate adaptation tool. Integrated design supports water, ecology, and community resilience.

## 14.6 Community Preparedness & Early Warning Systems

Strengthening community preparedness reduces loss during climate events. Jal Mitras, panchayats, and local institutions receive training on flood evacuation, drought planning, and emergency water management. Early warning systems integrate river gauges, rainfall sensors, weather forecasts, and mobile alerts. Community-based disaster response teams monitor river levels, wetlands, and critical infrastructure. Education campaigns build awareness and resilience across rural and urban communities.

### 14.7 Integration of Climate Resilience in DRMPs

Climate resilience is embedded in DRMPs through climate-risk mapping, prioritisation of nature-based interventions, resilient infrastructure planning, and integration of drought and flood strategies. Recharge structures, perennialisation, wetland restoration, agricultural diversification, and soil carbon improvements form the backbone of district climate adaptation. Monitoring tracks climate indicators to guide future revisions of DRMPs.

### 14.8 Summary of Climate Strategy

The climate strategy integrates hydrology, ecology, agriculture, communities, and infrastructure into a unified adaptation framework. Nature-based solutions reduce vulnerability, restore ecological buffers, and ensure sustainable river flows. GRBMP 2.0 builds systemic resilience to climate variability across all districts.

## 15. Arth Ganga: Economic & Livelihood Systems

This chapter positions the Ganga Basin not only as an ecological system but as an economic engine that can generate sustainable livelihoods through nature-based enterprises, circular economy models, green jobs, and cultural heritage activities. Arth Ganga integrates river restoration with economic revitalisation by promoting community-led livelihood models linked to biomass utilisation, fisheries, ecotourism, crafts, organic agriculture, and river-based cultural activities. GRBMP 2.0 recognises that long-term river rejuvenation requires economic incentives for communities to protect river systems. This chapter outlines livelihood pathways, value-chain development, financing options, skill development programs, and institutional mechanisms for creating a river-based economy. Arth Ganga ensures that ecological rejuvenation becomes economically self-sustaining, socially inclusive, and culturally meaningful.

### 15.1 Principles of Arth Ganga

Arth Ganga is grounded in three principles:

1. **People–River Connection** — Communities must see value in river restoration and derive livelihoods from healthy ecosystems.
2. **Circular Economy** — Waste becomes a resource, biomass becomes compost or biochar, and treated water supports agriculture.
3. **Inclusive Green Growth** — Livelihood opportunities must benefit women, youth, artisans, and marginalised groups.

Arth Ganga ensures sustainable development by linking economic activities with ecological restoration. It promotes low-impact industries, nature-based enterprises, decentralised value chains, and local ownership. These principles guide district-level planning and align with national development missions.

## 15.2 Categories of Establishments Under Arth Ganga

This section categorises enterprises that can thrive under river-centric economic systems:

- **Wetland-based enterprises** (fisheries, lotus cultivation, reed harvesting)
- **Biomass enterprises** (compost, vermicompost, biochar, handicrafts from hyacinth)
- **Organic and natural farming units**
- **Eco-cottage industries** (handlooms, pottery, bamboo crafts)
- **Ecotourism and nature education centres**
- **Waste recycling and resource-recovery enterprises**
- **Riverfront cultural enterprises** (art, cuisine, heritage walks)

The section outlines how districts can identify demand, map resources, train communities, and build market linkages. These categories serve as templates for DRMP-linked livelihood clusters.

## 15.3 Green Livelihood Models (Biomass, Fisheries, Agriculture)

Green livelihood models revolve around ecological regeneration:

- **Biomass-based livelihoods:** harvesting hyacinth and algae for compost, biochar, or handicrafts; running small-scale pyrolysis units; community compost centres.
- **Fisheries:** sustainable fish farming in restored ponds and wetlands; native fish stocking; value-addition through drying, processing, and packaging.
- **Agri-based livelihoods:** organic farming, horticulture, floriculture, seedling nurseries, and agroforestry enterprises.

These models utilise restored ecological systems that include wetlands, floodplains, drains, and ponds to create income. They reduce pressure on ecosystems by promoting regenerative practices. Green livelihoods make river restoration financially attractive to communities, ensuring sustainability.

## 15.4 River-Based Entrepreneurship

River-based entrepreneurship includes a wide range of small and medium enterprises dependent on clean water, healthy riparian zones, and restored wetlands. Examples include river cruises, boating services, eco-guiding, birdwatching services, river-based homestays, eco-cafes, and heritage tourism. Enterprises also include river-cleaning technologies, sensor installation, maintenance services, and green product manufacturing. Entrepreneurship is supported through skill development, access to finance, incubation, branding, and digital marketing. Local youth become custodians of river resources through enterprises linked to restoration.

## 15.5 Eco-Tourism & Cultural Tourism

Eco-tourism develops around restored wetlands, riparian forests, bird habitats, oxbow lakes, and ecological parks. Activities include guided nature walks, birdwatching, photography tours, cycling trails, and seasonal migration festivals. Cultural tourism builds on ghats, temples, historic settlements, river festivals, traditional crafts, and folk performances. Integrated eco-cultural circuits enhance visitor experience. Ecotourism centres managed by local communities promote environmental education. Tourism revenue supports conservation efforts and creates long-term economic incentives for local stewardship.

## 15.6 Value Chain Strengthening & Market Linkages

Value chain development ensures that communities earn steady income from Arth Ganga activities. This includes training in product design, quality control, branding, packaging, and online marketing. Aggregation centres help consolidate products like compost, biochar, crafts, and organic produce. Partnerships with e-commerce platforms expand market reach. Institutional buyers such as municipalities, industries, agricultural departments can create assured markets for compost and biochar. Fisheries cooperatives add cold-chain storage and processing capabilities. Strengthened value chains reduce middlemen losses and enhance community profits.

## 15.7 Riverine Transport & Navigation

Sustainable navigation integrates inland waterways with ecological preservation. GRBMP 2.0 encourages low-impact boats, solar-powered river taxis, and eco-friendly jetties. Navigation supports tourism, cargo movement, and connectivity for remote communities. Safe navigation requires maintaining adequate ecological flows, dredging only where necessary, and monitoring habitat impacts. Riverine transport links economic activities to river health, creating a shared interest in clean, perennial rivers.

## 15.8 Cultural Economy & River Heritage

The Ganga Basin hosts a living cultural heritage that include rituals, festivals, crafts, music, food, and riverfront traditions. The cultural economy includes artisan groups, spiritual tourism, heritage walks, and traditional medicine. GRBMP 2.0 integrates cultural heritage with ecological restoration by revitalising ghats, protecting sacred ponds, promoting traditional crafts, and enhancing riverfront cleanliness. River-based cultural economies strengthen emotional connections to rivers and create non-extractive livelihood opportunities.

### 15.9 Community-Based Enterprises (SHGs, Cooperatives)

Community-owned enterprises ensure equitable distribution of benefits. SHGs, women's groups, youth clubs, farmer cooperatives, and Jal Mitra networks manage biomass harvesting, compost units, fish ponds, nurseries, eco-parks, and tourism services. Collective ownership ensures transparency, accountability, and sustained engagement. Cooperatives receive training in financial management, enterprise planning, and governance. Community enterprises anchor Arth Ganga at the grassroots level.

### 15.10 Financing Models (PPP, CSR, Microfinance)

Arth Ganga enterprises require blended financing. PPP models support infrastructure like ecoparks, compost plants, and tourism facilities. CSR funds rehabilitate wetlands, support community enterprises, and provide equipment for biomass harvesting. Microfinance and SHG-bank linkages fund small-scale units like crafts, nurseries, composting, and eco-tourism. Government schemes such as NRLM, PMEGP, and MSME programs provide subsidies and credit. Financing models ensure scalability and sustainability of river-based enterprises.

### 15.11 Skill Development & Capacity Building

Skill-building is essential for transitioning communities to green livelihoods. Training covers compost preparation, biochar production, eco-guiding, fish farming, craft making, hospitality, digital marketing, and enterprise management. Technical institutions, NGOs, KVKs, and district skill centres conduct workshops. Continuous learning networks ensure quality improvement. Skill development creates a workforce aligned with Arth Ganga's economic and ecological aspirations.

### 15.12 Summary of Arth Ganga Strategy

The Arth Ganga strategy transforms ecological restoration into a source of green livelihoods, sustainable enterprises, and circular economies. Wetlands, drains, floodplains, and restored rivers become platforms for biomass utilisation, fisheries, ecotourism, crafts, and regenerative agriculture. It empowers communities, strengthens district economies, and ensures that river rejuvenation delivers long-term socio-economic benefits.

## 16. Governance, Institutions & Policy Framework

This chapter outlines the institutional architecture required for implementing GRBMP 2.0 across the Ganga Basin. It integrates national, state, district, and local institutions into a unified governance system driven by clear roles, accountability, data systems, financial pathways, and legal support. The chapter emphasises that successful river rejuvenation is fundamentally a governance challenge, not a technical one, requiring coordination across water, agriculture, urban development, industry, forests, and disaster management. It defines the institutional relationships between NMCG, cGanga, State Missions, District Ganga Committees, ULBs, Panchayats, and community groups such as Jal Mitras. Policy reforms are proposed to mainstream DRMPs, integrate river health into development planning, enforce environmental compliance, promote nature-based solutions, and align river management with economic development (Arth Ganga). Governance under GRBMP 2.0 shifts from project-based interventions to long-term, cyclical, adaptive basin management.

## 16.1 Governance Architecture of GRBMP 2.0

The governance architecture is built on a multi-tiered system:

- **National Level:** NMCG provides strategic direction, basin-wide coordination, standards, and funding mechanisms.
- **Technical Backbone:** cGanga serves as the think tank, developing frameworks, protocols, and advanced tools.
- **State Level:** State Ganga Committees coordinate DRMP implementation, sectoral alignment, and inter-departmental integration.
- **District Level:** District Ganga Committees operationalise DRMPs, manage data, oversee projects, and supervise local institutions.
- **Local Level:** ULBs and Gram Panchayats implement ground-level interventions. This layered system functions through structured communication channels, periodic reviews, and shared digital dashboards. Governance depends on collaboration, transparency, and adaptive planning.

## 16.2 Inter-Departmental Coordination

River health responsibilities span multiple departments that include, but not limited to, irrigation, agriculture, rural development, industry, urban development, forest, pollution control, disaster management, and fisheries. Historically, poor coordination has led to fragmented actions. GRBMP 2.0 mandates integrated coordination through District Ganga Committees, which convene all relevant departments under the District Magistrate. Joint planning, shared budgeting, synchronized timelines, and common data platforms ensure coherence. Sectoral convergence is embedded into routine government functioning, linking irrigation schedules with sewage treatment, wetland restoration with groundwater management, and agricultural extension with nutrient control. Coordination reduces redundancy, prevents contradictions, and accelerates basin rejuvenation.

## 16.3 Roles of District Ganga Committees (DGCs)

DGCs are the operational hubs of GRBMP 2.0. Their responsibilities include:

- Preparing, updating, and executing DRMPs

- Mapping drains, wetlands, water bodies, and pollution hotspots
- Monitoring flows, water quality, biomass, groundwater and project progress
- Enforcing regulations and ensuring compliance
- Coordinating ULBs, Panchayats, and sectoral departments
- Mobilising communities (Jal Mitras, SHGs, youth networks)
- Reporting monthly to State Ganga Committees

DGCs act as data-driven, multi-disciplinary, local governance units. They ensure that basin-wide strategies translate into site-specific actions and ground-level improvements. Their performance determines long-term river health outcomes.

## 16.4 Roles of Urban Local Bodies & Panchayati Raj Institutions

ULBs manage sewage networks, decentralised STPs, stormwater drains, solid waste systems, and urban wetlands. They enforce zoning regulations, prevent encroachments, maintain ghats, and implement green infrastructure. Gram Panchayats oversee village ponds, greywater systems, farm drainage, sanitation, and agricultural extension. Panchayats facilitate biomass harvesting, composting, and wetland stewardship through SHGs and Jal Mitras. GRBMP 2.0 strengthens ULB–Panchayat linkage to manage entire urban–rural continua. Local institutions ensure sustained operation, maintenance, and community participation.

## 16.5 Legal & Regulatory Frameworks

This section summarises key legal provisions governing river health:

- Environment (Protection) Act
- Water Pollution Control Act
- Wetlands (Conservation & Management) Rules
- Solid and Plastic Waste Rules
- Groundwater Regulation Guidelines

GRBMP 2.0 recommends strengthening compliance through district-level enforcement teams, digital monitoring, and penalty systems. It also calls for riverfront zoning regulations, floodplain protection laws, groundwater extraction permits, and wetland notification processes. Legal reforms ensure that ecological assets receive statutory protection and sustainable use norms.

## 16.6 Policy Reforms & Mainstreaming River Health

River health must become integral to development planning. Policy reforms include integrating DRMPs into district development plans, mandating environmental flows in irrigation planning, promoting nature-based wastewater systems, and recognising wetlands as hydrological infrastructure. Incentives for sustainable agriculture, water-efficient crops, and circular economy enterprises are proposed. Policies encourage industries to adopt zero-liquid discharge where feasible. River health indicators become part of administrative performance reviews. These reforms embed river rejuvenation into everyday governance.

## 16.7 Environmental Standards & Compliance Mechanisms

Environmental standards for water quality, effluent discharge, groundwater extraction, and waste management guide regulatory action. Compliance is ensured through continuous monitoring, random inspections, public disclosure, and graded enforcement. Industries must maintain real-time monitoring equipment. ULBs and Panchayats are held accountable for wastewater and waste systems. Non-compliance triggers penalties, closures, or remedial directives. A compliance dashboard under GRBMP 2.0 enhances transparency and builds public trust.

## 16.8 Governance Challenges & Systemic Barriers

Challenges include capacity deficits, fragmented data, weak enforcement, overlapping jurisdiction, unreliable funding, and limited community engagement. Rural–urban coordination gaps hinder integrated planning. Political and administrative turnover disrupt continuity. Public awareness is uneven. GRBMP 2.0 addresses these barriers through robust institutional frameworks, digital systems, capacity building, financial innovations, and community mobilisation. Overcoming these challenges is crucial for sustaining long-term river rejuvenation.

## 16.9 Institutional Innovations & Capacity Building

Institutional innovations include digital DRMP tools, district-level water labs, mobile monitoring teams, wetland management committees, and Jal Mitra networks. Capacity building programs train officials, engineers, and frontline workers in hydrology, ecology, GIS, wastewater systems, and community engagement. Leadership modules strengthen the ability of officers to coordinate multi-sectoral planning. Capacity development ensures efficient implementation and adaptive management.

## 16.10 Role of NMCG & cGanga

NMCG sets national direction, mobilises funds, defines standards, coordinates basin-level planning, and supervises implementation. cGanga develops scientific, technological, and methodological frameworks such as DRMP, RHMP, governance protocols, monitoring systems, and digital tools. It acts as a knowledge and innovation hub. Together, NMCG and cGanga oversee state missions, support divisional level committees (except in West Bengal, where divisions encompassing a few districts are not created instead the nomenclature of subdivisions is used for sub-district), district committees, conduct evaluations, and ensure coherence across the basin. Their combined role is foundational for GRBMP 2.0.

### 16.11 Integration of DRMPs into Governance

DRMPs become statutory planning instruments guiding water, land, agriculture, and urban systems. They are incorporated into district development plans, gram panchayat plans, urban master plans, and irrigation schedules. DRMP indicators are linked with annual reporting and financial allocations. Integration ensures that river health shapes local governance priorities. DRMPs evolve through cyclical monitoring, feedback loops, and periodic reviews.

### 16.12 Public Participation & Community Stewardship

Communities play a central role in river stewardship. SHGs, schools, fishermen groups, youth clubs, religious institutions, and environmental groups participate in monitoring, cleaning, awareness, and livelihood activities. Jal Mitra networks track water levels, biomass, pollution, and biodiversity. Public hearings ensure transparency. Community mobilisation strengthens behavioural change and creates collective responsibility for river health.

### 16.13 Digital Governance Tools

Digital tools such as GIS portals, mobile apps, dashboards, water quality sensors, AI-enabled monitoring, CCTV networks, and drone mapping support transparent and data-driven governance. Digital DRMP platforms track projects, budgets, compliance, and environmental indicators. Data integration across departments prevents information silos. Real-time monitoring enhances enforcement and public accountability. Digital governance accelerates decision-making and adaptive planning.

### 16.14 Integrated Monitoring & Evaluation Frameworks

Monitoring combines remote sensing, field surveys, hydrological data, biodiversity indicators, and socio-economic metrics. Evaluation tracks progress on flow restoration, pollution reduction, wetland rejuvenation, groundwater stability, and livelihood outcomes. Third-party audits ensure credibility. Periodic evaluations feed into adaptive management cycles. Strong M&E systems sustain long-term basin rejuvenation.

### 16.15 Summary of Governance Strategy

Governance under GRBMP 2.0 integrates institutions, policies, digital tools, community networks, and compliance systems to create a unified river management framework. It shifts from reactive project-based planning to proactive, cyclical, data-driven, multi-sectoral governance. Institutions at all levels work collaboratively to maintain Nirmal, Aviral, and ecological Ganga.

# 17. Digital Systems & Monitoring Infrastructure

This chapter establishes the digital backbone required for implementing, tracking, and continuously improving GRBMP 2.0. River rejuvenation depends on real-time data, transparent reporting, predictive analytics, and integrated digital maps. Digital systems unify hydrology, water quality, wetlands, groundwater, drains, agriculture, industry, climate variability, and socio-economic data. GRBMP 2.0 introduces a basin-wide digital architecture integrating IoT sensors, satellite data, GIS platforms, dashboards, and AI-enabled analytics. These tools support early warnings, decision-making, enforcement, and adaptive management. Digital infrastructure ensures accountability, enhances governance, and enables district-level DRMPs to function as living, continuously updated documents. Citizen-facing platforms increase transparency and encourage public participation. Digital systems are the central nervous system of the Ganga River Basin's management framework.

## 17.1 Digital Architecture of GRBMP 2.0

The digital architecture integrates multiple platforms into a single interoperable framework. Core components include:

- **Basin GIS Portal** integrating all spatial layers—rivers, drains, wetlands, floodplains, groundwater, land use
- **Digital DRMP Platform** for district-level planning, monitoring, and reporting
- **Hydrology & Water Quality Monitoring Network** linking sensors to dashboards
- **Data Exchange Layer (APIs)** enabling departments to share data in real time
- **AI/ML Analytics Engine** for forecasting flows, pollution loads, and risks

The architecture ensures seamless communication across national, state, district, and community levels. Data governance protocols ensure accuracy, security, and transparency. The system serves as the backbone for decision-making and coordination across the basin.

## 17.2 GIS-Based Basin & District Maps

GIS mapping is essential for understanding hydrology, land use, biodiversity, pollution hotspots, and infrastructure. Layers include drainage networks, wetlands, ponds, canals, floodplains, forest cover, agricultural zones, groundwater depth, aquifer types, STPs, industrial clusters, and soil erosion risk. GIS enables spatial prioritisation—identifying where interventions are most needed. It supports DRMPs by linking each project to a geospatial location, enabling block-wise planning. Historical and seasonal maps help track changes in wetland area, river morphology, encroachments, and vegetation. GIS-based risk maps guide flood zoning, drought mitigation, and climate adaptation planning.

## 17.3 IoT-Based Water Quality & Flow Monitoring

IoT sensors installed at key river, tributary, drain, and STP locations monitor key parameters—DO, pH, temperature, conductivity, and water levels. Flow meters track discharge volumes and seasonal variations. Sensors transmit real-time data to central dashboards through GSM/LoRa networks. Alerts are triggered when parameters exceed permissible limits. IoT monitoring reduces manual errors, improves transparency, and strengthens enforcement. Flow sensors help verify environmental flows and detect blockages or illegal discharges. Sensor networks and participative monitoring (e.g. based on RHM pilot by cGanga) involving river side communities form the backbone of Nirmal and Aviral Ganga monitoring.

## 17.4 Remote Sensing for Wetlands & Floodplains

Satellite imagery (Sentinel, Landsat, CartoSAT) supports monitoring of wetland health, floodplain dynamics, vegetation cover, siltation, water spread, and seasonal inundation. Remote sensing detects encroachments, illegal constructions, solid waste accumulation, and hydrological blockages. It assesses changes in wetland boundaries, river morphology, and flood extent. Time-series analysis tracks long-term trends and provides early warning for degradation. Remote sensing complements ground surveys and integrates into DRMPs to guide restoration and policy decisions.

## 17.5 Drone-Based Surveys for River Monitoring

Drones capture high-resolution imagery of rivers, drains, wetlands, illegal activities, sand mining, and riverbank encroachments. They map channel morphology, erosion-prone areas, sediment bars, and restoration progress. Drones are especially useful in remote, inaccessible, or densely populated areas where ground surveys are difficult. GRBMP 2.0 uses drone surveys to validate GIS layers, inspect project sites, and support enforcement teams. Drone data improves accuracy and reduces survey costs.

## 17.6 Digital Dashboard for Ganga Basin Management

A unified digital dashboard aggregates data from sensors, GIS layers, remote sensing, ULB reports, and DRMP platforms. It displays real-time water quality, flows, biomass harvesting volumes, STP performance, groundwater levels, wetland status, flood alerts, and project progress. Dashboards have user-specific access layers—national, state, district, departmental, and citizen view. They support decision-making, transparency, and rapid response. Drill-down features allow stakeholders to track block-level indicators and enforcement actions. Dashboards make governance data-centric and proactive.

## 17.7 Integration of DRMP Data & Analytics

DRMPs contain extensive data on hydrology, drains, wetlands, agriculture, industry, soil, and climate. Integrating this data into digital platforms enables advanced analytics—pollution load modelling, groundwater balance assessments, land use simulations, and climate risk forecasting. Predictive models guide project prioritisation, infrastructure design, and seasonal planning. Integration also supports progress tracking and adaptive management. Districts use analytics to update DRMPs annually, convert data into actionable insights, and strengthen accountability.

## 17.8 Digital Compliance Tools (STP, CETP, Industry)

Digital compliance systems track STP and CETP performance through real-time sensor data, periodic calibration checks, and automated reporting. Industries must install online effluent monitoring systems integrated with pollution control boards. Alerts notify regulators of violations. Digital logs prevent tampering and allow traceable compliance histories. GIS-tagged inspections and digital sampling ensure transparency. Compliance tools reduce pollution, improve enforcement, and promote responsible industrial behaviour.

## 17.9 Early Warning Systems (EWS) for Floods & Pollution

Early Warning Systems combine sensor networks, weather forecasts, satellite data, hydrological models, and machine learning algorithms. Flood EWS monitors rainfall intensity, river levels, wetland storage, and drainage capacity to predict flash floods and inundation. Pollution EWS detects sudden effluent releases, sewage bypasses, or STP failures. Alerts are sent via SMS, apps, sirens, and public address systems. EWS reduce disaster losses, protect vulnerable communities, and enable rapid interventions.

## 17.10 Data Governance & Security

Data governance ensures quality, interoperability, security, and responsible use of digital information. GRBMP 2.0 defines standards for data collection, validation, storage, sharing, and access control. APIs enable seamless exchange across departments. Security measures protect sensitive data that include critical infrastructure, industrial compliance, citizen information. Data protocols ensure transparency while maintaining privacy. Strong data governance builds trust and ensures effective digital functioning.

## 17.11 Research & Innovation Platforms

Innovation ecosystems link academic institutions, research labs, startups, and technology providers with river rejuvenation. Platforms support R&D in hydrology, AI/ML modelling, wastewater technologies, wetland ecology, climate resilience, drones, sensors, and circular economy models. Pilot projects test new technologies before adoption. Innovation funding supports early-stage solutions. Research collaborations accelerate learning and technological advancement across the basin.

### 17.12 Public-Facing Information Platforms

Public portals display river status, project updates, maps, water quality trends, and compliance data in accessible formats. Mobile apps allow citizens to report illegal dumping, water pollution, or encroachment. Educational dashboards engage schools and communities. Public transparency builds trust and fosters a participatory culture around river rejuvenation. Citizens become active stakeholders in monitoring and protection.

### 17.13 Summary of Digital Infrastructure Strategy

Digital infrastructure transforms GRBMP 2.0 into a continuously monitored, adaptive, and accountable system. Sensors, GIS, drones, remote sensing, analytics, dashboards, and EWS work collectively to ensure real-time governance, transparency, and resilience. Digital systems empower districts to manage rivers scientifically and proactively, forming the foundation of a modern river basin management framework.

## 18. Implementation Framework & Phasing

This chapter outlines how GRBMP 2.0 transitions from planning to execution at basin, state, and district levels. River restoration demands staged implementation—prioritising critical hotspots, rapidly deploying proven technologies, and gradually scaling basin-wide systems. The framework integrates governance structures, financing mechanisms, technical protocols, digital tools, and community participation into a time-bound action plan. It describes how DRMPs become the primary vehicle for district-level execution, coordinated through State Ganga Committees and monitored by NMCG. Implementation emphasises modularity, decentralisation, convergence with government schemes, and multi-sector alignment. The chapter defines strategic phases: Immediate (0–2 years), Medium-Term (2–5 years), and Long-Term (5–15 years ensuring that interventions become sustainable, climate-resilient, and institutionally embedded.

### 18.1 Implementation Architecture (National–State–Division-District–Local)

Implementation flows through a four-tier architecture:

**National:** NMCG provides guidelines, funding pathways, standards, monitoring protocols, and cross-state coordination.

**State:** State Ganga Committees integrate DRMPs into departmental plans, align budgets, and oversee multi-district operations.

**Division:** Divisional level committees chaired by the Divisional Commissioner with support from NMCG, SMCG, Concerned Districts, cGanga, NGOs, etc. for preparation, monitoring and evaluation of DRMPs where such divisions exist.

**District:** DGCs operationalise DRMP projects; coordinate departments, ULBs, and Panchayats; and manage day-to-day execution.
**Local:** ULBs and Panchayats implement on-ground works—decentralised treatment, wetland restoration, desilting, recharge structures, agricultural reforms, and monitoring.

Technical support from cGanga ensures methodological consistency. Clear vertical and horizontal linkages prevent fragmentation and enable collaborative, transparent implementation.

## 18.2 Institutional Responsibilities & Accountability

Roles and responsibilities are assigned to ensure efficiency and accountability.

- **Divisional Level Committees** lead on preparation of DRMP as well as monitoring and evaluation of implementation of DRMMPs.
- **DGCs**: lead project execution, data collection, monitoring, and reporting.
- **ULBs**: manage sewage, drains, STPs, SWM, and urban wetlands.
- **Panchayats**: maintain ponds, greywater systems, farm drains, and biomass harvesting.
- **Line Departments**: agriculture, forest, irrigation, industry, and rural development implement sectoral components.
- **Pollution Control Boards**: enforce environmental standards and monitor effluents.

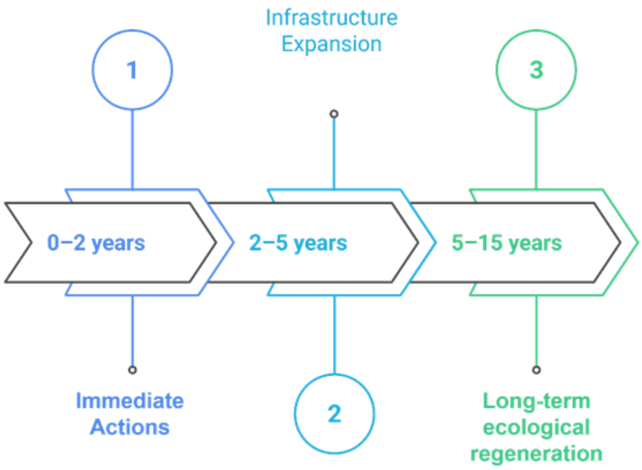
Accountability is strengthened through MIS dashboards, monthly reviews, performance indicators, and public transparency. Inter-departmental MoUs define shared responsibilities.

## 18.3 Implementation Phasing Strategy

Implementation is staggered across three phases:

**Phase 1 (0–2 years):** Quick-win interventions—bioremediation, nala restoration, STP optimisation, wetland desilting, enforcement, digital mapping, sensor installation.
**Phase 2 (2–5 years):** Infrastructure expansion—d-STPs, citywide reuse networks, major wetland rejuvenation, groundwater recharge structures, basin-level coordination.
**Phase 3 (5–15 years):** Long-term ecological regeneration—floodplain restoration, agroecological transformation, cultural landscape development, climate resilience systems, circular economies.

Phasing ensures realistic execution, stable financing, and adaptive learning.




## 18.4 Immediate Actions (0–2 Years)

Priority actions include mapping drains/wetlands, strengthening enforcement, sewer/stormwater segregation, nala tapping, temporary bio-remediation, pond desilting, source control of industrial effluents, blocking illegal discharges, and removing encroachments. Digital platforms (GIS, dashboards, IoT sensors) are deployed. Jal Mitra networks are formed for community monitoring. Recharge measures such as check-dams and soak pits are initiated. Quick-win DRMP projects demonstrate visible improvements, build trust, and create momentum for larger interventions.

## 18.5 Medium-Term Actions (2–5 Years)

Medium-term actions scale structural interventions: decentralised STPs, polishing wetlands, reuse water grids, floodplain restoration projects, urban lake rejuvenation, plantation belts, erosion control, groundwater recharge parks, industrial CETP upgrades, and wetland hydrology restoration. Wider adoption of micro-irrigation, regenerative farming, biochar, and compost-based soil recovery occurs. Industrial compliance systems mature. Blue–green infrastructure networks expand in urban areas. This phase consolidates the ecological foundation of river rejuvenation.

## 18.6 Long-Term Actions (5–15 Years)

Long-term actions reshape basin-scale hydrology and ecosystems. Full floodplain reconnection, river morphology stabilisation, aquifer recharge, sustained perennialisation of drains, and biodiversity recovery occur. Agricultural landscapes shift to climate-resilient, low-input systems. Eco-cultural zones develop along the river. Wastewater reuse becomes standard in agriculture and industry. Ecological flows become stable across seasons. Local economies built on Arth Ganga principles become self-sustaining. Long-term actions ensure irreversible ecological recovery.

## 18.7 Project Prioritisation Framework

Projects are prioritised using criteria such as pollution load reduction, hydrological impact, ecological value, community benefit, economic viability, climate resilience, implementation readiness, and convergence potential. GIS-based spatial scoring identifies high-need zones—industrial drains, degraded wetlands, critical groundwater blocks, flood hotspots. Projects addressing multiple objectives (pollution, recharge, livelihoods) receive higher priority. This ensures efficient allocation of resources and maximum basin-wide impact.

## 18.8 Financial Planning & Mobilisation

Funding is mobilised through NMCG allocations, state budgets, municipal funds, convergence with schemes (AMRUT, SBM, MGNREGA, PMKSY, JJM), CSR contributions, PPP models, green bonds, carbon credits, and multilateral financing. Financial planning involves cost estimation, project phasing, O&M budgeting, and lifecycle cost analysis. A blended finance ecosystem ensures that large-scale ecological restoration is financially sustainable. Districts prepare annual DRMP-linked financial plans aligned with priorities.

## 18.9 Convergence with Government Schemes

GRBMP 2.0 integrates with central/state schemes to avoid duplication and maximise impact.

- **Urban:** AMRUT, SBM, Smart Cities Mission
- **Rural:** MGNREGA, SBM-G, PMKSY, NRLM
- **Agriculture:** PMFBY, RKVY, Soil Health Mission
- **Forestry:** CAMPA, Green India Mission
- **Industry:** MSME programs, ZLD incentives

Convergence enables multi-sectoral projects such as wetland restoration, recharge systems, agricultural diversification, urban green infrastructure, and rural sanitation. Departments collaborate under joint Divisional Level Committees and DGC leadership for integrated execution.

## 18.10 Capacity Building & Training

Training programs build capacity for technical staff, engineers, block officers, Panchayats, ULB workers, SHGs, and Jal Mitras. Topics include hydrology, ecology, STP operations, monitoring tools, GIS, wetland restoration, biomass management, regenerative agriculture, and climate adaptation. Training institutions, cGanga, KVKs, universities, and technical agencies support learning. Regular refresher courses ensure long-term skill retention.

### 18.11 Operation & Maintenance Systems

Sustained river health requires strong O&M systems. Decentralised STPs need regular sludge removal, aeration checks, and sensor calibration. Wetlands require periodic desilting, inlet–outlet cleaning, and biomass harvesting. Recharge systems need clearing of clogged percolation zones. O&M plans assign responsibilities, budgets, monitoring schedules, and performance indicators. Community participation improves vigilance. A dedicated O&M fund ensures continuity.

### 18.12 Annual DRMP Renewal Cycles

DRMPs are living documents that must be updated annually. Renewal cycles include:

- reviewing last year's progress
- updating maps and data
- recalibrating priorities
- integrating climate trends
- identifying new hotspots
- adjusting project phasing

DGCs submit annual DRMP reports to State Ganga Committees and NMCG. Renewal cycles maintain relevance and guide adaptive planning.

### 18.13 Performance Indicators & Evaluation

Evaluation uses indicators such as DO levels, environmental flows, groundwater levels, wetland area restored, biomass harvested, agricultural changes, and community participation. Performance audits assess effectiveness, cost-efficiency, and compliance. Results inform phasing adjustments and funding allocations. Transparent indicators build trust and ensure accountability.

### 18.14 Summary of Implementation Strategy

The implementation strategy transforms GRBMP 2.0 into a practical, time-bound, and adaptive program. Phased execution, convergence with schemes, robust O&M, financial planning, capacity building, and annual DRMP renewals ensure sustainability. Governance, digital systems, community engagement, and technical interventions converge to achieve long-term river rejuvenation.

## 19. Monitoring, Evaluation & Adaptive Management

This chapter establishes the mechanisms through which GRBMP 2.0 remains a dynamic, responsive, and continuously improving system. Monitoring captures data on water quality, flows, wetlands, groundwater, ecological indicators, and socio-economic parameters. Evaluation assesses whether interventions achieve intended outcomes, identifies gaps, and recommends course corrections. Adaptive management uses this evidence to refine strategies, redesign projects, and update DRMPs annually. The chapter emphasises real-time monitoring through sensors, satellite imagery, mobile apps, and dashboards; independent third-party evaluations; and community-based tracking through Jal Mitras. It creates a feedback loop where data → analysis → decisions → implementation → monitoring form a continuous cycle. Adaptive management ensures resilience against climate variability, urbanisation pressures, and emerging challenges. GRBMP 2.0 becomes a living basin management framework that evolves with changing conditions.

## 19.1 Monitoring Framework for GRBMP 2.0

The monitoring framework integrates physical, chemical, biological, hydrological, and socio-economic parameters. Key components include water quality monitoring across rivers, drains, and wetlands; ecological monitoring of biodiversity; groundwater depth and quality mapping; wetland hydrology tracking; project performance monitoring; industrial compliance checks; and community feedback. The framework defines sampling protocols, frequency, quality assurance, and reporting formats. Data flows from sensors, remote sensing, ULBs, Panchayats, DGCs, and departments into unified dashboards. The monitoring framework provides early warnings, confirms progress, and supports enforcement.

## 19.2 Water Quality Monitoring (River, Drains, Wetlands, STPs)

This section establishes a comprehensive water quality monitoring network covering:

- **Rivers and tributaries** (DO, BOD, COD, nutrients, pathogens, metals)
- **Urban and rural drains** (pollution loads, seasonal variations)
- **STPs and d-STPs** (effluent quality, bypass events, performance trends)
- **Wetlands and lakes** (trophic state, algal blooms, dissolved oxygen, depth)

Monitoring includes fixed stations, mobile labs, IoT sensors, and periodic manual sampling. Upstream–downstream comparisons identify hotspots. Data verifies compliance with environmental standards and guides restoration efforts. Water quality data is tied directly to DRMP indicators.

## 19.3 Flow Monitoring & Environmental Flows

Flow monitoring assesses river discharge, velocity, seasonal patterns, and flow duration. It tracks Environmental Flows (E-Flows) requirements necessary for ecological health, fisheries, sediment transport, and cultural uses. Real-time flow gauges monitor river levels and detect abnormal events—flood surges, sudden drops, or illegal diversions. Flow monitoring ensures that irrigation, hydropower, and groundwater extraction do not compromise river stability. In perennialised drains, flow sensors check maintenance of base flows created through treated wastewater discharge. Flow data feeds into hydrological models used for climate adaptation and long-term planning.

## 19.4 Groundwater Monitoring

Groundwater is monitored through observation wells, piezometers, digital loggers, and CGWB datasets. Parameters include water level, recharge rate, extraction trends, quality (nitrates, fluoride, salinity), and pollution hotspots near drains and industrial clusters. Data is mapped block-wise to identify critical, semi-critical, and safe zones. Monitoring supports groundwater budgeting, regulation, and recharge planning. District Ganga Committees integrate groundwater data with wetland, drain, and agricultural interventions to maintain hydrological balance. Groundwater trends guide crop planning, industrial licensing, and water supply design.

## 19.5 Wetland Monitoring & Habitat Tracking

Wetland monitoring tracks water spread, depth, vegetation cover, invasive species, algal blooms, inlet–outlet functioning, biodiversity, and encroachments. Tools include satellite imagery, drone surveys, sensor buoys, and field assessments. Biological monitoring identifies indicator species such as fish, birds, macroinvertebrates that reflect ecological health. Regular monitoring ensures wetlands function as nature-based treatment systems, flood buffers, and recharge zones. Data informs wetland management plans, biomass harvesting schedules, and hydrological interventions.

## 19.6 Biodiversity Monitoring

Biodiversity monitoring assesses species richness, abundance, and habitat quality across rivers, wetlands, floodplains, and forests. Parameters include fish populations, aquatic fauna, migratory bird counts, riparian vegetation, and macroinvertebrate indices. Biodiversity reflects ecological integrity and responds quickly to hydrological and pollution changes. GRBMP 2.0 establishes biodiversity observatories, citizen science programs, seasonal bird surveys, and fish catch assessments. Biodiversity data guides habitat restoration, pollution mitigation, and e-flow requirements.

## 19.7 Monitoring of Urban–Industrial Systems

Urban systems are monitored for sewage generation, network coverage, stormwater performance, STP operations, and solid waste management. Industrial systems are monitored for effluent discharge, CETP performance, hazardous waste handling, and compliance violations. Digital logs and GIS tagging track each discharge point. Alerts flag illegal effluents, bypassing, and sludge mismanagement. Monitoring ensures that urbanisation and industrialisation do not compromise river health.

## 19.8 Monitoring of Agriculture & Soil Systems

This subsection monitors agricultural water use, crop patterns, fertiliser consumption, soil health, erosion, and non-point pollution. Soil Health Cards, GIS layers, and field surveys assess nutrient status, organic carbon, and infiltration rates. Monitoring identifies high-risk zones for nutrient runoff and guides interventions such as buffer strips, micro-irrigation, and regenerative practices. It links agricultural management with hydrological stability and nutrient control in water bodies.

### 19.9 Monitoring of Climate & Hydrological Risks

Climate and hydrological risk monitoring includes rainfall intensity, temperature patterns, flood inundation, drought severity, soil moisture, and reservoir levels. Early warning systems combine sensor data, weather forecasts, and hydrological models to predict floods and droughts. Monitoring supports climate-resilient district planning and infrastructure design. Long-term datasets track climate trends and help calibrate adaptation strategies in DRMPs.

### 19.10 Community Monitoring (Jal Mitras & Citizen Science)

Community volunteers, Jal Mitras, schools, and youth groups participate in monitoring river conditions, reporting pollution, measuring basic parameters (pH, turbidity), observing algal blooms, tracking illegal dumping, and documenting changes in biodiversity. Citizen science tools that include mobile apps, low-cost kits, training workshops empower communities to support formal monitoring systems. Public involvement increases vigilance, accountability, and stewardship at the local level.

### 19.11 Evaluation Frameworks

Evaluation assesses progress against GRBMP targets through periodic reviews, independent audits, and performance scoring. It measures improvements in water quality, flows, wetland area, groundwater status, biodiversity, livelihoods, and governance. Evaluation identifies systemic gaps, delays, or unintended impacts. Findings inform decision-making, funding allocations, and corrective measures. Evaluations occur annually at district level and every 3–5 years at basin level.

### 19.12 Adaptive Management Processes

Adaptive management ensures GRBMP 2.0 evolves with changing environmental, climatic, and socio-economic conditions. Data from monitoring and evaluations feed into redesigning interventions, adjusting project priorities, modifying hydrological models, and revising DRMPs. Adaptive cycles involve continuous learning, experimentation, piloting, and refinement. This dynamic approach makes the basin resilient, efficient, and future-ready.

### 19.13 Mid-Term Review & Basin-Level Assessment

Mid-term reviews (every 5 years) assess basin-wide status and evaluate cumulative progress toward Nirmal, Aviral, and ecological goals. Reviews examine hydrology, pollution, wetlands, climate risks, agriculture, governance, and livelihoods. They identify emerging issues, refine policies, and recalibrate phases. Basin-level assessments align state, and district plans with updated hydrological realities, climate models, and technological advancements.

### 19.14 Summary of Monitoring & Adaptive Strategy

The monitoring–evaluation–adaptation system forms the backbone of GRBMP 2.0. It integrates sensors, remote sensing, community networks, independent audits, and dynamic planning cycles. This ensures transparency, accountability, and scientific rigor. The framework transforms GRBMP into a living, adaptive basin management system capable of responding to complex and evolving challenges.

## 20. Financing & Economic Sustainability

This chapter explains how GRBMP 2.0 becomes financially viable, scalable, and self-sustaining. River rejuvenation requires long-term and consistent investment, not sporadic project funding. Sustainable financing integrates government schemes, innovative financial instruments, private sector partnerships, community enterprises, and cost-recovery mechanisms. Funding models emphasise decentralised, nature-based, and circular economy approaches that reduce operational costs. Financial planning is linked directly with DRMPs, ensuring that district-level projects receive predictable resources. Lifecycle costing, O&M budgeting, green jobs, and revenue-generating activities (under Arth Ganga) strengthen sustainability. Economic valuation of ecosystem services such as flood protection, groundwater recharge, carbon sequestration supports rational investment decisions. The chapter ensures that the economic foundation of GRBMP 2.0 is robust, diversified, and capable of driving continuous river system regeneration.

### 20.1 Funding Landscape for GRBMP 2.0

Funding for GRBMP 2.0 comes from multiple streams:

- **Central Government** (NMCG allocations, MoJS schemes)
- **State Governments** (irrigation, urban development, forest budgets)
- **District & Municipal Funds**
- **Convergence with national schemes** (JJM, AMRUT, SBM, PMKSY, MGNREGA)
- **International funding** (World Bank, ADB, JICA, UN agencies)
- **Private sector and CSR**

This blended landscape ensures flexibility and equity across districts. Capital expenditure is supported by government grants, while nature-based and decentralised systems reduce long-term O&M costs. The funding ecosystem supports short-term interventions (bio-remediation, nala restoration), medium-term infrastructure (d-STPs, recharge parks), and long-term ecological regeneration (floodplain restoration, agroecological transitions). A multi-source landscape ensures resilience to economic fluctuations and political cycles.

## 20.2 National & State Government Funding Sources

National funding supports basin-wide standards, monitoring systems, technological upgrades, and major infrastructure such as STPs and CETPs. Key schemes include Namami Gange, AMRUT 2.0, Smart Cities Mission, SBM-U, Atal Bhujal Yojana, and PMKSY (Har Khet Ko Pani). State funds support floodplain protection, catchment treatment, wetland restoration, soil conservation, and agricultural diversification. States also finance ULB reforms, sewer expansion, and enforcement mechanisms. Co-financing ensures shared ownership and reduces dependency on central budgets. Government funding prioritises projects with high ecological and social returns, including nature-based solutions and circular economy models.

## 20.3 Convergence with Government Schemes & Missions

Convergence ensures that existing schemes finance parts of the DRMP and GRBMP framework.

- **MGNREGA** funds desilting, check-dams, wetland buffers, plantation.
- **SBM-G/SBM-U** funds greywater management, FSTPs, solid waste systems.
- **JJM** enables water supply, treatment, and community monitoring.
- **Agriculture schemes** support soil carbon enhancement, micro-irrigation, crop diversification.
- **Forestry schemes (CAMPA, Green India Mission)** support riparian buffers and afforestation.

This reduces duplication and maximises value from government expenditure. Convergence is operationalised at the district level through DGC-led planning, where each DRMP project is mapped to appropriate funding schemes.

## 20.4 Private Sector Participation (PPP/CSR)

The private sector supports wastewater treatment, wetland development, recycling infrastructure, biochar units, riverfront development, solid waste systems, and ecotourism. PPP models include design–build–operate contracts, viability gap funding, and revenue-sharing models. CSR funding supports wetlands, compost units, Jal Mitra networks, and digital monitoring systems. Industries fund zero-liquid-discharge, effluent recycling, and cleaner production initiatives. Partnerships with startups bring innovation in sensors, drones, analytics, and biomass utilisation. Private sector involvement accelerates technology adoption and enhances financial sustainability.

## 20.5 Innovative Finance (Green Bonds, Blue Bonds, Impact Funds)

GRBMP 2.0 promotes innovative financial instruments such as:

- **Green Bonds** for wetlands, urban green infrastructure, and low-carbon systems
- **Blue Bonds** for wastewater reuse, river restoration, and aquifer recharge
- **Impact investment funds** for SMEs involved in circular economy
- **Environmental credit markets** for biodiversity offsets and nutrient trading

These instruments attract institutional investors and long-term capital. Returns come from reduced flood damages, improved water security, lower O&M costs, and revenue from green enterprises. Innovative finance diversifies funding sources and aligns private profit with ecological outcomes.

## 20.6 Cost Recovery & User Charges

Cost recovery mechanisms ensure financial sustainability while maintaining equity. Examples include:

- Nominal user charges for treated water supplied to industries and construction
- Fees for compost, biochar, and nursery products
- Charges for ecotourism amenities
- Municipal charges for desludging and waste services

Cost recovery reduces the financial burden on government and creates local revenue streams. Tiered pricing ensures affordability for vulnerable groups. Revenues support O&M of decentralised treatment plants, wetlands, and drainage systems, strengthening long-term sustainability.

## 20.7 Circular Economy & Green Business Models

Circular economy models convert waste (biomass, sludge, organic waste, hyacinth, urine-diverted waste) into valuable products—compost, biochar, vermicompost, biogas, handicrafts, fish feed, and soil conditioners. Green enterprises include wetland tourism, craft hubs, agroecology, and decentralised waste management. Revenue from these enterprises finances restoration activities. Circular models create jobs, reduce pollution, and minimise dependence on resource-intensive technologies. GRBMP 2.0 positions circularity as a central pillar of Arth Ganga, creating ecological and economic resilience.

## 20.8 Lifecycle Costing & Long-Term O&M

Lifecycle costing evaluates capital expenditure (CapEx), operation and maintenance (O&M), depreciation, and replacement costs over the project's lifespan. Many past river projects failed due to inadequate O&M budgeting. GRBMP 2.0 mandates detailed lifecycle costing for STPs, wetlands, recharge systems, and digital infrastructure. O&M funds are pre-allocated through municipal budgets, convergence schemes, or user charges. Lifecycle costing ensures that systems remain functional, preventing deterioration and maintaining long-term ecological gains.

## 20.9 Long-Term Financial Sustainability Strategy

Long-term sustainability depends on diversified funding, robust O&M, revenue generation, community ownership, and adaptive investment planning. Eco-economies under Arth Ganga create stable income for communities, reducing pressure on state funds. Financial strategies align with climate adaptation plans, recognising future hydrological uncertainties. Digital monitoring reduces wastage, fraud, and inefficiency. Long-term financial planning integrates cost savings from nature-based solutions, ecosystems services valuation, and circular economy revenue streams. This stabilises river rejuvenation as a permanent, self-sustaining system—not a short-term mission.

## 20.10 Carbon Credits & Ecosystem Services

Wetlands, floodplain forests, agroforestry, soil carbon enhancement, and biochar sequester significant carbon. GRBMP 2.0 proposes developing **carbon credit programs** for districts implementing soil–water restoration, regenerative agriculture, and biomass utilisation. Ecosystem services such as flood buffering, groundwater recharge, pollution treatment are valued economically to justify investment decisions. Carbon markets provide new revenue streams for Panchayats, SHGs, and farmers. Ecosystem services valuation ensures that nature-based interventions receive priority in planning and funding.

## 20.11 Budgeting Processes Under GRBMP 2.0

Budgeting occurs at national, state, and district levels. Districts prepare DRMP-linked annual budgets detailing project costs, convergence funding, O&M allocations, digital infrastructure needs, and green livelihood financing. State missions consolidate district budgets and align them with state schemes. NMCG allocates basin-level funds based on priority, urgency, and hydrological impact. Transparent budgeting ensures accountability, reduces duplication, and guides phased implementation.

## 20.12 Financial Reporting & Transparency

Financial transparency builds public trust. GRBMP 2.0 mandates digital financial reporting dashboards, quarterly expenditure reports, project-level accounting, and third-party audits. GIS-linked financial tracking ensures funds are spent where intended. Public disclosure of budgets and expenditures encourages participation and oversight. Transparent finance systems reduce wastage and improve efficiency, reinforcing confidence in GRBMP implementation.

## 20.13 Summary of Financial Strategy

The financial strategy blends government funding, convergence, private participation, innovative finance, circular economy models, and carbon markets. It ensures robust O&M, supports livelihoods, and reduces long-term dependence on central budgets.

Sustainable financing anchors GRBMP 2.0 as a resilient, scalable, and future-proof river management framework.

## 21. Integration, Synthesis & Long-Term Vision

This chapter brings together all thematic components of GRBMP 2.0: hydrology, ecology, agriculture, urban systems, governance, digital tools, climate resilience, and finance, into a unified, long-term, basin-wide strategic vision. It synthesizes how each subsystem interacts with others, creating a coherent river management framework grounded in science, policy, community participation, and economic viability. The chapter emphasises integrated landscape management where rivers, wetlands, floodplains, agriculture, cities, and industries function as a connected whole. It outlines milestones for Nirmal (clean), Aviral (continuous), and ecological (healthy) Ganga, and details how institutional reforms, monitoring cycles, and adaptive management ensure sustainability. The long-term vision positions the Ganga Basin as a global exemplar of regenerative river basin management, demonstrating India's leadership in ecological restoration, climate resilience, and community-centric development.

### 21.1 Integrated River Basin Management Approach

Integrated River Basin Management (IRBM) aligns land, water, biodiversity, agriculture, and social systems within a single hydrological framework. This subsection explains how GRBMP 2.0 operationalises IRBM by linking DRMPs, RHMPs, URMPs, RRMPs, and sectoral plans. It embeds upstream–downstream coordination, cross-border collaboration (e.g., with Uttarakhand, Nepal), and multi-sector alignment at district and state levels. IRBM ensures that interventions in one sector (e.g., agriculture) do not undermine another (e.g., groundwater recharge). It promotes system-wide optimization restoring environmental flows, rebuilding wetlands, stabilizing soil, managing climate risks, and integrating economic activities under Arth Ganga. IRBM forms the backbone of the basin's long-term ecological and socio-economic resilience.

### 21.2 Cross-Sectoral Integration (Water–Soil–Biodiversity–Economy)

This section synthesises how GRBMP 2.0 integrates water management, soil health, biodiversity conservation, and economic growth. Healthy soils enhance infiltration and reduce runoff; wetlands filter pollutants and recharge aquifers; biodiversity stabilises ecosystems; and green livelihoods reduce resource stress. Integration occurs through nature-based solutions (e.g., wetland rejuvenation, riparian forestry), agricultural transitions (regenerative, organic, diversified systems), urban reforms (decentralised STPs, blue–green infrastructure), and eco-economies (biomass utilisation, ecotourism, circular industries). Each sector reinforces the others, creating a positive feedback loop. Cross-sectoral integration ensures that river rejuvenation is not a stand-alone activity but deeply embedded in the region's development pathways.

### 21.3 Inter-District & Inter-State Coordination

Rivers cross administrative boundaries; therefore, long-term rejuvenation requires coordination among districts and states. This subsection describes mechanisms for coordinated planning between upstream–downstream districts (e.g., Uttarakhand–UP), aligned water releases, pollution control at borders, and joint monitoring of tributaries. Basin-level committees oversee multi-district interventions for flood management, sediment control, and ecological flow maintenance. Shared data platforms, joint reviews, and cross-state working groups ensure continuity beyond political transitions. Effective coordination prevents isolated interventions from undermining basin-wide outcomes and builds a cohesive system-wide strategy.

### 21.4 Integration with National Priorities & SDGs

GRBMP 2.0 aligns with national priorities such as Jal Jeevan Mission, Swachh Bharat Mission, AMRUT, PMKSY, PMFME, Green India Mission, and the National Action Plan on Climate Change. It also advances several SDGs:

- **SDG 6 (Clean Water and Sanitation)**
- **SDG 13 (Climate Action)**
- **SDG 14 & 15 (Life Below Water & Life on Land)**
- **SDG 11 (Sustainable Cities)**
- **SDG 2 & 12 (Zero Hunger & Responsible Production)**

By linking river rejuvenation with global benchmarks, the Basin becomes a model of sustainable development. The integration ensures international cooperation, financing opportunities, and alignment with climate commitments.

### 21.5 Knowledge Integration & Scientific Foundations

This section highlights the scientific foundation of GRBMP 2.0: hydrology, geomorphology, ecology, agriculture, climate science, and socio-economic analysis. Knowledge integration consolidates insights from research institutions, universities, government departments, and community knowledge holders. It standardises methodologies (DRMP, RHMP), enhances data quality, and incorporates emerging science (AI, climate modelling, remote sensing). Continuous scientific input ensures GRBMP remains adaptive and evidence driven. Integrated knowledge strengthens planning, monitoring, and decision-making across all levels.

### 21.6 Long-Term Ecological Vision for the Ganga Basin

The long-term ecological vision aims for a river that is clean, continuous, and ecologically restored from source to sea. It envisions perennial flows in tributaries and drains, revitalised wetlands, protected floodplains, restored biodiversity, stable groundwater, resilient soils, and thriving riparian ecosystems. Rivers become living systems supporting fisheries, ecological corridors, and cultural identity. Pollution loads drastically decline; effluent systems operate reliably; natural buffers mitigate floods and droughts; and climate resilience is built into all landscapes. This vision guides phased interventions across decades, ensuring continuity despite political and administrative changes.

## 21.7 Long-Term Socio-Economic Vision (Arth Ganga)

The socio-economic vision transforms river-based communities through green livelihoods, circular economies, and sustainable enterprises. Arth Ganga evolves into a diverse economic network that include organic agriculture, creek fisheries, eco-cottages, birding circuits, compost industries, biochar units, and riverfront heritage tourism. Communities become custodians of river systems because ecological health directly benefits their incomes. Inclusive participation ensures benefits reach women, youth, SC/ST groups, artisans, and small farmers. Over time, the Basin transitions into a hub of socio-ecological prosperity.

## 21.8 Long-Term Climate & Hydrological Resilience

Long-term resilience requires stable hydrological regimes, reduced climate vulnerabilities, and adaptive management. Wetlands and floodplains serve as hydrological buffers; regenerative agriculture increases infiltration; decentralised STPs ensure cleaner baseflows; groundwater is stabilised through recharge systems; and forests and riparian buffers regulate microclimates. Climate-ready infrastructure withstands variable rainfall. Robust monitoring and risk modelling guide adaptive responses. The Basin becomes resilient to extreme events such as floods, droughts, heatwaves ensuring water and ecological security.

## 21.9 Pathways to Basin-Wide Regeneration

This subsection outlines practical pathways:

1. Complete DRMP rollout across all districts
2. Full digital integration (GIS, sensors, dashboards)
3. Wetland-floodplain restoration at scale
4. Closed-loop urban water systems
5. Regenerative agricultural transformation
6. Industrial compliance and circularity
7. Community-driven stewardship
8. Economic diversification under Arth Ganga

These pathways create a phased basin-wide regeneration model adaptable to diverse ecological, cultural, and economic contexts across the basin.

## 21.10 Framework for Periodic Revision & Versioning

GRBMP is not static. It evolves through **5-year revision cycles** based on updated science, monitoring data, climate projections, and ground realities. Versioning ensures the framework adapts to emerging technologies, ecological shifts, and administrative needs. Each revision integrates new insights into DRMP methodologies, monitoring systems, and governance structures. Versioning institutionalises learning, promotes innovation, and maintains long-term relevance.

## 21.11 Summary of Integration Strategy

The integration strategy weaves together hydrology, ecology, governance, economics, climate resilience, and technology. It builds a unified system where interventions reinforce each other. The synthesis ensures that river rejuvenation becomes a systemic transformation of ecological, economic, social, institutional, and technological processes and functions ensuring the Ganga Basin thrives across generations.

## 21.12 Long-Term Vision for GRBMP 2.0

The long-term vision sees a Ganga Basin that is **cleaner, healthier, resilient, economically vibrant, and culturally enriched**. It envisions strong institutions, empowered communities, smart digital systems, and thriving ecosystems. Rivers and wetlands serve as engines of ecological stability and economic wellbeing. Cities and villages operate within regenerative cycles of water, soil, and biomass. The Basin becomes a global lighthouse for sustainable river basin management showcasing India's leadership in environmental governance, climate action, and socio-ecological innovation.

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