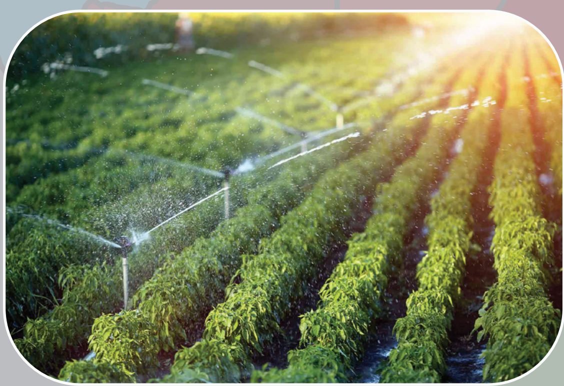
Integrated Action Plan for Augmenting Groundwater in Karnataka



Watershed Development Department
and
Centre of Excellence on Watershed Management
University of Agricultural Sciences, GKVK, Bangalore

2024

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Contents

Abbreviations used

ARS	:	Artificial Recharge Structures
BBMP	:	Bruhat Bengaluru Mahanagara Palike
BCM	:	Billion Cubic Metre
BDA	:	Bangalore Development Authority
BWSSB	:	Bangalore Water Supply and Sewerage Board
CADA	:	Command Area Development Authority
CGWB	:	Central Groundwater Board
CGWB	:	Central Groundwater Board
CoE-WM	:	Centre of Excellence on Watershed Management
DoWR, RD & GR	:	Department of Water Resources, River Development & Ganga Rejuvenation
GKVK	:	Gandhi Krishi Vigyan Kendra
GoK	:	Government of Karnataka
GW	:	Groundwater
GWA	:	Ground Water Authority
GWD	:	Groundwater Directorate
IT	:	Information Technology
KAMIC	:	Karnataka Antharaganga Micro Irrigation
KSNDMC	:	Karnataka State Natural Disaster Monitoring Centre
KSRSAC	:	Karnataka State Remote Sensing Application Centre
LRI	:	Land Resource Inventory
MGNREGA	:	Mahatma Gandhi National Rural Employment Guarantee Act
NAQUIM	:	National Project on Aquifer Management
NGOs	:	Non-Government Organization
NLSIU	:	National Law School of India University
PCB	:	Pollution Control Board
RDED	:	Rural Development Engineering Department
RDPR	:	Rural Development and Panchayat Raj Department
REWARD	:	Rejuvenating Watersheds for Agricultural Resilience through Innovative Development
RO	:	Reverse Osmosis
RWH	:	Rain Water Harvesting
STP	:	Sewage Treatment Plants
UAS	:	University of Agricultural Sciences
WDD	:	Watershed Development Department

Executive Summary

Karnataka state faced acute shortage of water during the summer of 2023. This is due to the cumulative effect of deficient and variable rainfall, over exploitation of Groundwater over the previous years. The situation was aggravated due to the failure of rainfall in the monsoon of 2022. The state has reached a stage wherefrom the over exploitation of groundwater cannot be drastically reduced, and there is no means to guarantee assured rainfall year after year. This alarming situation was a wakeup call, which led to device a comprehensive module of action plan to avoid recurrence of such a situation in the coming years.

Objective of the study include - a Review of Groundwater status, assessment of major causes leading to resource depletion, measures to augment the aquifer and protect it from further depletion, latest techniques to manage and conserve water in agricultural and allied sectors, and an 'Integrated Action Plan' for effective Implementation. The report is presented in eleven sections.

Preamble as to how and why preparation of this document is taken up, and Historical background of groundwater utilisation in the country is discussed in the first section

In the second section, a brief on status and utilisation of groundwater across the international level, at National level and at our state level is presented. 'India is the largest groundwater user globally with an estimated withdrawal of 251 km^3 per year through an estimated 20 million wells and Tube wells', as per The 'United Nation World Water Development' report 2022.Israel, Western Australia, Namibia and Arizona, USA are some of the areas facing groundwater deficiency. In the India, the annual extractable groundwater resource has been assessed as 407.21 BCM. The annual groundwater extraction (as of 2023) is 241.34 BCM. The average stage of groundwater extraction for the country as a whole works out to be about 59.26 %. Likewise in Karnataka state also extraction of groundwater is continuously on the rise leading to 44 taluks as Over-exploited and 12 taluks as Critical based on the total groundwater extraction. More than 25 lakh hectares are irrigated by groundwater and Net income generated works out to Rupees 56,376 crores. Water Use Efficiency works out to **Rs.55.90/ham.**

Section three and four present a brief on surface water resources, and groundwater resources of the state respectively. The annual utilisable yield of surface water from the rivers of has been roughly estimated as 98,406 MCM (3475 TMC). The state also has about 37,000 traditional tanks with a potential command area of 685,000 hectares. Annual extractable groundwater resource amounts to 17.08 ham

as of March 2023. Of this 11.31 ham of water is utilised. Stage of groundwater development is 66.26 %.

In section five, major causes for groundwater depletion is discussed in detail. Increase in population has led to increase in demand for water. Unabated drilling of borewells, encroachment of tanks and streams, non-adoption of water conservation practices in irrigation etc are a few of the major causes

Section six deals with different measures to augment groundwater resource in urban, rural, and peri-urban areas. Mandatory adoption of water harvesting system, Recharge through abandoned wells and borewells, rejuvenation of irrigation tanks, afforestation and agro-forestry, construction of more number of check dams, Vented dams, Nala bunds, Percolation tanks, Recharge shafts etc are suggested. Different types of Artificial recharge structures suitable for different Districts in the state is also presented.

Coming to agricultural sector, latest technologies available in agriculture and allied sectors to conserve groundwater without compromising crop yields is presented in section seven. The State comprises of Ten Agro-climatic zones. Depending on the characteristics of each zone different water conservation measures such as – Rainwater management; Agronomic measures such as Contour cropping Strip cropping, Contour strip cropping, Field strip cropping, Buffer strip cropping, etc; Proper irrigation practices for increased Water Use Efficiency; Participatory groundwater management etc are all explained in depth. In section eight, an 'Integrated Action Plan' for implementation to be taken up by the concerned departments of the state government is presented. The department wise responsibilities for implementation of integrated action plan for augmenting groundwater elaborated. A summary of the activities to be taken by the relevant departments are presented for immediate action by the Government.

In section nine and ten deals with strengthening of institutions and importance of water credit. Section eleven gives a few examples on success stories from Israel, Gujarat and Karnataka states. Israel developed Drip irrigation technology in the year 1959. Their revolutionary method slowly applies water directly to the roots of crops through a network of tubes, valves and drippers. This technology has been adopted in Karnataka too. Israel also managed to treat and recycle 86% of its wastewater for agricultural operations, leading the world in wastewater reclamation. Another success story is a noteworthy initiative by the Gujarat government is the 'Sujalam Sufalam Yojana', a water conservation scheme. The scheme revolves around the twin objectives of deepening of water bodies before monsoons and enhancing water storage for rainwater collection. Another benchmark initiative by the state is a water management system that injects and stores excess rainfall water underground and later uses it for irrigation during summers. The third one is a Linear Programming

Optimization model developed to operate the multi-purpose multi-reservoir system in the Narmada River basin. The objective of this is to allocate water to the command area of the Narmada Main Canal (NMC) in Gujarat and Rajasthan during the low flow year by curtailing the hydropower demands. A success story from Karnataka state is the Rejuvenation of Kumudvathi watershed on the left bank of Cauvery River. Recharge structures have been built across the entire stream network. The work being carried out by the 'Art of Living' over the last eight years has yielded positive results. In section twelve modifications/additions to the existing policy measures required for groundwater management in the state is recommended. This section also includes a note on introducing 'water credit' across the state which will encourage all the people in general to adopt 'rainwater harvesting'.

The report is supported by relevant technical data, maps and figures. A quick review of the status of groundwater resources in the state as on March 2023 suggests that out of the total 234 taluks, 44 taluks are Over-exploited, 12 taluks are Critical, and 32 taluks are Semi-critical. Remaining 146 taluks are under 'Safe' category. The Stage of groundwater extraction is 66.26%. In the Over exploited taluks the stage of groundwater extraction varies from 102.28% (Anekal taluk) to 225.69% (Yalahanka taluk), both in Bangalore urban district. Making implementation of Rainwater Harvesting mandatory, Constructing terrain specific Artificial groundwater recharge structures, Adopting ecologically sustainable cropping pattern with modern irrigation practices, and Maintaining a natural balance between land use and land cover is the need of the hour.

1. Preamble

The state is facing a severe shortage of water and drought this summer (2024) due to overexploitation and deficient rainfall during 2023. The magnitude of the current drought's impact in the state is severe compared to previous drought events, even though it was preceded by excess rainfall over the four preceding years. During those years, the situation was managed smoothly with the available groundwater resources. However, this summer's situation is different and quite acute. This year's severe shortage is a cumulative effect of depleting groundwater resources. The burgeoning population, reduced green cover, increased water demand from all sectors, and temperature-induced evaporation are major causes of groundwater depletion.

In light of the current situation, a core group meeting was held by the Commissioner of the Watershed Development Department, Government of Karnataka, on February 1, 2024, at the Centre of Excellence on Watershed Management, UAS, GKVK, Bengaluru. During the discussion, it was determined that there is an urgent need to refocus efforts and prepare an action plan for immediate implementation. Directions were given to create a brief action plan for groundwater augmentation. Therefore, this Integrated Action Plan for Groundwater Augmentation has been prepared for early implementation. The report covers the following themes: Introduction, Groundwater Resources in the State, Causes of Groundwater Depletion, and Augmentation Strategies in Rural and Urban Areas.

The state experiences arid, semi-arid, and humid tropical climates. The climatic conditions vary according to topography and distance from the sea. A large share of the state's rainfall comes from the South-West Monsoon (70 percent), which occurs over four months. The North-East Monsoon and thunderstorms during the summer months also contribute a significant amount of rainfall. The annual rainfall in the state ranges from 400 mm in the eastern part to more than 4,000 mm in the coastal region.

Karnataka is known for its hard rock terrain, consisting of igneous rocks such as granite and basalt, metamorphic rocks like gneiss, phyllite, quartzite, and amphibolite, and sedimentary rocks including sandstone and limestone. Igneous and metamorphic rocks typically have a low rate of infiltration. Parts of the coastal districts, as well as Shivamogga, Belgaum, and Bidar districts, have laterite capping on the underlying rocks. Laterite generally has high porosity and facilitates a higher rate of infiltration.

Historical background

Groundwater is a cornerstone of India's water supply, supporting agriculture, drinking water, and industry. Over the past four decades, India has transitioned from traditional rainfed agriculture to more intensive irrigation practices, largely driven by the Green Revolution from 1970 to 1990. This period saw significant increases in cereal production due to the adoption of high-yield varieties, fertilizers, pesticides, and extensive irrigation networks. However, these advancements have also led to severe groundwater depletion, with water tables declining at alarming rates due to over-extraction. The introduction of cereal crops and groundnut cultivation, along with the expansion of irrigation facilities, marked a new era in Indian agriculture but also brought forth new challenges.

The increased reliance on groundwater to sustain high-yield crop varieties has resulted in unsustainable extraction practices. The challenges posed by fluctuating rainfall patterns, exacerbated by climate change, have further strained groundwater resources. This introduction outlines the urgent need for a comprehensive groundwater augmentation action plan that incorporates sustainable practices, innovative management strategies, and policy reforms to address these challenges and ensure water security for future generations.

India's agricultural evolution highlights the dynamic interplay between technological innovation and environmental factors. Before the Green Revolution, Indian agriculture was primarily dependent on rainfed systems with limited irrigation infrastructure. Crops such as millets and pulses, which are less water-intensive, dominated the agricultural landscape. The Green Revolution, initiated in the late 1960s and continuing into the 1980s, marked a significant shift towards high-yielding varieties of wheat and rice, supported by synthetic fertilizers and pesticides. This transformation was enabled by the development of extensive irrigation systems, including the construction of large dams and canals, which provided reliable water supplies for agriculture.

However, this shift also increased the dependency on groundwater, particularly in regions with limited surface water resources. Groundwater extraction for irrigation became widespread, driven by the need to sustain high-yield crop varieties. This period saw the proliferation of tube wells and borewells, which allowed farmers to access deeper groundwater reserves. The use of groundwater for irrigation provided a buffer against the variability of monsoon rains, enabling multiple cropping systems and increasing agricultural productivity. However, the lack of regulatory mechanisms and incentives for sustainable water use led to over-extraction, causing a significant decline in groundwater levels across many regions.

2. Review of groundwater status and utilization

2.1 International

Water is an important and vital resource required for humanity and it has become critical in recent years. About 71% of the earth's surface is covered by water. 97.5 % of this water is found in the oceans not fit for drinking and growing crops due to the concentration of salts. Only 2.5 % of the earth's water is freshwater (WWAP, 2006) useful to humanity. Again, out of this 2.5 % of fresh water, 68.7 % resides in Glaciers and is not readily available for use, 0.4 % as surface water in lakes, rivers, etc., and 30% is in underground as Groundwater. Thus, the groundwater resource which makes up about 30% of the 2.5% % of freshwater is in great demand owing to its access and reliability. Aquifers are the primary, and sometimes the only water source for many of the world's driest and drought-stricken regions. Our overall dependence on groundwater is expected to rise as surface water availability becomes increasingly limited due to climate change.

Globally, half of the drinking water needs are fulfilled by Groundwater, and around 25%of all water is used for irrigation. The 'United Nation World Water Development' report 2022, mentions that 'India is the largest groundwater user globally with an estimated withdrawal of 251 km^3 per year through an estimated 20 million wells and Tube wells. The ten countries that abstracted the largest quantities of groundwater throughout the year 2010 according to the compiled and processed statistics presented in the publication Groundwater around the world: A Synopsis, are given below in Table 01.

Table 01: Top 10 groundwater abstraction countries.

Sl. No.	Country	GW Abstraction (km^3 /year)
1.	India	251
2.	China	112
3.	USA	112
4.	Pakistan	65
5.	Iran	64
6.	Bangladesh	30
7.	Mexico	29
8.	Saudi Arabia	24
9.	Indonesia	15
10.	Turkey	13

(Groundwater around the world: A Synopsis 2022)

In the above table, country-wise Geographical area may vary but still India ranks the top in groundwater utilization. Several countries are engaged in augmenting the resource with artificial recharge measures to improve and preserve the resource for the future.

Artificial Recharge to the aquifer, also referred to as 'Managed Groundwater Recharge' has been practiced in several countries around the world for long. Artificial groundwater recharge is one technique that can make the use of water more circular.

i) Israel: Israel is practicing artificial recharge of groundwater aquifers through infiltration ponds and recharge wells since the 1960's as part of the integrated management of surface and Groundwater for the following objectives –a. Seasonal storage of excess surface water in the National Water Supply (NWS) system, which carries water from the Jordan sources in the north to the central (coastal) regions. b. Reclamation of overexploited aquifers. c. Utilization of rainwater runoff and flash floods, where surface storage is unavailable. d. Soil – Aquifer Treatment (SAT) of sewage treatment effluents, aimed at the removal of residual contaminants by filtration and adsorption on the aquifer's solid skeleton, by upper soil aeration, and by long retention time in the aquifer.

ii) Australia: In the year 2010, Perth city in Arid western Australia embarked on one of the country's first large-scale groundwater recharge projects. The idea was to take wastewater, treat it to drinking-level quality, and then inject it back into Perth's deep aquifers. The initiative was a response to a drastic reduction in groundwater levels in the region since 1980, because of climate change, reduced rainfall, and increased water use.

iii) Arizona, USA: The US state of Arizona has quietly poured huge amounts of Colorado River water into dozens of large sand and gravel-filled aquifers until the state is ready to use it. So far, the state has stored nearly 3.6 million acre-feet of water across 28 sites. Arizona is now evaluating plans to tap into this 'water bank' as record-breaking droughts sweep the Western US.

V) India: India being the major user of groundwater is already working in the direction to improve and increase the resource. Apart from modern artificial recharge structures, the irrigation tanks which are spread over the state which were constructed long back were the first recharge structures in the state. Long before the ARS, these tanks were supplying water for irrigation as well as recharging the aquifer. More on artificial recharge in the state is discussed in the following paragraphs.

2.2 National

In India, the management of groundwater resources calls for a systematic approach that involves scientific assessment of the availability of water resources and their utilization. Groundwater, in the Indian context, has emerged as a key resource for the sustenance of life and sustainability of livelihood. The World Bank and Government of India estimate that Groundwater contributes nearly ten percent to India's GDP.

i) Rajasthan: Rajasthan has only 1.16 percent of India's total surface water resources or 21.71 billion cubic meters (BCM), however 16.05 BCM of this is economically usable. The state has created capacity to harness and store 11.29 BCM, or around 70 percent of available water. The state has 1.72 percent of the country's groundwater, translating into 11.36 BCM. Khadins (one of the traditional water harvesting system of Rajasthan) are runoff-harvesting systems that store water from rocky catchments in the soil profile of the reservoir bed, for later use in crop production. Western Rajasthan, especially Pali and Nagaur districts, have thousands of traditional water-harvesting systems including Khadins. Renovation of Khadins for runoff harvesting is expected to increase crop production particularly in the non-rainy season. The intervention seeks renovating Khadins for runoff harvesting for crop production in the non-rainy season.

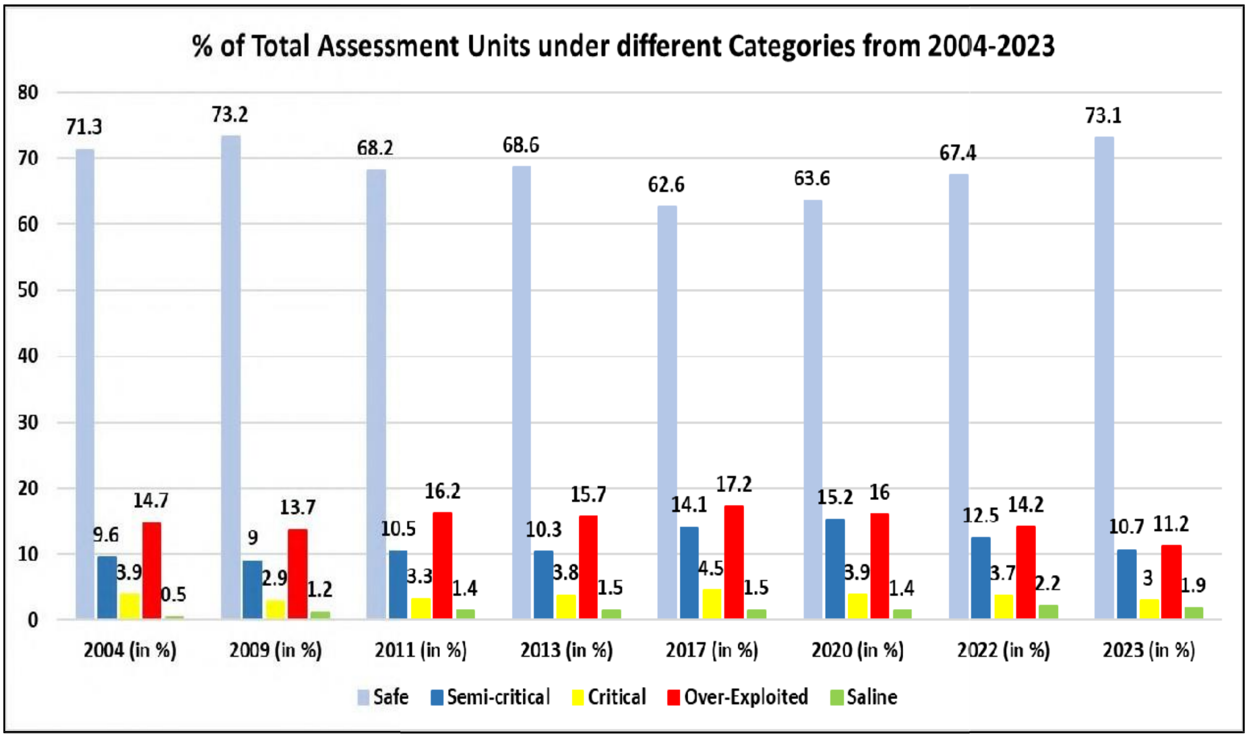
Table 02: Status on Average Annual Water Availability

Precipitation received	4000 BCM (100%)
Water Resources Potential	1869 BCM (46.7%)
Utilisable Water Resources	1123 BCM (28.1%)
Groundwater	433 BCM (10.8 %)
Surface Water	690 BCM (17.2%)
(Figures in parentheses are per cent of total precipitation)	

(Composite Water Management Index-Niti Ayog 2017)

ii) Niti Ayog (2017) has summarised the utilizable water potential of the country as given in the following table 02. About 53.3 percent of total precipitation is lost due to evapotranspiration which leaves a balance of 1869 BCM water in the country. The total water potential of the country is estimated to be 1123 BCM consisting of 690 BCM of surface water and 433 BCM of ground water. The increasing reliance on groundwater as a dependable source of water has led to its extensive and sometimes unplanned exploitation in various regions of the country, often overlooking the crucial aspects of aquifer recharge and other environmental factors.

This unchecked development in certain parts of the country threatens the long-term sustainability of this precious resource. As per the latest groundwater resource jointly carried out by the Central Ground Water Board (CGWB) and state groundwater departments all over the country, the total annual groundwater recharge in the country has been assessed as 449.08 BCM. Keeping an allocation for natural discharge, the annual extractable groundwater resource has been assessed as 407.21 BCM. The annual groundwater extraction (as of 2023) is 241.34 BCM. The average stage of groundwater extraction for the country as a whole works out to be about 59.26 %.



(Central Ground Water Board (CGWB) report 2023)

Figure 01: Percentage of Groundwater utilization categories

Out of the total 6553 assessment units (Blocks/ Mandals/ Talukas) in the country, 736 units in various States/ UTs (11.23%) have been categorized as 'Over-exploited' indicating groundwater extraction exceeding the annual replenishable groundwater recharge. In 199 (3.04%) assessment units, the stage of groundwater extraction is between 90-100% and has been categorized as 'Critical'. There are 698 (10.65 %) "Semi-critical'' units, where the stage of groundwater extraction is between 70 % and 90 %, and 4793 (73.14 %) 'Safe' units, where the stage of groundwater extraction is less than 70 %. This analysis is schematically shown in Figure 01. Apart from these, there are 127 (1.94%) assessment units, which have been categorized as 'Saline', as a major part of the groundwater in phreatic aquifers in these units is brackish or saline. Salient details of the status of groundwater resources and the categorization of assessment units in 2004, 2009, 2011, 2013, 2017, 2020.2022, and 2023. Details are given in Table 03 and Table 04.

Table 03: Groundwater Resources Assessment 2004 to 2023

Sl. No.	Ground Water Resources Assessment	2004	2009	2011	2013	2017	2020	2022	2023
1.	Annual ground water recharge (BCM)	433	431	433	447	432	436	438	449
2.	Annual extractable ground water Resource (BCM)	399	396	398	411	393	398	398	407
3.	Annual ground water extraction for irrigation, domestic & industrial use (BCM)	231	243	245	253	249	245	239	241
4.	Stage of ground water Extraction (%)	58	61	62	62	63	62	60	59

Table 04: Categorization of assessment units from 2004 to 2023

	2004		2009		2011		2013		2017		2020		2022		2023	
Categorization of Assessment Units	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Total Assessed units	**5723**		**5842**		**6607**		**6584**		**6881**		**6965**		**7089**		**6553**	
Safe	4078	71.3	4277	73.2	4503	68.2	4519	68.6	4310	62.6	4427	63.6	4780	67.4	4793	73.1
Semi-critical	550	9.6	523	9	697	10.5	681	10.3	972	14.1	1057	15.2	885	12.5	698	10.7
Critical	226	3.9	169	2.9	217	3.3	253	3.8	313	4.5	270	3.9	260	3.7	199	3
Over-Exploited	839	14.7	802	13.7	1071	16.2	1034	15.7	1186	17.2	1114	16	1006	14.2	736	11.2
Saline	30	0.5	71	1.2	92	1.4	96	1.5	100	1.5	97	1.4	158	2.2	127	1.9

(Central groundwater report 2023)

A perusal of the above estimates shows that there is a marginal increase in the annual groundwater recharge and annual extractable groundwater resources from 2004 to 2023. The same trend was observed in the case of annual groundwater extraction for irrigation, domestic and industrial use. However, the stage of groundwater extraction is maintained in the range of 58 to 63% (Table 03). This shows that regardless of the increase in demand for groundwater from 2004 to 2023, there is not much change in the stage of groundwater extraction for the same period. This may be due to the efforts made to improve management practices implemented during this period by the government and other agencies in the country.

As per the estimates, 736 units in the country are categorized as over-exploited as per the level of groundwater extraction. Over-exploitation of groundwater resources could be due to various region-specific reasons. Assessment units located in the north-western part of the country (particularly in the states of Punjab, Haryana, Delhi, and Uttar Pradesh) have plenty of replenishable groundwater resources but because of the over-extraction beyond the annual groundwater recharge, many of these units have become Over-exploited. Over-exploited units are also common in the western part of the country, particularly in Rajasthan and Gujarat where the prevailing arid climate results in low recharge of groundwater and hence stress on these sources. In peninsular India, over-exploited units are widespread in the states of Karnataka, Tamil Nadu, and parts of Andhra Pradesh and Telangana which could be attributed mainly to the low storage and transmission capacities of aquifers of the hard rock terrains, which results in reduced availability of the resource.

A review of the groundwater resource estimation exercises and the inferences drawn are utilized as input by the planners and stakeholders for taking appropriate management measures for optimal utilization and sustainable development of the groundwater resources. Several measures, primarily based on the findings of the resource assessment, have been taken up by the Government of India to replenish/augment groundwater resources. They broadly cover the following components-

i. Constitution of Central Ground Water Authority for regulation of groundwater development in the country.

ii. The Ministry of Jal Shakti has circulated a Model Bill to all States/UTs to enable them to enact suitable legislation for the regulation of groundwater development, which includes the provision of rainwater harvesting and artificial recharge to groundwater.

iii. Compilation of a conceptual document titled "Master Plan for Artificial Recharge to Groundwater in India" by CGWB, which envisages the implementation of nearly 11 million Rainwater Harvesting and Artificial Recharge structures to augment the groundwater resources of the country.

iv. National Aquifer Mapping & Management Program (NAQUIM), for mapping of major aquifers, their characterization, and formulation of Aquifer Management Plans to ensure the sustainability of the resources, prioritizing Over-exploited, Critical and Semi-critical assessment units in association with groundwater departments of various states. State Governments are implementing watershed development programmes, in which groundwater conservation forms an integral part. Water conservation measures are also taken up as a part of the MGNREGA.

v. Launching of various other programs like Jal Kranti Abhiyan, Atal Bhujal Yojana, Pradhan Mantri Krishi Sinchai Yojana (PMKSY)-Har Khet Ko Pani (HKKP), Jal Shakti Abhiyan etc. Similarly, various states have also embarked upon their own schemes and programs aimed at consolidating water conservation and management initiatives through a holistic and integrated approach involving all stakeholders.

vi. The Jal Shakthi Abhiyan is characterized by the expeditious execution of five discerning interventions namely water conservation and the harnessing of rainwater, revitalization of traditional and contemporary aquatic ecosystems, the recycling and replenishment of water, watershed development, and the deliberate augmentation of afforestation efforts.

2.3 Karnataka State

Like the water resources at the National level, groundwater finds prominence for irrigation and Domestic water needs in the State also. Almost the entire state of Karnataka is covered by hard rocks and being an agrarian state, the dependence on groundwater is very high. Geographical area of the state is 1,91,791 Sq kms. Agriculture provides the main economic support to the state.

Table 05: Source wise irrigation during 2010-11 (Area in '000 hectares)

Source	**Net area irrigated**	**Per cent hectare to net area irrigated**
Canals	931	28.50
Tanks	148	4.53
Wells	377	11.54
Tube/Bore wells	1518	46.46
Other sources	293	8.97
Total	**3267**	**100**

(Report on Dynamic Groundwater Resources of Karnataka as on 2023-GWD and CGWB 2024)

For providing drinking and domestic water supply also the government heavily depends on Groundwater. First, let's see how groundwater irrigation is contributing to the economy of the state. Source-wise irrigation prevailing during the years 2010-11 and ten years later in 2020-21 is given in the following two Tables - Table 05, and Table 06. Water for irrigation purposes comes from various sources such as wells, ponds, canals, rivers, dams, reservoirs, rainfall etc. Among all the source wise irrigation, the net area under Groundwater irrigation is the highest.

The net area irrigated by surface water is 1,372,000 hectares, and the net area irrigated by Groundwater is 1,895,000 hectares using nearly 58% of the net annual Groundwater resource available. The area irrigated by Groundwater is higher than the area irrigated by surface water.

Table 06: Source-wise Irrigation during 2020-21 (Area in lakh hectares)

Source	Net area irrigated	Per cent hectare to net area irrigated
Canals	14.77	29.95
Tanks	1.65	3.35
Wells	3.45	7.00
Tube/Bore wells	21.61	43.83
Other sources	7.83	15.88
Total	**49.31**	**100**

(Report on Dynamic Groundwater Resources of Karnataka as on 2023-GWD and CGWB 2024)

During 2010-11 Net area irrigated was 32,67,000 hectares, and this was increased to 49,31,000 hectares during 2020-21. A large increase in the net irrigated area i.e., an addition of 16,64,000 hectares has taken place. The net area irrigated by surface water is 2,425,000 hectares, and that by Groundwater is 2,506,000 hectares using nearly 59% of the net annual Groundwater resource available.

Table 07: Well Statistics from year 2001 to year 2023

	Type of Structure			
Year	Dug wells	Borewells	Dug cum Borewells	Total no. of structures
2001	2,76,171	6,12,900	NA	8,89,071
2004	3,17,596	7,04,835	NA	10,22,431
2009	3,02,199	7,67,204	668	10,70,071
2011	1,85,108	7,85,557	680	9,71,345
2013	1,88,810	8,01,268	694	9,90,772
2017	1,27,812	8,93,835	745	10,24,409
2020	1,35,481	9,47,465	790	10,83,736
2023	2,11,000	9,66,000	1,930	12,65,000

(Central groundwater board report 2023)

The area under groundwater irrigation has increased by 6,11,000 hectares over the last ten years. The total number of wells and Borewells used for irrigation, which was 9,71,345 in 2010-11, has increased to 12,65,000 after ten years. However, groundwater utilization has increased by only 1 %. This may hint at the adoption of sprinklers, Drip etc, for irrigation. It may also be due to reduced yield from these wells due to the depletion of water levels in groundwater developed pockets. Number of wells and Borewells working between 2001 and 2023 is given in Table 07.

The second major source is canal irrigation using mainly surface water from reservoirs. Irrigation tanks have been considered the principal source of irrigation historically. They were/are also a major source of Recharge to the aquifer. But now their contribution is diminishing as it has come down to 3.35% of the net area irrigated. This may be due to the discontinuance of periodic maintenance and the disappearance of tanks due to encroachments by the greedy. However, as the Tanks are still a good source of rainwater storage, irrigation, and recharge, there is an urgent need to rejuvenate and restore them. Removing the accumulated silt will increase storage and the rate of recharge. Strengthening of Bund, Supply canals, etc. will help to restore the designed command area.

Groundwater irrigation in the state is also contributing largely to the state economy. As an example the income generated from Groundwater irrigation during 2020-21 is detailed in Table 08. More than 25 lakh hectares are irrigated by groundwater and Net income generated works out to Rupees 56,376 crores. The dependance and importance of groundwater may expand further as rainwater is not reliable and sufficient enough due to increasing demand and climate change effects. To meet the future demands, groundwater resources should be made dependable and sustainable by enhancing recharge and conserving water. A number of recharge structures have been constructed over the years by government departments and NGOs subject to fund availability and area of operation. But the quantum of water added through artificial recharge falls short of overdraft. The solution has to be multifold – Recharge, Mass awareness, modernizing agriculture, Crop diversity, Rainwater harvesting etc.

With regard to the supply of drinking water in the state, Groundwater is the major/only source for rural areas. During the year 2023-24, the number of Borewells in use for rural water supply was 2,69,057. However, this figure is a dynamic one because some borewells may go dry, and new borewells would be drilled in their place. Apart from this there are borewells supplying water to town municipalities, city corporations, etc.,

Groundwater draft for Industrial use is reported as 12820.62 ha m for the year 2023. The extraction of groundwater may increase since there is a rise in mini–RO Plants (water purification Plants) for public water supply in addition to the RO Plants (water Bottling Plants) on an industrial scale. All these Plants generate 3 times reject water for every liter of filtered water. It should be mandatory for them to recycle this reject water and reuse it. All industries and Mining areas in the state should have a rainwater harvesting facility in their premises.

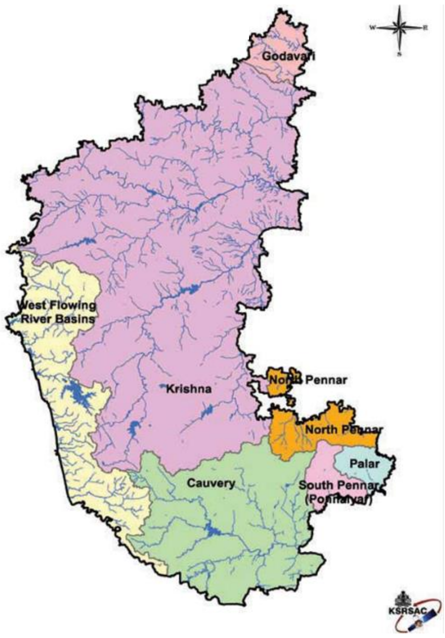
Table 08: Income generated from groundwater irrigation for 2020-21 is approximated as under-

Particular	**Value/formula**
Area under Groundwater Irrigation-Wells	344729 ha
Area under Groundwater irrigation-Borewells	2160897 ha
Total:	25,05,626 ha
Cropping intensity (CI) under GW irrigation	≈ 150 %
∴ Gross cropped area under irrigation	Net irrigated area x CI
That is =	25,05,626 X 150/100
That is =	37,58,439 ha
Gross income under GW irrigation (weighted average)	Rs. 3.00 lakh/ha
Cost of cultivation (weighted average)	Rs. 1.50 lakh/ha
Net income =	Rs. 1.50 lakh/ha
Gross income =	Rs 37,58,439ha x 3.00 lakh
That is =	Rs. 1,69,129 crores
Net income realized from GW irrigation	**Rs. 56,376 crores**
Groundwater used for irrigation	**1008531 ha m**
Water Use Efficiency =	**Rs.55.90/ha m**

3. Surface Water Resources of Karnataka

Water resources in Karnataka:

Karnataka has a water potential of about 102 km^3. The state accounts for about 6% of the country's surface water resources. Around 60% of which constitute west flowing rivers, while the remaining comes from the east flowing rivers. There are seven river basins in all formed by the Godavari, Krishna, Cauvery, the west flowing rivers, South Pennar and Palar.



Surface Water Rivers: Karnataka has seven river systems. Together with their tributaries they form a catchment of 191,773 km^2. The average annual yield of the rivers of the Karnataka has been roughly estimated as 98406 m.cum. (3475 TMC).

The Western Ghats are a major divide for river basins. Rivers flowing westward into the Arabian Sea carry 40% of the state's surface water and those flowing eastward 60%. The availability of water from these river basins is estimated to be 7,663 thousand million cubic feet per annum (TMC/a) of which 45% (3,475 TMC/a (or) 98 billion m^3/a) can be economically utilised. The state can utilise only 40% of the potential (1,690 TMC/a or 48 billion m^3/a) because the west flowing rivers cannot be harnessed.

Table 09: Rivers of Karnataka

Sl. No.	River System	Drainage Area	
		1000 Sq. km	Percentage
1.	Godavari	4.41	2.31
2.	Krishna	113.29	59.48
3.	Cauvery	34.27	17.99
4.	North Pennar	6.94	3.64
5.	South Pennar	4.37	2.29
6.	Palar	2.97	1.56
7.	West flowing rivers	24.25	12.73
	Total	**190.5**	**100**

(Report on Dynamic Groundwater Resources of Karnataka as on 2023-GWD and CGWB 2024)

Lakes and Tanks: Karnataka has about 37,000 traditional tanks with a potential command area of 685,000 ha. About 60% of these are on the southern plateau, 25% in the Malnad region and 15% on the northern plateau. Most of them (50%) have a command area of 4 to 20 ha and 38% have less than 4 ha. Only 11.4% have a command area greater than 20 ha. Besides traditional tanks, there are about 20,000 irrigation tanks in the state with an irrigation potential of 6.5 lakh ha. Tanks alone serve nearly 80% of the minor irrigation potential. The state also has about 1,100 other minor surface irrigation structures that include barrages, bridges-cum-barrages, moles in river courses (anicuts) and pick-ups for lift irrigation. The relative contribution of tanks in the irrigation potential since 1951 has declined with the development of surface water irrigation and the shrinking of tanks owing to encroachment and siltation. Urban areas including Bangalore have a large number of lakes and tanks for impounding monsoon runoff to meet drinking water needs.

The Karnataka state receives 92% of water through rainfall and 8% from the upper riparian state Maharashtra, accounting to 236 billion/ m^3 year. About 50% is lost in evaporation from the soil and transpiration from plants. This is generally referred to as evapotranspiration. Karnataka with growing water uses will face water deficits and is unlikely to meet future agricultural, industrial and domestic water requirements. However, a thought can be given to the possibilities of utilizing water of west flowing rivers; but potential ecological costs must be considered. Construction of dams, irrigation projects, land use change, encroachment of river beds, deforestation, diversion of water from rivers, groundwater extraction, channel dredging have affected water balances of rivers and other water bodies in recent years.

4. Groundwater resources of Karnataka

Groundwater occurs under unconfined to semi-confined conditions. Groundwater from shallow aquifers is available only in coastal areas and some parts in Bidar and Belgaum and Maland Districts. Increased borewell drilling led to quicker drying of shallow aquifers. Now we are tapping groundwater from deeper aquifers only, which is of quantitatively small and qualitatively poor.

The annual groundwater resource is estimated jointly by the State Groundwater Department and Central Groundwater Board, Southern Region Bangalore. As per their first 'Report on Dynamic Groundwater resources of Karnataka as on March 2004', there were only 22 taluks categorized as over-exploited. As per the latest report 'Report on Dynamic Groundwater resources of Karnataka as of March 2023', the number of over-exploited taluks is 44; along with 12 critical taluks and 32 semi-critical taluks, while the number of taluks in Safe category is 146. It can be observed in the Map in Figure 02 and Figure 03 shows that conspicuously, the Over-exploited taluks are found in the central part of the state in a NE-SW direction. Compare this with the rainfall distribution map (Figure 04), and it is evident that most of this area receives low rainfall. So orientation to reclaim the over-exploited area should be this central patch.

Table 10: Dynamic Groundwater Resources of Karnataka

Year of assessment	Annual extractable GW Resources (ha m)	Annual GW extraction (ha m)	Stage of development (%)
2008-09	14.81	10.01	68
2010-2011	14.81	9.41	64
2012-2013	14.83	9.76	66
2016-2017	14.79	10.34	70
2019-2020	16.40	10.64	64.85
2021-2022	16.04	11.22	69.93
2022-2023	17.08	11.31	66.26

(Report on Dynamic Groundwater resources of Karnataka 2023)

It could be observed in this table that the annual groundwater extraction is highest in 2022-2023 as compared to previous assessment years. The recharge component is wholly dependent on the quantum of rainfall, and infiltration factor which remains almost constant for a particular rock type and soil cover. Thus, annual groundwater resources remain almost the same with a possible variation of plus or minus 10%.

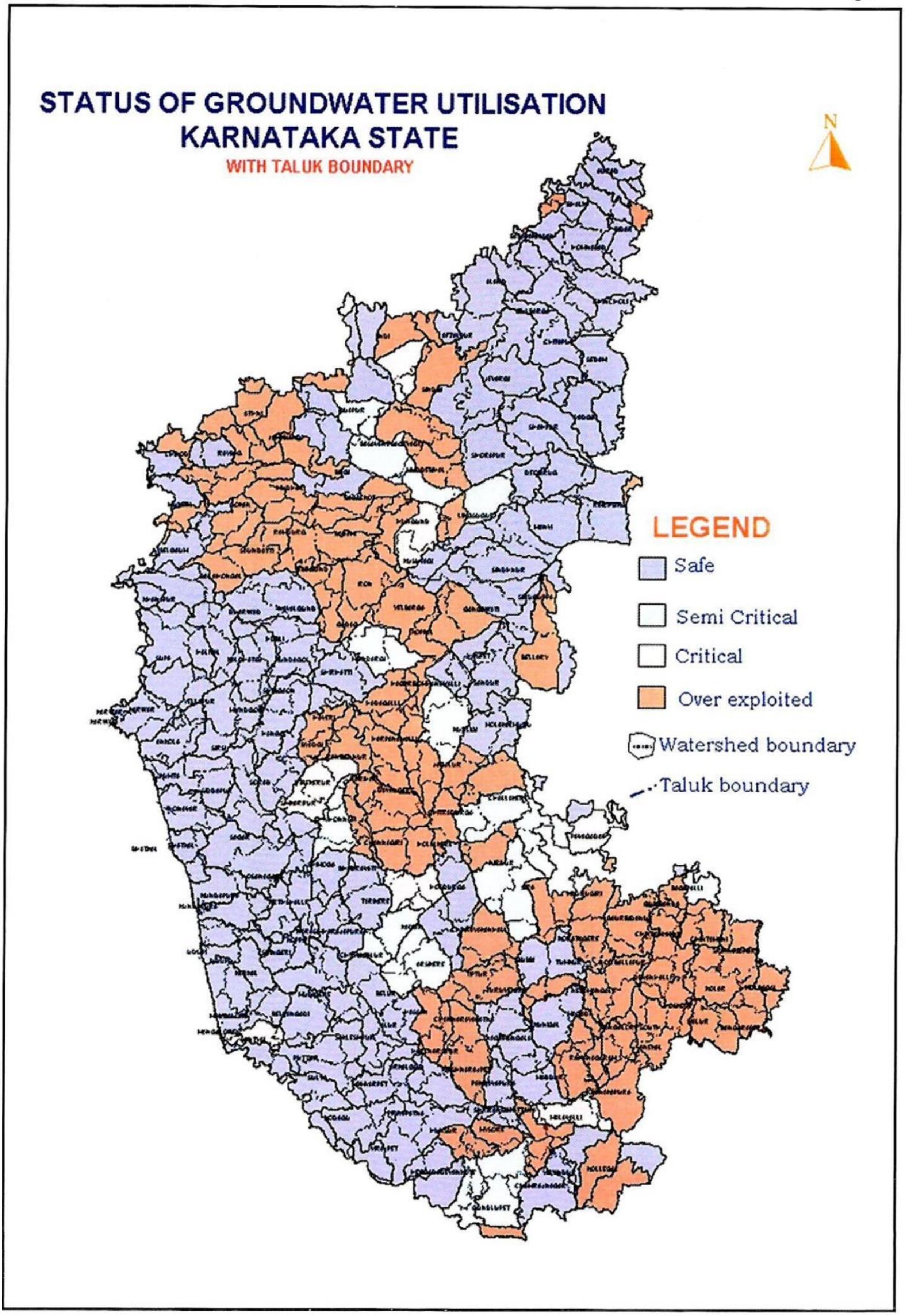


Figure 02. Categorization of assessment units as on March 2004

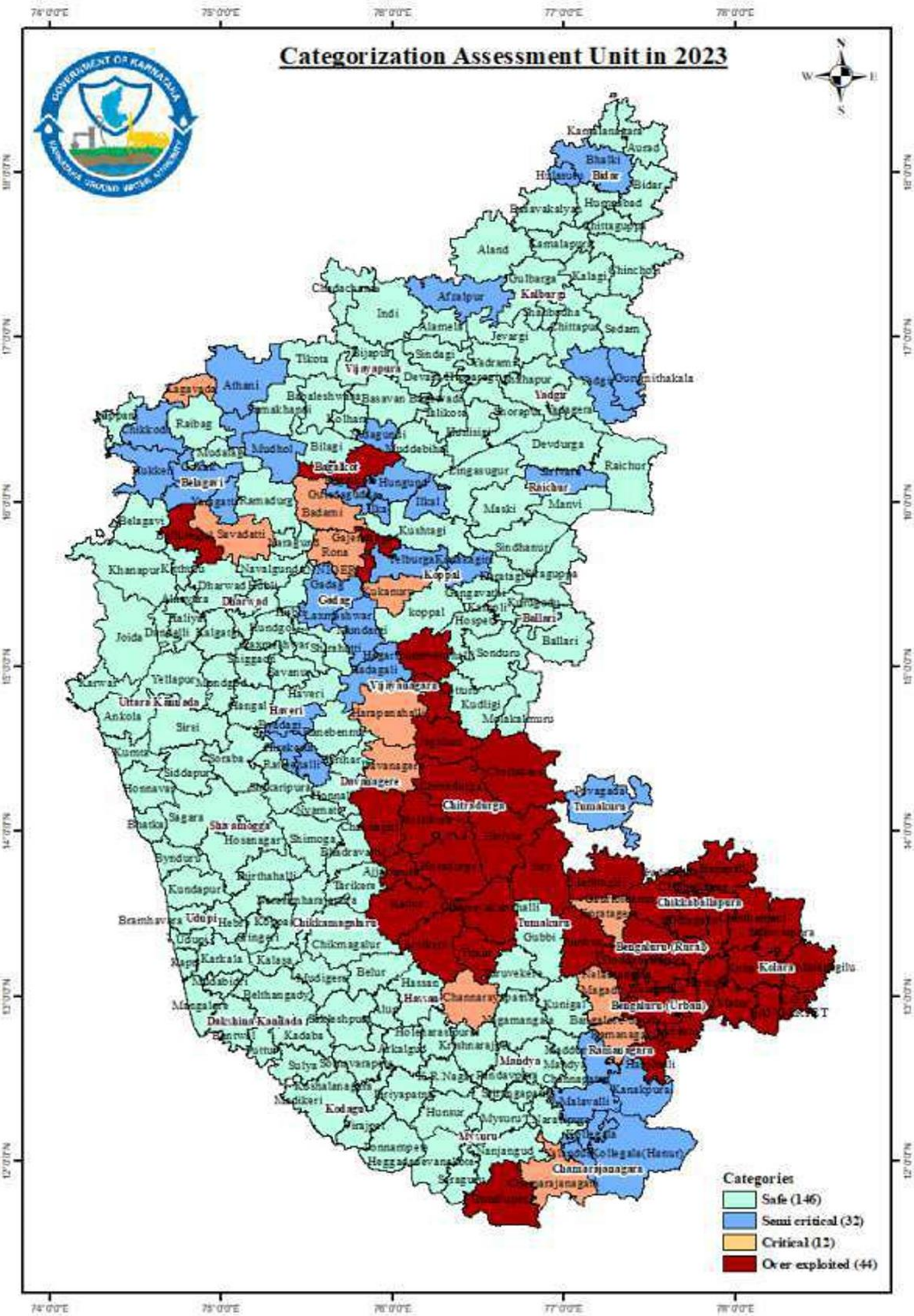


Figure 03. Categorization of assessment units as on March 2023

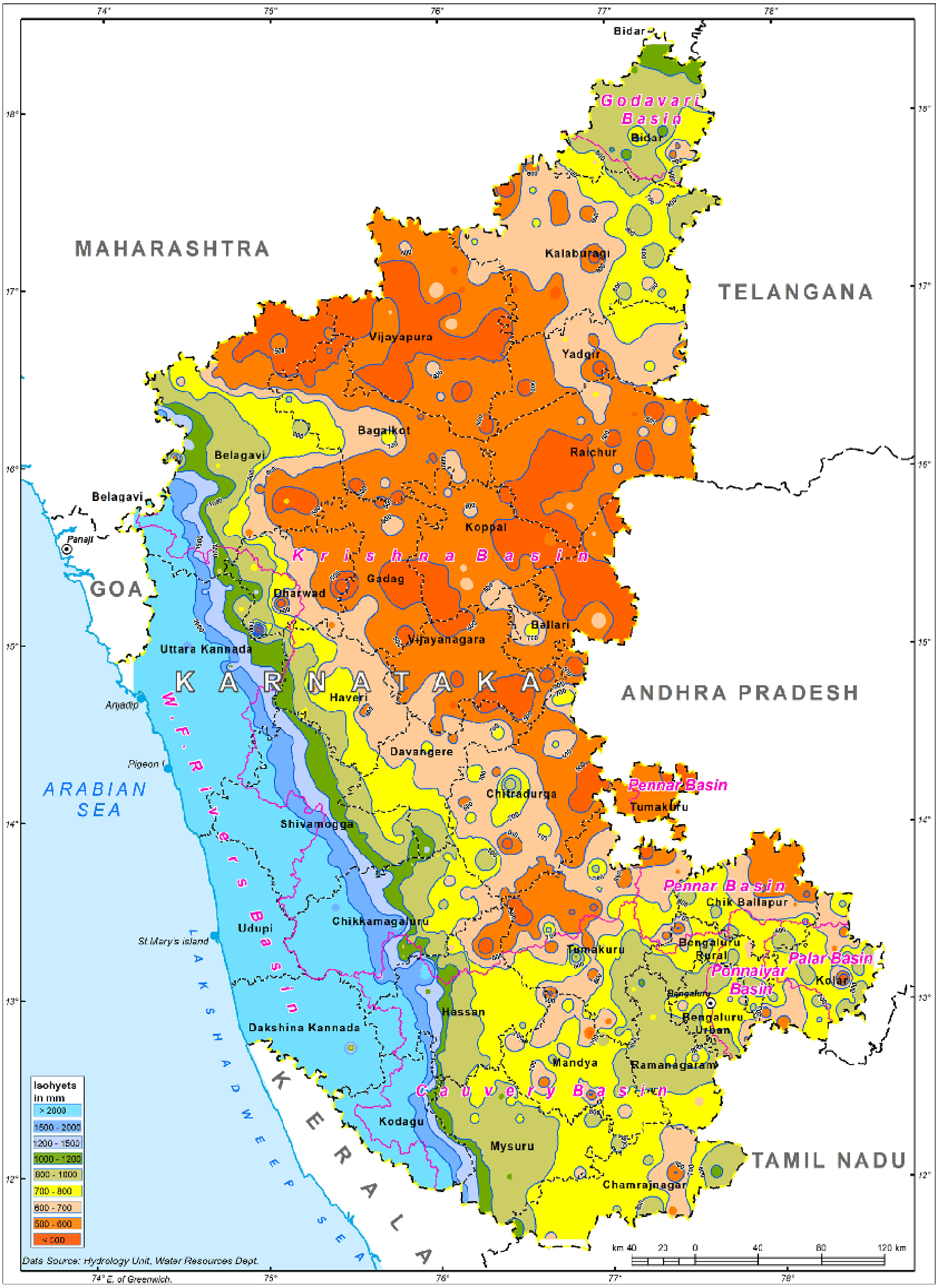


Figure 04. Distribution of average annual rainfall 1992-2022

From table 11, 12 and 13 provides details of Groundwater recharge, utilization, and categorization in different districts in the state as on March 2023 is presented. Based on the stage of development in using the groundwater annually, the Taluks are categorized as over-exploited, critical, semi-critical, and safe. Out of 234 taluks during 2023-24, 44 Taluks are classified as over-exploited, 12 are critical, 32 are semi critical and 146 are safe.

Table 11: Resource assessment for different periods

#	***Parameter***	***2017***	***2020***	***2022***	***2023***
1	Total Annual GW Recharge (BCM)	16.84	18.16	17.74	18.93
2	Annual Extractable GW Resources (BCM)	14.79	16.40	16.04	17.08
3	Annual GW Extraction (BCM)	10.34	10.63	11.22	11.32
4	Stage of GW Extraction (%)	69.87	64.85	69.93	66.26

Table 12: Status of dug wells and borewells during 1986-87 and 2022-23

#	***Wells in use***	***Number of wells***	
		1986-87	***2022-23***
1	Irrigation Dug and Dug cum Borewells	4,01,023	2,11,668 (1930)
2	Irrigation Borewells	47,923	9,66,290
4	Industrial Dug wells		4
5	Industrial Borewells		21334
6	**Total No of Wells**	**4,48,946**	**12,01,226**
7	Rural water supply Borewells	1,22,000 (1991-92)	NA

Table 13: Stage of development of groundwater

#	***Category***	***1986-87***	***2023-24***
1	Total number of taluks	175	234
2	Dark / Overexploited Taluks	18	44
3	Gray / Critical Taluks	16	12
4.	Semi critical		32
5	Safe Taluks	141	146
6	**Stage of GW development**	**29.80%**	**66.26%**

(Report on Dynamic Groundwater resources of Karnataka as of March 2023)

Depth to groundwater levels is also equally important as it hints at the resource being surplus or not. The depth of groundwater level is consistently depleting year after year based on the level of extraction of groundwater in an area. The development of the groundwater resource is always accompanied by a decline in water levels. There is a need to prevent the water levels from further declining leading to a shortage of resources.

5. Major causes for groundwater depletion

1. **Replenishable resource:** Unlike petroleum reserves, which are certain to exhaust one day in the future, groundwater is replenished annually by rainfall events. However, annual extraction should always be less than the annual recharge to maintain sustainability. In the past 3-4 decades, over-exploitation has taken place and with failure in rainfall, acute shortage is experienced over the entire state. The time has come to consider Groundwater resources as precious and use it sparingly, recycle, and reuse, so that we don't experience scarcity again when rains fail in the coming years. As narrated above, the imbalance between recharge and extraction is the major cause for the present water scarcity in the State. The situation is not wholly due to shortage/failure of rain, but the infrastructure to support the rapid growth could not cope with it. Some of the major factors causing this water shortage are listed below:

2. **Increase in population and water demand:** India after independence marched ahead with the green revolution, industrialization, and urban development. The requirement of groundwater is increasing year after year in all these sectors. In many of the urban areas, particularly Bengaluru, it is the rapid urbanization that led to the coming up of many IT hubs, shopping malls, apartments etc. To cater to the burgeoning population, many ancillary setups such as hotels, shops, and hospitals came up. Many high-rise apartments have come up in all localities causing vehicle congestion, and pressure on water supply, and other civic amenities. The employment opportunities in cities are attracting the youth from the rural areas. Sufficient water supply, proper solid waste/sewage disposal, and avoiding traffic congestion, all these are posing problems. Many of the urban areas cannot carry this load in different sectors. In rural areas, due to a shortage of rains, and the desire to grow multiple crops, more and more groundwater is extracted. The annual extraction of groundwater is exceeding the annual recharge in many of the Taluks in the State.

3. **Elevated lifestyle practices**: Civilization increased per capita domestic water needs greatly. Climate change-induced rise in temperature added undesirable dimensions to water demand. The effects of modern-day elevated lifestyle practices are having an impact on the local resources. The water needs for bath, cooking, cleaning etc., has increased considerably with the developments. In cities, the swimming pools in hotels, resorts, apartments, etc., are a luxury requiring large quantities of water, and frequent refilling. Further, the swimmers again require fresh water for bath after finishing swimming. The water jets used for washing vehicles also consume large quantities of water.

4. **Cropping practices:** In a tropical semi-arid country such as India, groundwater is predominantly used for agricultural purposes, especially irrigation and many large aquifers vital to agriculture in the country, are under threat from overexploitation. Cropping practices do not adhere to the respective agro-climatic conditions. Crops like paddy, sugarcane, arecanut, etc., which require large quantities of water, are normally grown in high-rainfall Malnad and coastal areas. But in recent times, these crops are grown in dry and semi-dry Districts using groundwater from borewells. There is a need to create awareness among the farmers to switch to local variety of crops. The agricultural sector is the largest consumer of extracted groundwater (80-90 per cent).

5. **Delay in Water conservation practices:** Most of the farmers have yet to adopt modern water conservation practices to conserve water. Several practices like drip, sprinklers and crops with low water requirements, etc., are not used extensively. It is also possible that the equipment may not be affordable for small farmers.

6. **Poor maintenance of Rainwater harvesting structures:** Apart from the natural recharge due to falling rain, rainwater harvesting is done through Artificial Recharge Structures. Many such structures are constructed throughout the State by different Departments of the State Government and several NGOs. Because of the lack of regular and periodic maintenance for these structures, several check dams are filled up with soil flown during floods, streams bringing water to the irrigation tanks, and recharge pits are silted up. Owing to this, the recharge structures are not serving the purpose for which they are built, and expected recharge to the aquifer is not practically happening.

7. **Encroachment of tanks/water bodies**: Several tanks and Water bodies are either vanishing or shrinking in size, in the State. More so in the urban areas, either in the name of development or due to the greed of some people. These tanks/water bodies serve as an important source of recharge to aquifers. Removing a thin layer of silt before monsoon will enhance the rate of recharge.

8. **Closing of Natural stream networks:** Closing up/ narrowing down/ Diversion of natural stream courses are happening at several places. Many of the networks of sub-streams carrying water to tanks/water bodies do not exist today. In rural areas, they are used for cultivation by the nearby farmers, and in urban areas, their course is diverted, or they are closed down and are used for construction. These tiny streams make up for higher-order streams and hence, they should be restored. Also, the major streams also called *Raja kaluves* are allowed to carry raw sewage along with rainwater. Thus, the surplus rain water flows out of the city along with untreated sewage water.

9. **Reduced recharge potential in urban areas:** In all urban and semi-urban areas, the roads are either asphalted or white-topped with concrete. The bottom of the storm water drains running by the roadside are either covered with stone slabs or cement concrete. Whenever it rains, all the rainwater flows out of the city; at times water pools are seen at the lowest points. During heavy floods, some of the posh residential areas were inundated with water. Therefore, a natural drainage network has to be maintained and water should be allowed for seepage freely in the stormwater drains.

10. **Poor adoption of Rooftop rainwater harvesting:** As already discussed in the above paragraphs, natural recharge to aquifers remains almost the same for any area. But now there is an urgent need to enhance the recharge to the aquifer. To achieve this, rooftop rainwater harvesting was proposed for adoption by the general public and made mandatory by the BBMP. But it is not taken seriously by the public in general. All the public buildings have to come forward and execute this as a priority. Independent houses and housing apartments are wasting the resources pouring over their residences. In rural, and semi-urban areas also roof rainwater harvesting is not adopted, and they depend on groundwater for domestic uses.

11. **Unabated drilling of borewells:** Unabated drilling of borewells is going on by individuals and Government departments without considering the available resource, and without maintaining a safe distance from the nearby borewells. This is leading to depletion in groundwater, and well interference among nearby borewells. Some time back when Maharashtra State faced such a situation, drilling of borewells was stopped completely, and all the drilling vehicles were driven out of the State.

12. **Lack of enforcement for controls:** There is one Central Ground Water Authority, and there is also a State Ground Water Authority for Regulation and management of groundwater extraction to prevent overexploitation and depletion. The rules framed by the Government of Karnataka for Regulation and Management of Groundwater in the State are furnished in Appendix 3. The first of such an Act for regulation and management of groundwater extraction to prevent overexploitation and depletion was brought into effect in 1965. In the later years, the rules were modified and strengthened, and the latest revision was in the year 2022. But, despite the promulgation of these rules, drilling of borewells and over-exploitation has continued unabated. The reason is obvious that there was no strict enforcement of the formulated rules at the field level. Drilling agencies were not reporting about the number of borewells they have drilled, and individuals getting borewells drilled were not reporting to the concerned authority. The GW Authority has no staff of its own, and the State Groundwater Department is understaffed to monitor this.

6. Augmentation of groundwater

The Government of India has launched the National Water Mission (NWM) and its main objective is "conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management" (IWRDM). One of the most important goals of the NWM is to improve the efficiency of water use at least by 20% by ensuring improved efficiency both on the demand side as well as the supply side. Managing groundwater resources in Karnataka is challenging considering its diversity from the supply and demand side. Rural areas are dominated by agriculture, urban and peri-urban with industries. Rainwater harvesting and groundwater recharge is an important study as it varies from urban and rural areas, to agricultural landscapes with varied topography; the strategies must be formulated separately.

Mandatory water harvesting: One of the conditions stipulated for the industries who apply for clearance to use Groundwater in the GWA is that the user should facilitate in his area to recharge the aquifer. He is required to recharge a quantity of water equal to or more than the quantity of groundwater he pumps out from the aquifer. This is applicable only to notified areas of groundwater overexploitation. In light of the scarcity experienced at present and likely to recur in the coming years, the government should bring out legislation that 'every user of borewell or dug well in the State should compulsorily recharge the aquifer a quantity of water equals to or more than the groundwater he pumps out. This should be made applicable to the entire state irrespective of Notified/Over-exploited area or otherwise.

6.1 Rural area:

Groundwater is a vital resource for sustaining life, agriculture, and ecosystems, especially in rural areas where access to surface water may be limited. Karnataka, a state rich in agricultural heritage, faces challenges in groundwater management due to over-extraction and erratic rainfall patterns. Addressing these challenges necessitates a holistic approach that emphasizes augmenting groundwater recharge.

The augmentation of groundwater recharge in rural Karnataka aims to mitigate water scarcity, enhance agricultural productivity, and ensure long-term sustainability. By implementing effective strategies, this initiative seeks to empower local communities, protect ecosystems, and fortify resilience against climate change impacts.

6.1.1. Key Strategies:

Rainwater Harvesting Systems: Promoting the adoption of rainwater harvesting techniques such as check dams, and percolation tanks to capture and store rainwater, replenishing aquifers during the monsoon season. Rain water harvesting is the process of collection and storage of rainwater at the surface or in sub-surface aquifers. Managing water resources in Karnataka is challenging since the annual rainfall ranges from 400 mm (Pavagada) to 4000 mm (Agumbe). Nearly half of surface water flows in 10 west flowing rivers in coastal and hilly zones. Normally 30 to 35 percent of the rainfall will go as runoff. Emphasis should be given for harvesting at least 30 to 35 per cent runoff through *in-situ* or *ex-situ* rainwater harvesting by adopting appropriate watershed management practices. The *in-situ* rain water harvesting can be achieved through bunding and agronomic management *viz.,* contour cultivation, conservation furrow, mulching etc.

Ground water Recharge through abandoned Dugwells: Dugwells also called as Open wells were a common structure for tapping groundwater for irrigation and also for drinking and other house hold uses since olden days. However, after a rapid growth in population and increase in demand for more and more water, partly owing to erratic monsoons, drilling of borewells started gaining popularity. Drilling of borewells was introduced during 1960s, and at that time it was Slow drilling machine. Boreholes were drilled from the bottom of the dug wells in use or dugwells abandoned due to dwindling water yield. With the advent of Fast Drilling machines, and encouragement by the Government to farmers in the form of subsidised loans an easy term, drilling of surface borewells became most common and increased in number and speedy growth. When the farmers realised that borewells were more rewarding, the dug wells which served them till then were put to neglect. They were either abandoned, or filled up with excavated soil and rock fragments and that patch of land reclaimed for irrigation. Same was the case with dugwells used as a village drinking water source. Thus, even to date there are a good number of such abandoned dug wells in farmers fields and in village residential limits. These dugwells could be used as a source of point recharge. Farmers could be advised to direct all the rainwater falling in their land limits to the abandoned dugwells, and recharge to aquifer takes place naturally.

Rejuvenation of Irrigation Tanks: Tanks constructed for irrigation and domestic needs is a invaluable gift from our ancestors. In the process these tanks also served as an important source of recharge to the aquifer which was required to operate the dugwells that were in vogue before the advent of borewells. In olden days the villagers close to a tank were taking care of the tank (periodic maintenance) with devotion. They were clearing the weeds and accumulated silt in the streams bringing run off water to the tank, cleaning the canals supplying water to the fields, removing silt from tank bed to restore the storage capacity, etc. They were celebrating community festivals like 'Kere Habba' annually. Thus those tanks were performing well. In recent years, the Minor irrigation department of the state who is in charge of the minor tanks is attending to annual maintenance.

In order to give a thrust to the tank rejuvenation, the state government formed the 'Karnataka State Community Based Tank Management Project' with financial assistance from the World Bank. Under this project (2002-2012) about 4000 irrigation tanks were rejuvenated with active participation of the local community. This was a successful venture and brought out positive results in the form of increase in water storage, irrigation potential, fisheries and groundwater recharge etc. The local community was also trained in identifying the repair and restoration works required, planning and estimation, operating the funds, and execution of works. Such projects are required to rejuvenate and restore periodically all the tanks in the state.

Afforestation and Agroforestry: Encouraging afforestation and agroforestry practices to increase vegetation cover, reduce soil erosion, and promote groundwater infiltration, thereby fostering a sustainable environment. Different studies have shown that the overall forest area is decreasing owing to multiple reasons. The forest cover has dropped to 22 per cent, besides poor tree density. Expanding the forest area and revival of lost forest areas by increasing tree density and diversity need to be undertaken by the Forest Department to increase forest cover to the sustainable level of 33 per cent. Adoption of agro-forestry in the arable lands could be encouraged with hand held support and incentives. The water conservation in the forest area should be promoted to augment groundwater and improve water availability to animals. In this regard, shallow and slopy ponds need to be constructed.

Promotion of Sustainable Agriculture: Advocating for sustainable agricultural practices such as drip irrigation, mulching, and crop rotation to minimize water usage, reduce runoff, and replenish groundwater resources (Detailed in chapter 7).

Community Participation and Awareness: Engaging local communities through capacity-building programs, workshops, and awareness campaigns to foster ownership, promote water conservation behaviors, and ensure the success and sustainability of the initiative.

Rejuvenation of Traditional Water Bodies: Restoring and reviving traditional water bodies like ponds, lakes, and tanks to enhance groundwater recharge while preserving cultural heritage and biodiversity. Rejuvenation of tanks is another area to improve ground water recharge. Presently, out of 36000 tanks, 14000 are defunct, hence it is a herculean task to maintain, refill and use the remaining tanks and facilitate recharge, besides bringing at least 5 lakh hectares under irrigation from the present 1.58 lakh ha. Many of the irrigation tanks are not filling up to the design capacity due to accumulation of silt, and several streams have also not delivered the intended flow due to accumulation of sediments. Rejuvenation of tanks through clearing the waterways in the catchment, nala stabilization by planting trees, de-siltation, strengthening of tank bund and weirs etc., should be made mandatory. Eviction of encroachment of tanks shall be done on priority. Also, recharge shafts can be additional measures to enhance groundwater recharge. The local Taluk or Gram Panchayats should be entrusted with the task of periodic maintenance.

i. Traditional water bodies, including ponds, lakes, and tanks, have played a pivotal role in sustaining water resources, ecosystems, and livelihoods in rural areas for centuries. However, these vital sources of water have been subjected to neglect, pollution, and encroachment, leading to their degradation and depletion.

ii. The rejuvenation of traditional water bodies presents a holistic approach to water resource management, aiming to restore their ecological, social, and economic significance. It is ideal to collaborate to derive appreciable outcomes of rejuvenating traditional water bodies in rural Karnataka, India.

iii. Rejuvenating traditional water bodies enhances water availability, storage capacity, and recharge potential, ensuring reliable access to water for drinking, agriculture, and livestock rearing, particularly during dry periods. Restoring the ecological functions of traditional water bodies promotes biodiversity, improves water retention, enhances soil fertility, and supports the ecosystem in the area. Preserving and revitalizing traditional water bodies fosters cultural identity, heritage conservation, reviving traditional practices, rituals, and social interactions associated with these water sources.

iv. Through collaborative efforts, innovative approaches, and informed decision-making, these invaluable water sources can be revitalized, ensuring water security, biodiversity conservation, and socio-economic prosperity for rural communities.

6.1.2 Rainwater harvesting through mechanical measures in Agricultural fields

Mechanical practices are engineering measures used to control erosion from slopping land surfaces and thus land surface modification is done for retention and safe disposal of runoff water. In the design of such practices, the basic approach is to (i) increase the time of ponding of runoff water to increase the infiltration time, (ii) decrease the effect of land slope on runoff velocity by intercepting the slope at several points so that the velocity is less than the critical velocity, and (iii) to protect the soil from erosion caused by the runoff water.

A. Contour bunds: are the small bunds across the slope on a contour so that the long slope is cut into a series of small ones and each contour bund acts as a barrier to the water flow, thus making the water to walk rather than run, at the same time impounding water against it for increasing soil moisture. Contour bunds divide the length of the slope, reduce the volume of runoff water, and thus preventing or minimizing the soil erosion. Contour bunds are constructed in relatively low rainfall areas, having an annual rainfall of less than 600 mm, particularly in light textured soils having slopes up to 8%.

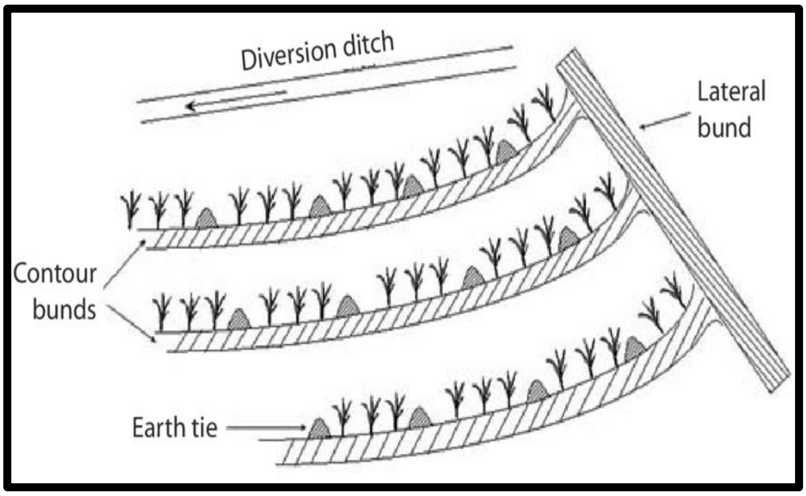


Figure 5: Contour bunds

The specifications followed for contour bunds is

Slope percentage	Southern region		Northern region	
	Vertical interval (m)	Corresponding horizontal distance(m)	Vertical interval (m)	Corresponding horizontal distance(m)
<1%	0.6	60	0.9	90
1 – 2%	0.6	39	0.9	60
2 - 3%	0.6	24	1.2	48
3 - 4%	0.9	21	1.5	33
4 - 5%	0.9	21	1.5	33
5 - 6%	1.2	21	1.5	27
6 - 7%	1.2	21	1.5	27
7 - 8%	1.5	18	1.5	27

By knowing the cross-section area of the bund, the volume of earth work per hectare and the cost of earthwork per hectare can be determined.

Bund design: Bunds are designed by determining the base width by considering impounding depth of water on the upstream plus the depth of flow on the weir and free board (20 to 25% of the above two). Further, side slope ratio is arrived from the angle of repose, being the characteristic feature of a given soil. In general, for light soils 1:1 and for heavy soils 1.5:1 side slope is adopted. This will ensure that saturation line (hydraulic gradient) falls within the two-thirds of the base width, resulting in bund stability. After knowing the height of the bund and assuming the top width of the bund (considering its usage) the base width is calculated. The contour plan is brought to the field, and examined whether the proposed bunds are further dissecting the field and / or the length of the bund is crossing the prescribed limit of 300 to 400 m. In such cases adjustments are made in the plan in consultation with land owners. After this, the first bund is located at 1.5 to 2.0 times the contour interval from the top most ridge line. Then drive pegs of longer size to mark top width and pegs of shorter size to mark the base width, after making adjustments in location of the bund while crossing ridge and valley.

Leaving 1.5 m of berm from the upstream line of the bund base, locate borrow pits with equalizers (septum with groove to a depth of 0.15m) of 30 cm width at every 5 m interval of required size to form the designed section of bund. Initially the soil is disturbed in the area where the bund is to be formed without disturbing the pegs used to mark base width and top width. The soil excavated from the borrow pits located preferably on the upstream side is placed between the pegs marked for base width and gradually bund is formed to have the desired top width. Subsequently, the soil is consolidated by breaking clods and shaping to the desired size. More rain water can be held against the bund by providing deeper and narrow pits of 1.0 m width. However, depth of the pit varies with the section of the bund. This arrangement is more suitable for lands where horticultural crops are grown.

Table 14: The recommendations of bund section and size of borrow pits is given below.

Top width (m)	Base width (m)	Height (m)	Side slope (ratio)	Cross section (sq.m)	Soil type
0.3	1.2	0.50	0.9:1	0.375	Red gravelly soil
0.3	1.2	0.6	0.75:1	0.45	
0.3	1.5	0.6	1:1	0.54	Red sandy loam
0.3	2.1	0.6	1.5:1	0.72	Very shallow black soils
0.45	2.0	0.75	1:1	0.92	
0.45	2.4	0.75	1.3:1	1.07	Shallow black soils
0.6	3.1	0.70	1.78:1	1.29	Medium black soils
0.5	3.0	0.85	1.47:1	1.49	

B. Graded bunds: Graded bunds are laid out in areas susceptible to water erosion, the soil is less permeable and areas having water logging problems. A graded bund system is designed to dispose of excess runoff safely form agricultural fields. A graded bund is laid out with a longitudinal slope gradient leading to outlet. The gradient can be either uniform or variable. The uniformly-graded bunds are suitable for areas where the bunds need shorter lengths and the runoff is lower. The variable-graded bunds are required where bunds need longer lengths, owing to which the cumulative runoff increases towards the outlets. In these bunds, variations in the grade are provided at different sections of the bund to keep the runoff velocity within the desired limit to avoid soil erosion.

Table 15: The recommended side slope and seepage line slope for graded bund

Soil type	Bund Side slope	Seepage line slope
	Side slope (horizontal: vertical)	
Clayey	1:1	3:1
Loamy	1.5:1	5:1
Sandy	2:1	6:1

(Source: Das, 2002)

Table 16: The specification for Bund Cross Section in graded bund is

Depth of soil (m)	Base width (m)	Top width (m)	Height (m)	Side slope (m)	Area cross section (sq.m)
Shallow soils (7.5 – 22.5 cm)	2.67	0.38	0.75	1.5 : 1	1.14
Medium soil (22.5 – 45 cm)	3.12	0.60	0.85	1.5 : 1	1.56
Medium deep soils	4.25	0.60	0.90	2 : 1	2.18

Table 17: The bunding options for different soil type, rainfall and slope situation is summarized below

Bunding options	Soil type	Rainfall (mm)	Slope (%)
Contour bund	Light soil	<600	>1.5
Graded bund	All soils	>600	1.5
Bench terraces	Deep soil	>1000	6.0
Graded boarder strip	Deep alfisol& related red soil	>800	>1.5

Table 18: Moisture conservation practices that can be adopted for i*n-situ* are

Soil Type	**Rainfall**	***In-Situ* Moisture Conservation Techniques**
Red soil	Low	Dead furrow: are opened at 3-6 m interval across the slope or aling the contour in the inter-bund area to conserve moisture *in-situ* in closely spaced crops, while intercropping can be followed with widely spaced crop in the closely spaced main crop and the dead furrow can be opened between the rows of widely spaced intercrop. Dead furrow serves dual purpose of conserving rainwater under deficit rainfall situation and also as channel to drain excess water under higher rainfall situation to avoid waterlogging of field and minimize damage on bunds.
	Medium	Sowing on flat bed and ridging later with eventual cultivation: Flat beds are used where water availability is adequate and there are no drainage problems. Crops like maize, sorghum, beans, and potatoes can besown / planted in flat bed; as the season progresses, earthing up in the crop rows need to be made to create ridges and furrows, conserve rainwater, support plant stand and drain excess water safely to avoid waterlogging.
	High	Graded border strips: Here the stripes are made across the slope and are levelled within the stripes.
Black soil	Low	Contour cultivation: All operations viz., tillage, sowing, Intercultivation practices are done across the slope, which all acts as a barrier for surface runoff and increase ponding time to infiltrate larger proportion into the soil.
	Medium	Dead furrows at 3-6 m interval as discussed above in red soil with low rainfall scenario.
	High	Graded open furrow (0.2 to 0.3 m^3) at 10 m interval across the slope

C. Terraces

A Terrace is an earth-embankment, constructed across the slope, to control runoff and minimize soil erosion. A terrace acts as an intercept to land slope, and divides the sloping land surface into strips. In limited widths of strips, the slope length naturally available for runoff is reduced. It has been found that soil loss is proportional to the square root of the length of slope; i.e. by shortening the running length, soil erosion can be reduced. The soil eroded by the runoff and the raindrop splash flows down the slope, and gets blocked up by terraces. The scour of soil surface because of runoff water is initiated by the runoff at a velocity above the critical value, attained during a flow on long length of the sloping run. Thus, by shortening the length of run, the runoff velocity remains less than the critical value and therefore soil erosion owing to scour is prevented.

Terraces include broad-base terraces and bench terraces. Broad-base terraces are adapted for both conservation of rainwater in deficit rainfall areas and safe disposal of runoff under excessive rainfall situation specially in black soils.Thebench terraces are being used to reduce the land slope in hilly areas with >20% slope.

Bench Terracing

The bench terrace system consists of a series of flat shelf-like areas that convert a steep slope of 20 to 30 percent to a series of level, or nearly level benches. It consists of construction of series of platforms along contours cut into hill slope for a step like formation. These platforms are separated at regular intervals by vertical drop or by steep sided and protected by vegetation and sometimes packed by stone retaining walls.

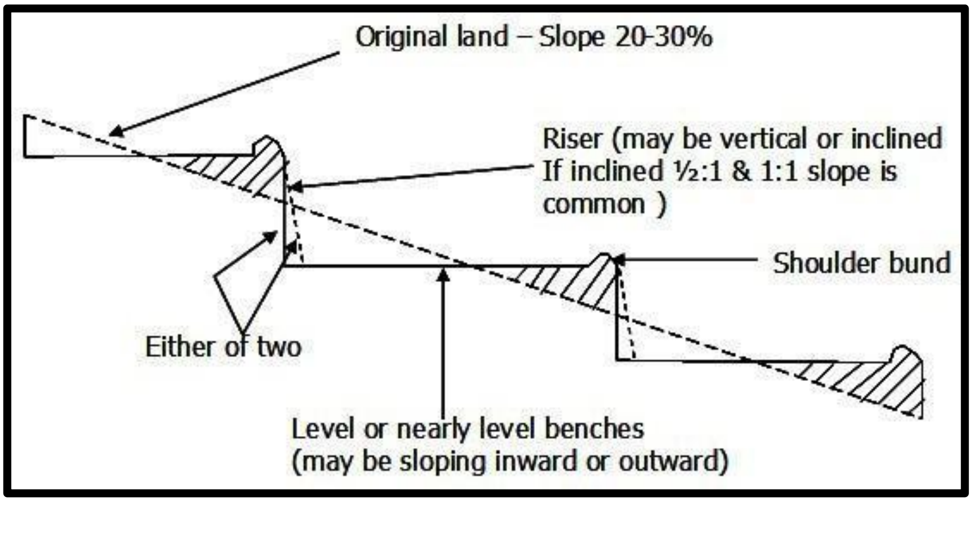


Figure 6: Bench terracing

Bench terraces with inward slopes are to be adopted in high rainfall areas where a major portion of the rainfall is to be drained safely as surface runoff. Here, a suitable drain at the inward end of each of these terraces is to be provided to drain the runoff. These drains ultimately lead to a suitable outlet. Bench terraces with level top are suitable for areas of medium rainfall, having deep and highly permeable soils. Due to the fact that no slope is given to the benches, it is expected that the most of the rainfall coming over the area is to be absorbed by the soil and very little water is to go as surface drainage. Bench terraces sloping outward are to be used in low rainfall areas with permeable soils. Bench terraces with narrow width (about 1 m) are sometimes constructed for orchards.

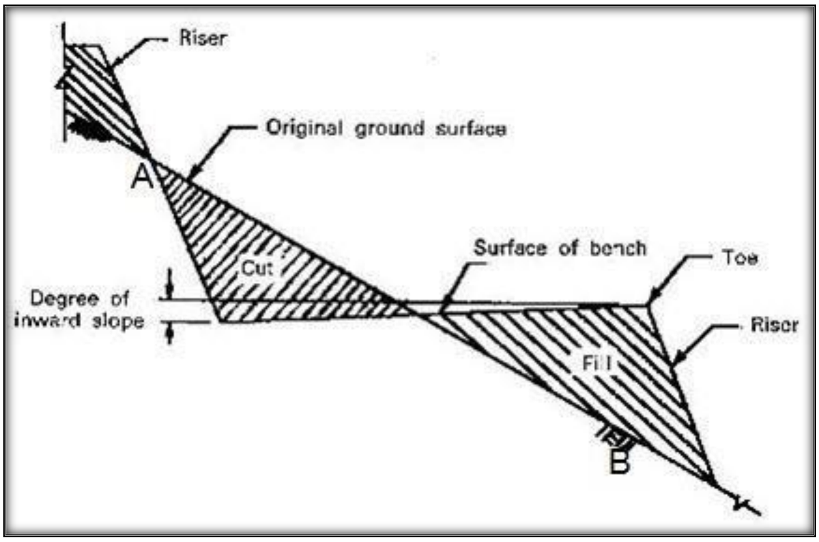


Figure 7: Cross section of bench terraces

The design of the terrace cross section consists of deciding (1) the batter slope, (2) dimensions of the shoulder bund, (3) inward slope of the terrace and the dimensions of the drainage channel in case of terraces sloping inward, and (4) outward slope in case of terraces sloping outward. The batter slope is mainly for the stability of the fill or the embankment. The flatter the batter slope, the larger the area lost due to bench terracing. Vertical cuts are to be used in very stable soils and when the depth of the cut is < 1 m. Batter slopes of ½: 1 can be used in loose and unstable soils. The size of the shoulder bunds in case of terraces sloping inward is nominal. In case of terraces with flat top and sloping outwards, larger sections of shoulder bunds are required as water stands against these bunds. The bund cross section depends on the terrace width and soil condition. The inward slope of the terrace may be from 1 in 50 to 1 in 10 depending upon the soil conditions. For these terraces a drainage channel is to be provided at the inner edge of the terrace to dispose excess runoff.

Alignment of bench terraces should start from the ridge and progress towards the valley. Contour lines may be marked and considered as the centre line to mark terrace width in the field. The alignment may then be examined and suitable adjustments should be made wherever necessary taking the local conditions like depressions, sharp turns, field boundaries etc. that exist at the site. Formation of bench terraces may be started from the top and preceded downwards. By this method, the top soil and the subsoil get mixed up and the top soil may not be available for the terrace surface. In cases where the subsoil condition is not good, it is necessary to keep the top soil apart and again spread it on the terrace. This can be accomplished by starting the construction of the terraces from the lower most one. After the construction of the first terrace, the top soil from the second terrace may be spread on the first terrace and the process continued for subsequent terraces. In bench terraced areas, suitable outlets should be provided to dispose runoff safely. One of the sides of the hill slope where vegetation is well established can be used as the outlet. Where such outlets are not available or feasible, waterways are to be formed to dispose of the runoff.

Zingg Terraces: These are earthen embankments, similar to contour bunds, constructed on contour with contributing / donor area and leveled / receiving area in 3:1 ratio with or without surplussing weir. This land shaping can be practiced in medium to deep black soils with infiltration rate higher than 6.0 mm/hr, having slope upto 5 per cent and receiving rainfall less than 950 mm. Zingg terraces are most suitable for cultivation of high value crops.

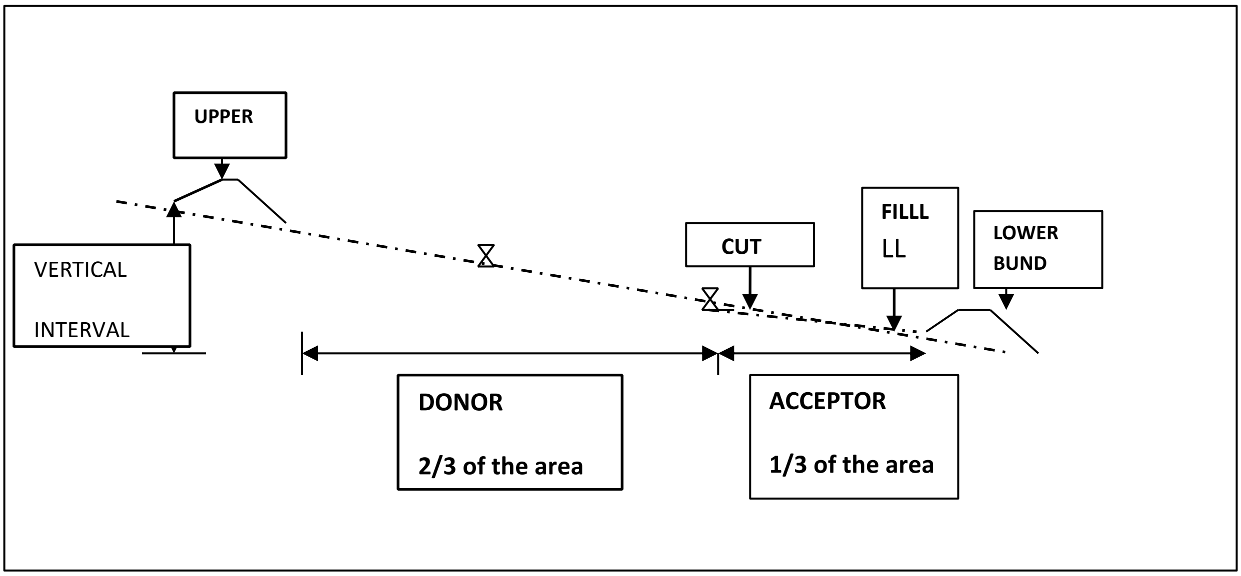


Figure 8: Zingg terraces

Bund positions are marked on the ground starting from the top field boundary taking all the precautions mentioned under contour bunding. Soil from the down streamside of the bund is scraped to form the bund. The bund is then shaped and consolidated. Surplussing weir is located at suitable place in the bund with crest level 20 to 30 cm above the leveled land surface. Then a strip of uniform width equal to one-third the inter-bunded area is plain–leveled all along the upstream side of the bund. The quantum of earth work involved is worked out as mentioned under contour border strips.

D. Micro catchments: These are the small basins designed to conserve moisture in-situ and reduce soil loss in low rainfall and less permeable soils. Making small depressions with basin listers or similar implements helps in retaining rain water *in situ*, increasing infiltration rate and to reducing erosion of medium deep and deep black soils, particularly in *rabi* tracts Here, circular basins of one meter diameter are to be formed in level lands or‘ V’ ditches of size 5m x 5m with trees planted centre in slopy lands I orchards or Saucer basins / semicircular bunds with 2m diameter to a height of 15-20cm across the slope.

Figure 9: Microcatchments

E. Broad beds and furrows: The broad bed and furrow system is laid within the field boundaries using animal or tractor drawn ridger to control erosion and to conserve soil moisture in the soil during rainy days.

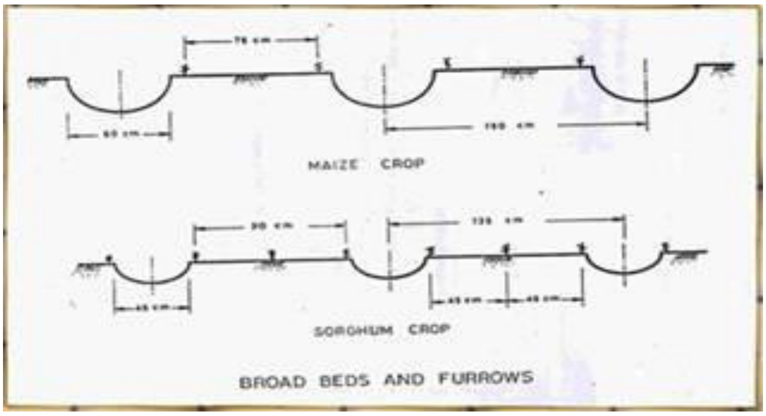


Figure 10: Broad bed and furrow

F. Compartment bunding: Compartment bunds of 15 to 20 cm height are formed in low permeability soils to retain water in the field, by increasing the opportunity time for infiltration. The operation is quite simple and can be completed with the help of bund former with a pair of bullocks. Size of the compartment bund depends upon the slope of the land as follows:

< 1%	-	6 m x 6 m
1-2 %	-	4.5 m x 4.5 m
2 to 3% slope	-	3 m x 3 m

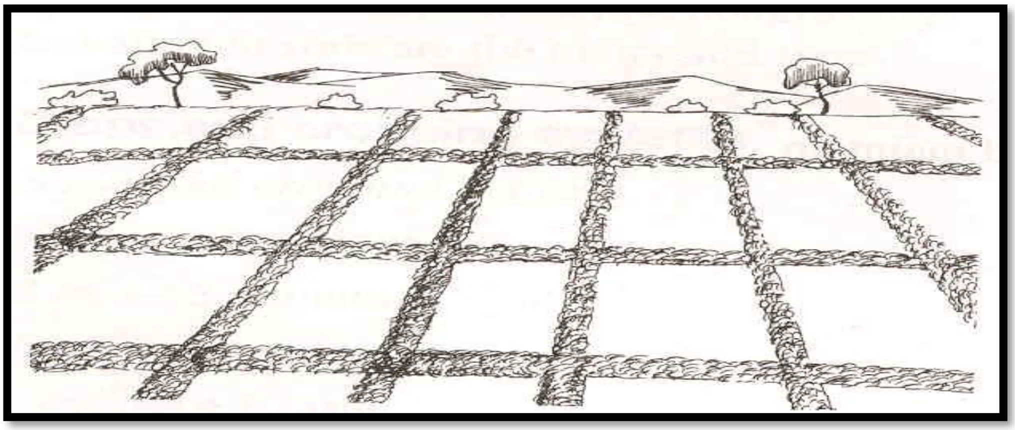


Figure 11: Compartmental bunds

G. Ridges and furrows : Most of the widely spaced crops like maize, sorghum, cotton, chillies, pigeonpea, tomato, castor, etc can be grown in ridge and furrow system. The usual procedure is to sow the crop first and form the ridges later by earthing-up operation to the crop rows. Tied ridges during final earthing up help conserving major portion of rain water.

H. Graded ridges: In contrast to the ridges and furrow system of cultivation as described above, the broad beds (ridges) are formed in advance in Broad Bed and Furrow (BBF) system using a special equipment called tropiculture which was developed at ICRISAT. These broad beds (1.5 m base) act as 'mini bunds' stopping water from flowing directly down the slope.

I. Graded furrows and dead furrows: For moisture conservation, opening furrows at 3 m interval across the slope as an inter terrace management is quite effective. When the land is uniformly sloping, it will be convenient to have these furrows on the contour (dead furrows) or on a gradient of 0.2 to 0.4 per cent (graded furrows). Dead furrows are more useful in light soils receiving rainfall of less than 650 mm and in areas receiving more than 650 mm, graded furrows are essential for draining the excess water. The width of a furrow should be a minimum of 20 cm.

J. Vertical mulching: In soils of low permeability, sub soil wetting will be rather slow. Movement of water into black soils takes place through cracks thereby charging the sub soil profile with moisture. Once the surface cracks are closed due to wetting, further downward movement is controlled by intake rate per se. This rate is low (as low as 0.08 mm/hr in deep black soils of Bellary) and results in a dry layer sandwiched between two wet layers in years of low rainfall, leading to crop failures.

Vertical mulching in such low permeability black soils, is highly beneficial to increase the intake rate of water to charge the entire soil profile.

K. Gully plugs: Gully Plugs are built using local stones, clay and bushes across small gullies and streams running down the hill slopes carrying drainage to tiny catchments during rainy season. Gully Plugs help in the conservation of soil and moisture. The sites for gully plugs may be chosen whenever there is a local break in the slope to permit the accumulation of adequate water behind the bunds**.**

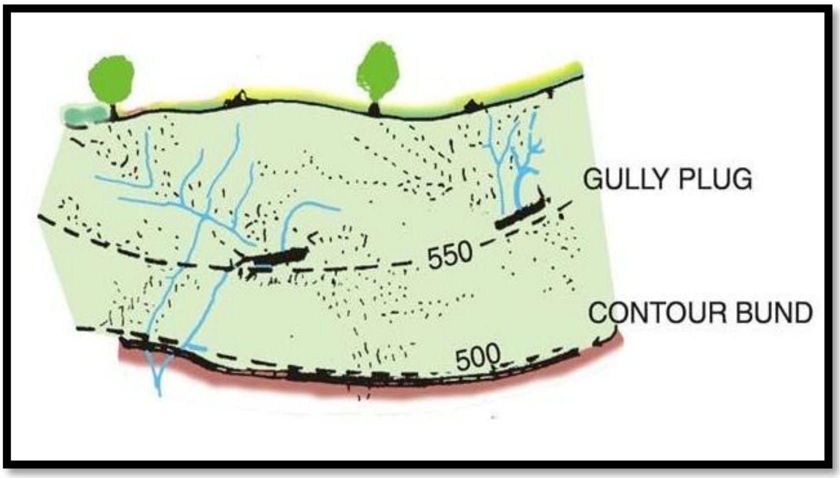


Figure 12: Schematic diagram of Gully Plug and Contour bund

6.1.3 Ex-situ conservation measures:

A. Dugout Ponds: The dugout ponds are constructed by excavating the soil from the ground surface. These ponds may be fed by ground water or surface runoff or by both. Construction of these ponds is limited to those areas which have land slope less than 4% and where water table lies within 1.5-2 meters depth from the ground surface.

B. Farm Pond: Farm ponds are constructed for multi-purpose objectives, such as irrigation, livestock, water supply, fish production etc. The pond should have adequate capacity to meet all the requirements. The location of farm pond should be such that all requirements are easily and conveniently met. Generally, the farm ponds are excavated in the shape of rectangular, square or inverted cone with circular cross section. Though, inverted cone and other curved shape ponds are difficult to construct but many times it provides higher ratio of volume to wetted surface that increases the net storage after moderating for seepage loss. The farm ponds supplement water for protective irrigation and reduce groundwater extraction.

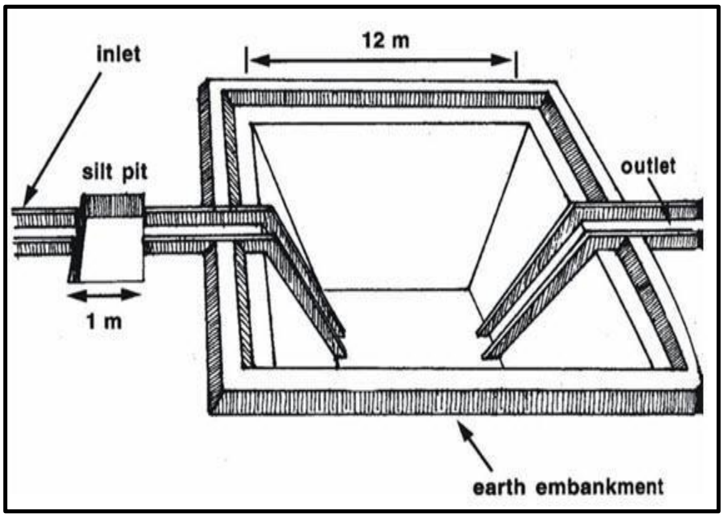


Figure 13: Farm pond

The optimum dimension of farm ponds should be based on the hydrological consideration and catchment area.

Table 19: The recommended side slope for different soil type

Soil type	**Slope (horizontal:vertical)**
Clay	1:1 to 2:1
Clay loam	1.5:1 to 2:1
Sandy loam	2:1 to 2.5:1
Sandy	3:1

The farm pond with respect to small catchment may not have sufficient runoff to be filled and risk of being dried during dry spell. Similarly pond with large catchment would require large water control structure and would be difficult to manage. Generally the area under dug out farm pond should not be more than 10% of the farm catchment. The depth of the farm pond is decided by considering soil depth, soil type and equipment used in excavation. Though, the evaporation loss component can be minimized by increasing the depth but, from practical point of view the ideal depth is limited to 3 to 3.5 meter. The side slope of the pond should not be steeper than the natural angle of repose of the excavated material.

C. Qanat System: it consists of a long tunnel or conduit leading from a well dug at a reliable source of groundwater (the mother well). Often, the mother well is dug at the base of a hill or in the foothills of a mountain range. The tunnel leading from the mother well slopes gradually downward to communities in the valley below. Access shafts are dug intermittently along the horizontal conduit to allow for construction and maintenance of the qanat. The Qanat system was used widely across Persia and the Middle East for many reasons. The system requires no energy, relies on the force of gravity alone. It can carry water across long distances through subterranean chambers avoiding leakage, evaporation or pollution. The discharge is fixed by nature, producing only the amount of water that is distributed naturally from a spring or mountain, ensuring that the water table is not depleted. More importantly, it allows access to a reliable and plentiful source of water to those living in otherwise marginal landscapes.

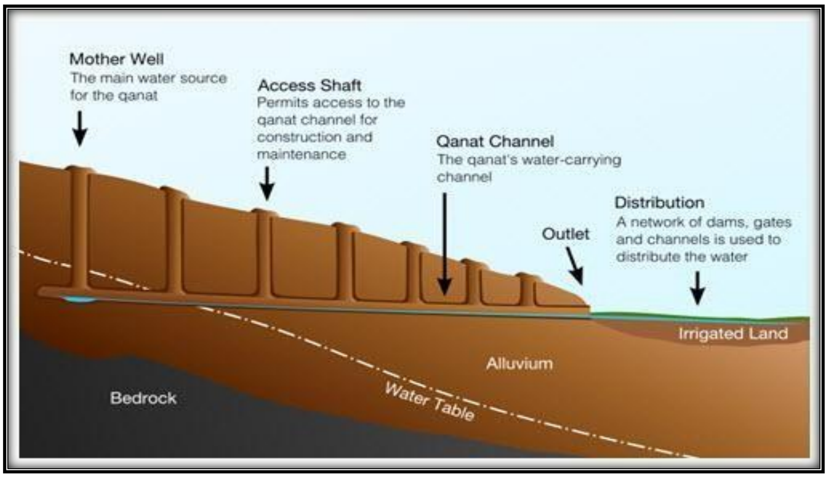


Figure 14: Qanat system

6.1.3 Rainwater harvesting through different structures

A. Gabion Structure

This is a kind of check dam commonly constructed across small streams to conserve stream flows with practically no submergence beyond the stream course. A small bund across the stream is made by putting locally available boulders in a mesh of steel wires and anchored to the stream banks. The height of such structures is around 0.5 m and is normally used in streams with a width of less than 10 m. The excess water overflows this structure storing some water to serve as a source of recharge. The silt content of stream water in due course is deposited in the interstices of the boulders in due course and with the growth of vegetation, the bund becomes quite impermeable and helps in retaining surface water runoff for sufficient time after rains to recharge the groundwater body.

B. Percolation Tank

A percolation tank is an artificially created surface water body, submerging in its reservoir a highly permeable land so that surface runoff is made to percolate and recharge the groundwater storage. Percolation tanks augment groundwater recharge, ensuring a sustainable and resilient water supply for rural communities, particularly during dry seasons or drought periods.

The functioning of percolation tanks revolves around the principles of rainwater harvesting and groundwater recharge. These tanks are strategically located in natural drainage channels or low-lying areas to intercept rainwater runoff and direct it into storage pits or recharge wells. The collected rainwater gradually infiltrates into the soil, replenishing groundwater aquifers and increasing water availability for domestic, agricultural, and environmental purposes.

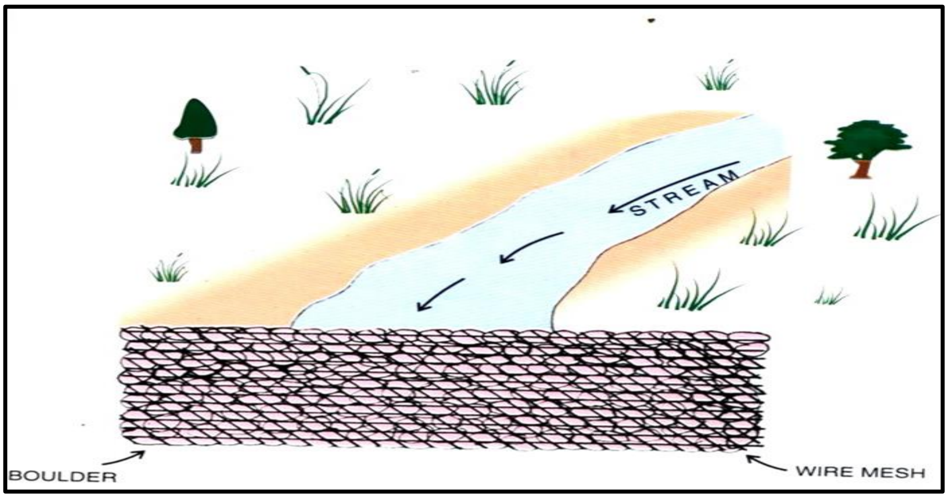


Figure 15: Schematic diagram of a Gabion structure

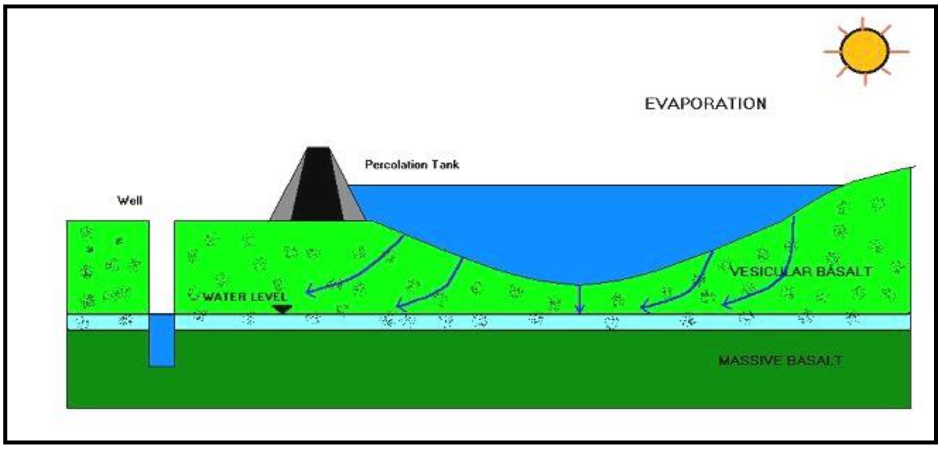


Figure 16: Schematic diagram of Percolation tank

Percolation tanks act as decentralized reservoirs, capturing and storing rainwater at the source, thereby minimizing losses due to evaporation, runoff, and surface water diversion. In the arid and semi-arid regions of rural Karnataka, where water scarcity is a pressing concern, percolation tanks emerge as a beacon of hope for replenishing groundwater resources. Percolation tanks should be constructed preferably on second- to third-order steams, located on highly fractured and weathered formation with lateral continuity downstream. The recharge area downstream should have enough wells and cultivable land to benefit from the augmented groundwater. The size of the percolation tank should be governed by the percolation capacity of strata in the tank bed. Normally percolation tanks are designed for storage capacity of 0.1 to 0.5 MCM. It is necessary to design the tank to provide a ponded water column generally between 3 & 4.5 m. The percolation tanks are mostly earthen dams with masonry structures only for spillways. The purpose of the percolation tanks is to recharge the groundwater storage and hence seepage below the seat of the bed is permissible. For dams up to 4.5 m in height, cut-off trenches are not necessary and keying and benching between the dam seat and the natural ground is sufficient.

C. Check Dams / Cement Plugs / Nala Bunds

Check dams are small, low structures constructed across seasonal streams or rivers to slow down the water flow and create small reservoirs behind them. These dams are strategically placed in natural drainage channels to intercept rainwater runoff, allowing sediment to settle and water to percolate into the ground. By slowing down the flow of water, check dams help in reducing soil erosion and replenishing groundwater aquifers. Check dams are constructed across small streams having gentle slopes. The site selected should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within a short period. The water stored in these structures is mostly confined to the stream course and the height is normally less than 2 m and excess water is allowed to flow over the wall. To avoid scouring from excess runoff, water cushions are provided at the downstream side. To harness the maximum runoff in the stream, a series of such check dams can be constructed to recharge on a regional scale. Clay-filled cement bags arranged as a wall are also being successfully used as a barrier across small *nalas.* At places, the shallow trench is excavated across the nala, and asbestos sheets are put on two sides. The space between the rows of asbestos sheets across the nala is backfilled with clay. Thus, a low-cost check dam is created. On the upstream side clay filled cement bags can be stacked in a slope to provide stability to the structure.

Figure 17: Field photo of a Check dam

D. Recharge Shaft

This is the most efficient and cost-effective technique to recharge unconfined aquifer overlain by poorly permeable strata. The recharge shaft may be dug manually if the strata is non-caving. The diameter of the shaft is normally more than 2 m. The shaft should end in more permeable strata below the top impermeable strata. It may not touch the water table. The unlined shaft should be backfilled, initially with boulders/ cobbles followed by gravel and coarse sand. In the case of a lined shaft, the recharge water may be fed through a smaller conductor pipe reaching up to the filter pack. These recharge structures are very useful for village ponds where a shallow clay layer impedes the infiltration of water to the aquifer. It is seen that in rainy season village tanks are filled up but water from these tanks does not percolate down due to siltation and tubewell and dug wells located nearby remain dried up. The water from village tanks gets evaporated and is not available for beneficial use.

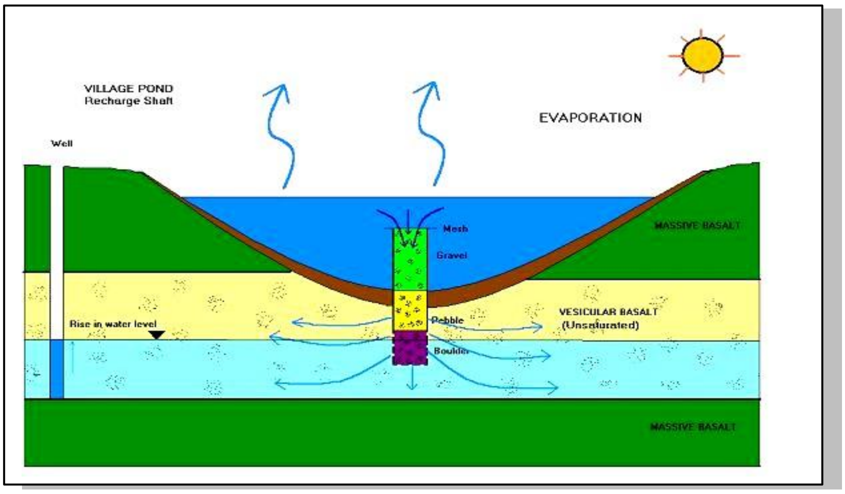


Figure 18: Schematic diagram of recharge shaft in a percolation tank

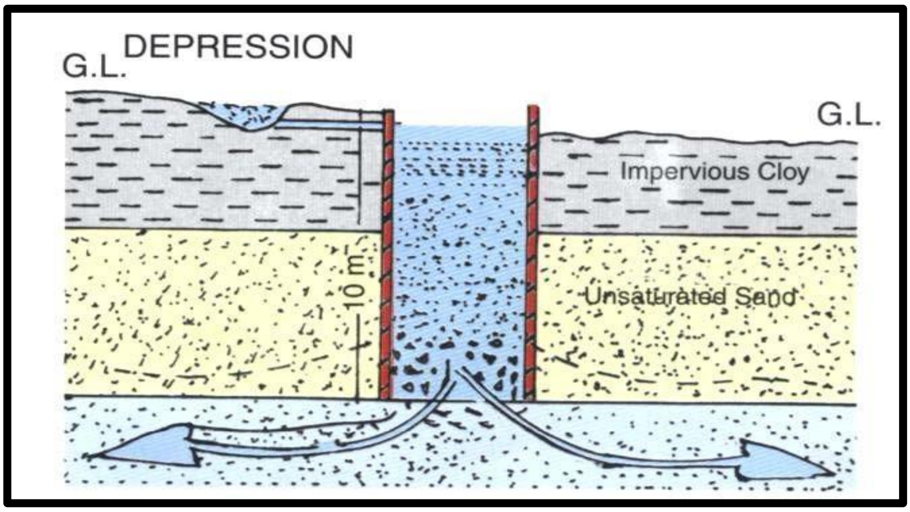
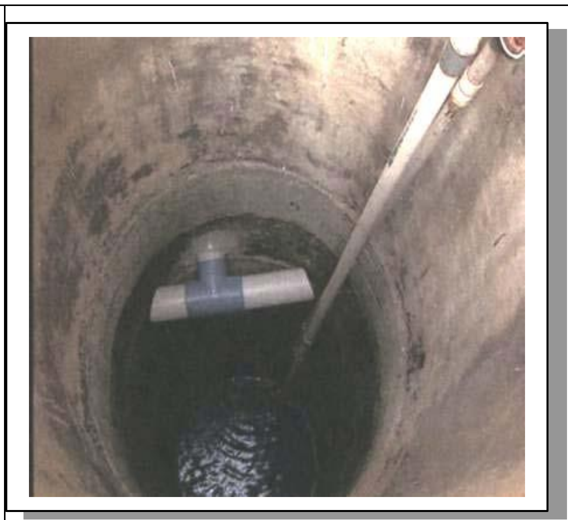


Figure 19: Schematic diagram of a recharge shaft

By constructing recharge shafts in tanks, surplus water can be recharged to groundwater. Recharge shafts of 0.5 to 3 m. diameter and 10 to 15 m. deep are constructed depending upon the availability of the quantum of water. The top of the shaft is kept above the tank bed level preferably at half of full supply level. These are backfilled with boulders, gravel, and coarse sand. In the upper portion of 1 or 2 m depth, the brick masonry work is carried out for the stability of the structure. Through this technique, all the accumulated water in the village tank above 50% full supply level would be recharged to groundwater. Sufficient water will continue to remain in the tank for domestic use after recharge.

E. Dugwell Recharge

Dugwells, traditional structures used for accessing groundwater, have been integral to rural water supply systems for centuries in Karnataka. However, with increasing demands on groundwater resources and declining groundwater levels, dug wells have gone dry in the major part of Karnataka except in the coastal Karnataka and in the Malnad regions. Still, a large number of unused dugwells are available in many regions of the state which can be used as a structure for groundwater recharge. Dugwell recharge, a method of replenishing aquifers through the diversion of surface water into dugwells, presents a promising solution to enhance groundwater availability and resilience. Existing and abandoned dug wells may be utilized as recharge structures after cleaning and desilting the same. The recharge water is guided through a pipe from the desilting chamber to the bottom of a well or below the water level to avoid scouring of the bottom and entrapment of air bubbles in the aquifer. Recharge water should be silt free and for removing the silt contents, the runoff water should pass either through a desilting chamber or filter chamber. Periodic chlorination should be done to control bacteriological contamination.

	
Abandoned Dug Well	**Abandoned Dug Well fitted with Rainwater Harvesting Mechanism**

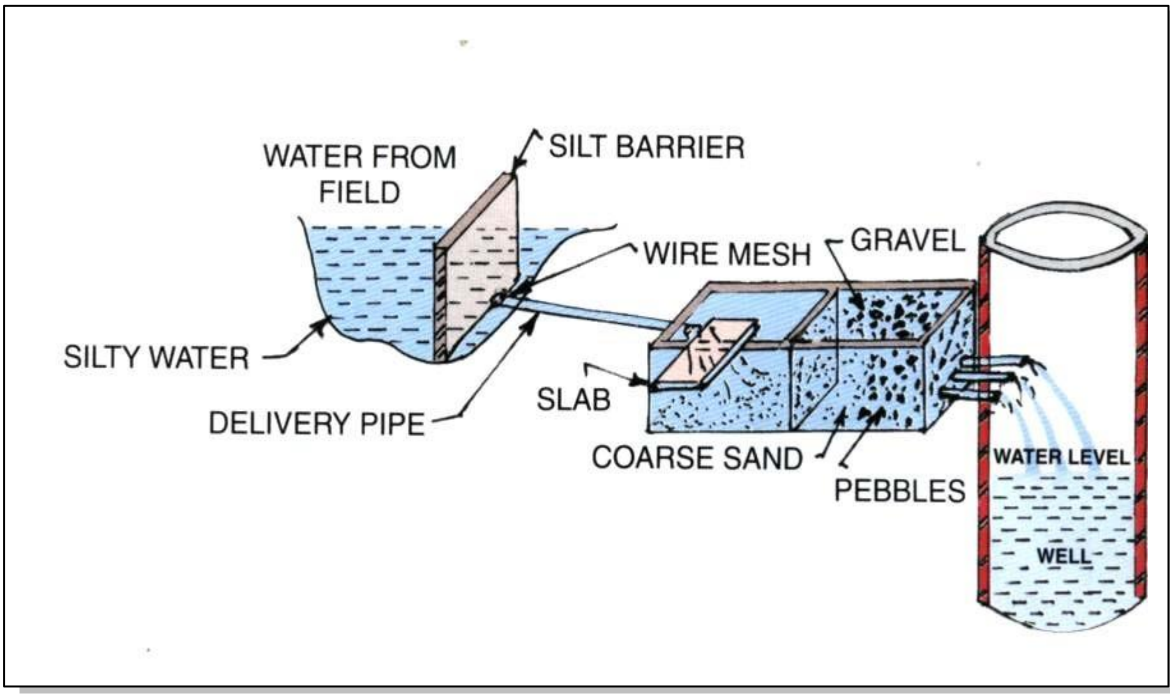


Figure 20: Dug well recharge – Field model

F. Groundwater Dams or Sub-Surface Dykes

In the semi-arid regions of rural Karnataka, where water scarcity poses a significant challenge to agricultural productivity and livelihoods, innovative solutions are imperative for groundwater replenishment. Groundwater dams, also known as sub-surface dykes, offer a promising approach to augmenting groundwater resources by capturing and storing surface water runoff underground. This write-up explores the concept, implementation, and benefits of sub-surface dykes as a sustainable solution for groundwater replenishment in rural Karnataka, India. Sub-surface dykes are underground barriers constructed across natural drainage channels or ephemeral streams to intercept and infiltrate surface water flow into the subsurface aquifers. Typically made of impermeable materials such as clay, concrete, or geomembranes, these dykes effectively trap surface water, allowing it to percolate slowly into the soil and recharge groundwater reserves. The site where the sub-surface dyke is proposed should have a shallow impervious layer with a wide valley and narrow outlet. After the selection of a suitable site, a trench 1-2 m wide is dug across the breadth of the stream down to an impermeable bed. The trench may be filled with clay or brick/ concrete wall up to 0.5m. below the ground level. For ensuring total imperviousness, PVC sheets of 3000 PSI tearing strength at 400 to 600 gauge or low-density polythene film of 200 gauges can also be used to cover the cut-out dyke faces. Since the water is stored within the aquifer, submergence of land can be avoided and land above the reservoir can be utilized even after the construction of the dam. No evaporation loss from the reservoir and no siltation in the reservoir takes place. Potential disasters like the collapse of the dams can also be avoided.

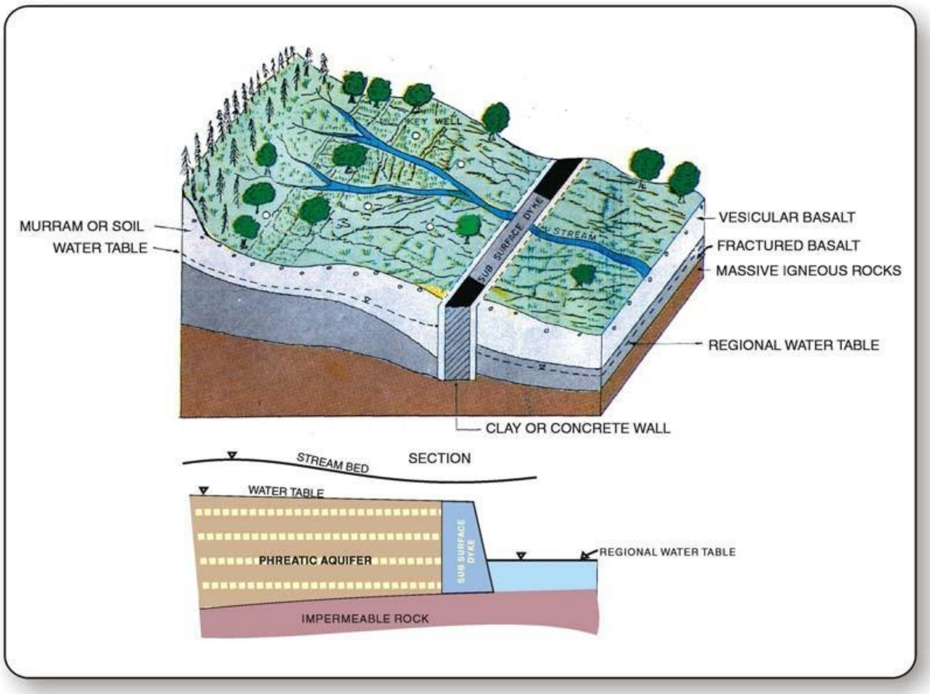


Figure 21: Schematic diagram of a sub-surface dyke

G. Point Recharge Structure (Prs) or Recharge Bore Well:

In hard rock aquifers, when the impervious layer overlies deeper aquifers, the infiltration from the surface cannot recharge the subsurface aquifers under natural conditions. Hence, measures are to be adopted to recharge deeper aquifers through a recharge borewell. The main purpose of a recharge well is to feed surface water directly to the aquifer. Recharge well is also known as an "Inverted well" because the movement of water in a recharge well is in the reverse direction. The depth of the recharge borewell well depends upon the present depth of exploitation so that the recharged water directly reaches the aquifer being exploited. It is suitable in areas where the aquifer is overlain by an impervious layer. The method involves constructing a bore well for recharge and designing a filter bed around the recharge well consisting of sand and jelly (road metal) of varying grades. The source water (i.e. surface water source that is available in the area either as storage in irrigation tanks or as seasonal flow in streams during monsoon) for recharge carries a certain quantum of silt load and hence needs to be made silt-free for recharge. The filter bed is designed in such a way that the recharge bore well is located within the filter bed and the length of the casing covered within the filter bed is slotted (in the bottom half) and wounded with coir rope. The source water enters the filter bed, passes through it, becomes silt-free, and is allowed to enter the recharge well. The recharge bore well can also be located outside the filter bed. In such cases, the filter bed's bottom part must be connected to the recharge borewell. The schematic diagram showing the design of a model PRS and some sample field photographs are also shown below.

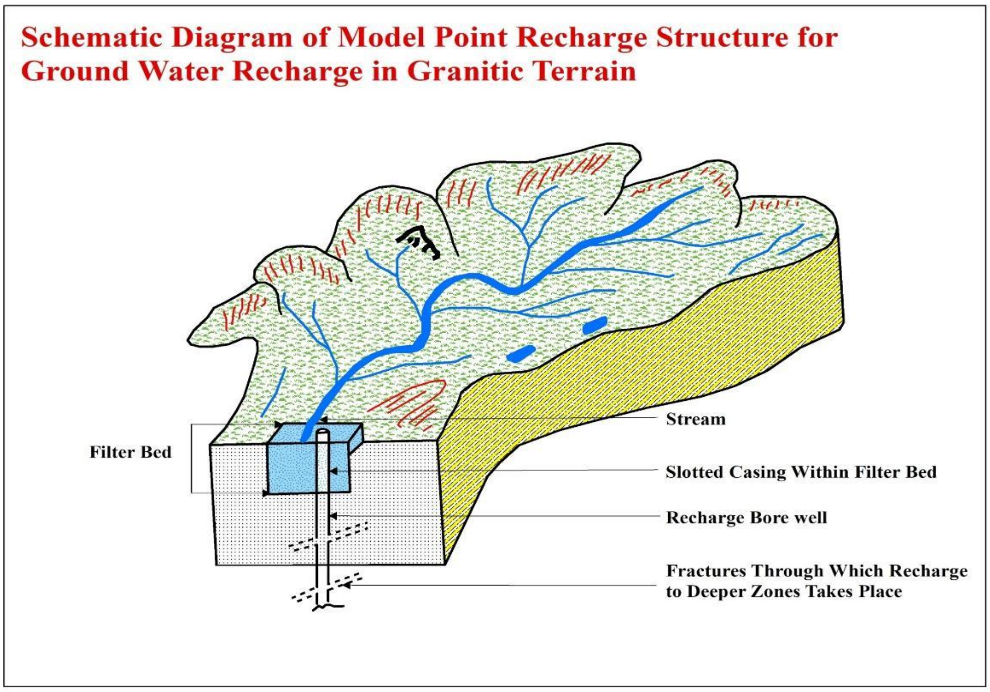


Figure 22: Schematic diagram of a Model PRS

	
Construction of Point Recharge structure Fixing of concrete Rings in the borewell pit Parshaganahalli, Kolar taluk	Construction of Point Recharge structure Laying of filtration media, Parshaganahalli, Kolar taluk
	
Construction of Point Recharge structure Placing of perforated RCC slab Parshaganahalli, Kolar taluk	Completed Recharge Borewell, Parshaganahalli, Kolar taluk

H. Vented Dams in Coastal Areas:

Though the coastal area of Karnataka is rich in water resources, the hydrogeological and physiographical conditions in this terrain do not permit large-scale surface and groundwater storage. There is large-scale surface run-off in the area due to steep gradients. Groundwater gets discharged quickly due to the steep hydraulic gradient and porous nature of lateritic aquifers. Hence wells dry up during the summer months and scarcity of water happens. Base flow occurs during the non-monsoon period and drains into the sea from the rivers. This source of water can be harnessed and conserved effectively to mitigate the deficit in the availability of water during the summer. The decline of water level can be reduced by arresting base flow by suitable water conservation structures namely vented dams which in turn helps to augment the recharge of the groundwater aquifer system in the area of influence and finally the groundwater sustainability. These structures are like check dams in plain lands. They are Check Dams with Vents provided for flow of heavy storm waters common in coastal areas. However, vented dams are used to arrest the non-monsoon base flow in the streams in the terrain of coastal districts. There are vents in the bunds of these structures through which the flood water during the rainy season is allowed to flow. Impounding is possible only during non-rainy seasons to retain the base flow for summer months. The typical design of the vented dams being constructed during the present time is shown in the field photographs given below.

Figure 23: Field Photographs of Vented Dams

6.1.4 Non Arable Land Treatments

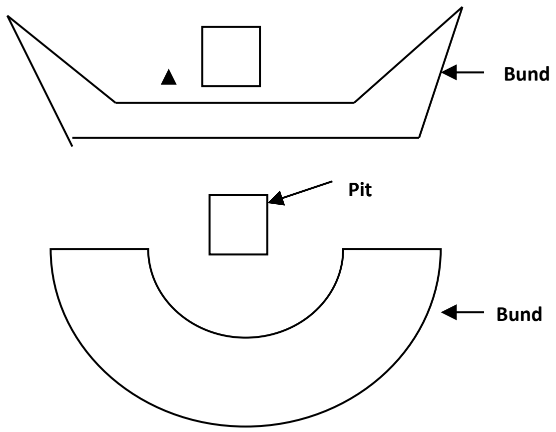
Non arable lands are those areas that are not fit for cultivation and the areas which are reserved for community use. Generally these are the lands lying on the ridge and on the valleys where limitations for crop production are many. These lands are best utilized by mechanical / social fencing so that natural vegetation comes up within a short time preventing soil erosion and reducing peak rate of run off. Alternatively, they also can be developed by adopting certain mechanical measures to promote soil and water conservation to enhance the growth of vegetation. Some of the suggested measures are given below.

A. **Continuous Contour trenches:** inarea receiving rainfall less than 750 mm/yr, rectangle shape trenches of 0.6 m width 0.45 m depth with varying length based on land slope (10 m for <5% slope, 7.5 m for 5-10% slope and 5 m for 10-20 % slope is advised.

B. **Staggered contour trenches:** These are for areas having undulated topography and areas receiving more than 750 mm annual rainfall. Shape, width, depth and interval are the same as for continuous contour trenches mentioned above. Length of 2 to 4 m and the berm between trenches is half the length of trench located below the berm.

C. **Graded trenches:** These are recommended for areas receiving more than 750 mm rainfall annual. Shape, width, depth, length and interval are same as above (contiuous contour trenches) and trenches are aligned on grade depending on soil type viz., Clayey soil: 0.1 – 0.2%, Red sandy loam: 0.3 – 0.4%andSandy soil – 0.5%.

D. **Crescent bund:** For planting horticultural and forest plants on undulating land pits are excavated and earth is used for formation of crescent bund on downstream side of the pit.1m x1m x 1m for horticultural crops and 0.5 m x 0.5 m x 0.5 m Forest plants is adopted.



E. **Gradonies:** These are narrow trenches with bunds on the downstream side, built along contour in the upper reaches of the catchment to collect runoff and to conserve moisture for trees or tree crops. Area between two successive bunds is used for cultivation of crops after development of sufficient fertile soil cover. It is cheaper compared to terracing for developing wastelands in to productive land. The principal purpose of trenches is to convert a wasteland into productive land. After silting of the trenches, proper height of the bunds is maintained to avoid overflowing. Any settling of the edge should be strengthened or repaired.

Proper distribution of water under irrigated commands

Enhancing water productivity in irrigated agriculture depends largely on its efficient conveyance from the source to the field of application, application methods, and distribution. A properly designed water distribution system will make irrigation easy & efficient. Several types of structures are used to convey, divert & control irrigation water on the farm.

Water control structures: During water conveyance and distribution, many control and diversion structures are to be used to regulate the water flow. The important structures are

A. Drop structure: Drop structure is used to discharge water in a channel from a higher level to a lower level. They may be open type or pipe drops. A drop structure consists of an inlet, a vertical fall section and an outlet. Open drop structure can be made of wood, concrete brick or stone masonry or by using discarded drums or barrels. Sometimes constructions of an open drop structure are not possible without disturbing an existing bund. In such cases, pipe drop is provided to discharge water from higher level to lower one.

B. Chute spillways: Chute spillways carry the flow down steep slopes through lined channel rather than dropping the water in free fall. The chute spill ways consist of an outlet, channel section and an inlet. These are made of concrete, brick or stone lay in cement mortar.

C. Check gates: Checks are placed in an irrigation channel to form an adjustable dam to control the elevation of surfaces in upstream. It is often necessary to raise the water level to apply irrigation to the elevated fields. Check gates consist of a masonry or metal wall across the channel and provided with a suitable gate. The gate may be made of wood or steel.

D. **Diversions**: In carrying water to different farms / parts of same farm, it is necessary to divert the water coarse or channel. Two way, 3 way or 4 way diversions made to control the flow at channel junction will permit the diversion of flow to all or any pre-determined direction

E. Turnouts: The water, delivered in an open canal or pipeline, can be supplied onto the fields with turnouts. Important turnouts are detailed below.

F. Bank breaching: Bank breaching involves opening a cut in the bank of a field canal to discharge water onto the field. Although this method is practiced widely, it is not recommended, as the canal banks become weak because of frequent destruction and refill.

G. Permanent outlet structures: Small structures, installed in the bank of a field canal are used to release water from the field canal onto the fields. The structures can be made of timber with wooden stop logs or of concrete with steel gates. This method is especially used for border strip and basin irrigation.

H. Spiles: Spiles are short lengths of pipes made from rigid plastic, concrete, steel, bamboo or other material and buried in the canal bank. A plug is used to close the spile on the inlet side.

I. Siphons: Siphons are short lengths of pipe usually made of plastic, rubber hose, or aluminium and are used to convey water from open channels to the field. They are portable and easy to install and to remove without disturbing the canal bank.

J. Box turnouts: They are portable wooden boxes with a gate at the inlet and a board at outlet. The gate slides in saw cut grooves in the box. It can be adjusted to divert any desired flow into the field or a secondary channel.

Piped water supply: The last 50 years have seen massive investments in large-scale public surface irrigation infrastructure as part of a state government effort to rapidly increase staple food production, ensure food self-sufficiency, and avoid drought. Private and community-based investment, particularly groundwater pumping, has grown rapidly since 1980s, propelled by cheap drilling technology, rural electrification, and inexpensive small pumps. Investments for new irrigation infrastructure viz., dams in the state is impaired by the physiographic feature of being upper riparian state and inter-state water disputes in most command areas besides the environmental implications. Hence, the strategy should focus on developing available irrigation infrastructure through modernization aiming to enhance conveyance and application efficiency. Conveyance efficiency can be improved through the piped irrigation and reduce the dependence on groundwater. This can lead to reduced groundwater exploitation and restoration in canal command areas.

The water supply system in most command areas in the state is with open canals having the conveyance efficiency of 35-40%. These canals in most part are unlined and poorly maintained. The state must focus its irrigation investment on phased conversion of open canals in to piped system, which can enhance irrigation efficiency to above 80%. Increased irrigation efficiency can definitely help to almost double the irrigated area in the command, reduce the dependence on groundwater besides, farmer can adopt advanced and pressurized efficient irrigations system viz., drip, sensors, automation.

Piped irrigation may be with a) semi-circular / rectangular / square shaped pre-cured half pipes covered with solar panels to minimize seepage and percolation losses besides, reducing weed menace in the canal; b) pressurized closed pipe supply to encourage advanced irrigation practices like micro-irrigation, automation etc.

6.1.5 Artificial recharge structures feasible for Karnataka - District wise:

The artificial recharge structures are to be planned depending on the hydrogeological conditions in the area. The details are summarised in the **Table 12** given below. The details are summarized based on the topography, geomorphology and hydrogeological conditions in these districts.

Table 20 : District-wise artificial recharge structures feasible in Karnataka

Sl. No.	District	Topography	Aquifer	Structures suitable
1.	Bagalkote	Plain area	Basalt, Limestone, Granite, Sand stone, Consolidated sediments (Kaladgis)	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.
2.	Bangalore Rural	Plain, Gently sloping, Plateau region	Granitic gneisses, schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.
3.	Bangalore (Urban)	Plain, Gently sloping, Plateau region	Granitic gneisse, Schists	Recharge Trenches, Percolation Tanks, Infiltration wells/Bore wells, Check dams, Sub-surface Dykes, Desilatation of Tanks, Afforestation
4.	Belgaum	Gently undulating area valley slopes, Forest area	Basalt, Late- rite, Consolidated sediments (Kaladgis)	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.
5-6	Bellary and Vijayanagara	Valleys, Plain area, Forest area	Granitic gneisses, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.

7.	Bidar	Plain area Gently undulating	Late-rite & Basalts	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.
8.	Vijayapura	Plain area	Basalt, Limestone, Granite, Sand Stone Consolidated sediments (Kaladgis)	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.
9.	Chamarajanagar	Forest, Plain area, Undulating	Granitic gneisses, Late- rites, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.
10.	Chikkballapur	Plain, Gently undulating	Granitic gneisses, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
11.	Chikkamagalur	Forest, Plain area, Valley slopes, Undulating foot hills	Granitic gneisses, Late- rites, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.

12.	Chitradurga	Plain area and gently undulating	Alluvial, Granitic gneisses, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.
13.	D. Kannada	Forest, Valley slope, steep slopes, Flood plains	Granitic gneisses, Late-rites, Schists	Vented Dams Infiltration wells, sub-surface dykes Percolation Tank.
14.	Davanagere	Plain area, Gently sloping forest area	Alluvial, Granitic gneisses, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
15.	Dharwad	Plain area, gently sloping forest area	Late-rites, Consolidated sediments (Kaladgis)	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
16.	Gadag	Plain area, gently sloping forest	Schists, gneisses, Late-rites, Consolidated sediments (Kaladgis)	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc

17.	Gulbarga	Plain area, Plateau region, undulating area	Late-rite, Alluvial, Basalt, Granitic Gneisses & Limestone	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
18.	Hassan	Forest, Plain area, Valleys slope, Undulation foot hills	Granitic gneisses, Late-rites, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
19.	Haveri	Plain area, gently sloping forest area	Schists, gneisses, Late-rites, Consolidated sediments (Kaladgis)	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
20.	Kolar	Plain, Gently undulating	Granitic gneisses, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
21.	Koppal	Plain area	Granitic gneisses	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc

22.	Madikeri (Kodagu)	Forest, Valley & Plateau	Granitic gneisses, Schists	Vented Dams Infiltration wells, sub-surface dykes Percolation Tank.
23.	Mandya	Plain area	Granitic gneisses, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
24.	Mysore	Forest, Plain area, Valleys	Granitic gneisses, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
25.	Raichur	Plain area	Granitic gneisses	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
26.	Ramanagara	Plain, Gently sloping, Plateau region	Granitic gneisses, schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc.

27.	Shivamogga	Forest, Plain area, Valleys	Granitic Gneisses, Late-rites, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
28.	Tumkur	Plain area, undulating valley slope	Granitic gneisses, Schists	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc
29.	Udupi	Forest, Valley slope, Steep slope, Flood plains	Granitic gneisses, Late-rites, Schists	Vented Dams Infiltration wells, sub-surface dykes Percolation Tank.
30.	Uttara Kannada	Forest, Alluvial plain, Foot hill zone, valleys	Granitic gneisses, Late-rite, Schists Graywacke	Vented Dams Infiltration wells, sub-surface dykes Percolation Tank.
31.	Yadgir	Plain area, Plateau region, undulating area	Late-rite, Alluvial, Basalt, Granitic Gneisses & Limestone	Check dam, Percolation tank, Point Recharge Structures, Subsurface dyke, Dugwell recharge, Watershed Treatment Structures like boulder checks, vegetative checks, gully plugs contour trenches, etc

6.1.6 Maintenance of artificial recharge structures:

Maintenance of artificial recharge structures is essential as the process of recharge is a continuous one and the benefits would be felt over some time and mostly indirect in nature. Further, the measures adopted are mainly oriented toward protecting and improving the natural groundwater environment. The structure becomes defunct if timely maintenance is not done which finally defeats the purpose and objective of the construction of the structure (refer to the field photograph below which refers to the check dams without maintenance). Here, for example, the maintenance of catchment areas with vegetation and tree cover are also important. co Similarly, it is also important to involve the public and their participation in implementing artificial recharge schemes. This needs proper awareness and understanding of such schemes. Hence, awareness and training programs are essential. The water harvesting and recharging of groundwater would require group action by communities, societies, and farmers with financial assistance from govt. and financial institutions.

Figure 24: Photographs: Check Dams without periodic maintenance

Regulated drilling of borewells: Drilling of new borewells is going on unabated. Potentiality of groundwater and the necessity for additional borewells is not considered while drilling new borewells in the rural areas led to overexploitation of groundwater for agriculture and domestic needs. This has resulted in severe ground water depletion even to the depth more than 1500 ft. in command areas too.

To avoid further dwindling of this scarce resource, and inter well interference, any new borewell should be drilled with a technical advice only by following groundwater usage norms. Stringent norms are to be imposed to regulate indiscriminate drilling of borewells. The groundwater situation elucidated by the CGWB, Groundwater Directorate and related organizations like KSRSAC, KSNDMC etc., should be considered as the basis for permitting new borewells. The Groundwater Directorate should be made as nodal agency for issue of permissions and RDPR for monitoring. Groundwater recharging with filtered bed system is to be made mandatory for all the borewells. Further, educating the public about the groundwater scenario, usage and regulations are to be intensified. Creating farmers/water users' awareness to be intensified and care to be taken while using this scarce resource.

Minimising groundwater exploitation: The groundwater usage in agriculture, domestic and industrial sector needs to be minimized by adopting efficient practices. Increasing awareness, regulated supply of water, imposing water charges for the usage above the set standard, conjunctive use of treated water, may be adopted in the rural areas. Industries in the rural areas should follow water efficient practice, adopt rain water harvesting/ groundwater recharge and waste water treatment for reuse. The regulation on water use by the industries shall be strictly enforced. In order to properly monitor the quantum of the groundwater extraction, it is necessary that every borewell used for any purpose have to be installed with digital water meter and the ground water draft data is to be collected on real time basis.

Participatory groundwater management: The groundwater data sets are required to be gathered frequently each year for updating aquifer condition in the micro-watershed. Devising a suitable participatory framework of gathering soft/ hard data sets of groundwater by stakeholders will address not only sustainable data gathering but also empower/ educate the stakeholders about groundwater system. Several successful experiments were carried out on participatory approaches and these can be dovetailed to the watershed programs for proper groundwater management of the micro-watershed by the stakeholders themselves. Farmers should be encouraged to involve themselves in village level participatory groundwater management, wherein they will assess the water availability after the monsoon season, and plan for optimum utilization among themselves. They decide on the extent of area to be irrigated and the type of crops to be grown etc., with the available resource during that year. They also measure hydrological parameters and maintain a record of the readings. In this regard, suitable legal frame works need to be developed in consultation with National Law School of India University and related departments

Conjunctive use: Conjunctive use of Rainwater, Surface water, Treated water and Groundwater is the appropriate means to conserve water and extend area under irrigation. Care should be taken in treating waste water and for its productive use in agriculture. This is partly being implemented in the form of filling of rural tanks in Chikkaballapura and Kolar districts with treated sewage water from Bangalore – a. Hebbala–Nagavara valley (HN Valley) this is a unique project to fill 65 tanks of drought prone districts of Chikkaballapura, Bangalore Rural and Bangalore urban with secondary treated sewage water from BWSSB.

It is intended to pump 210 MLD of secondary treated sewage water, which will add to groundwater recharge. b. Yattinahole project envisages a drinking water supply scheme to Chikkaballapura district along with other six districts – Bangalore rural, Kolar, Ramanagara, Tumkur, Hassan and chikmagalur. The water from this project is proposed for drinking water and tank filling. Implementation of this project helps to recharge 565 ham of groundwater.

Tank Rejuvenation

Rejuvenation of tanks is another area to improve ground water recharge. Presently, out of 36000 tanks, 14000 are defunct in the state hence, it is a herculean task to maintain, refill and use the remaining tanks and facilitate recharge besides, bringing at least 5 lakh hectares under irrigation from the present 1.58 lakh ha under tankfed ecosystem. Many of the irrigation tanks are not filling up to the design capacity due to accumulation of silt, and several streams have also not delivering the intended flow due to accumulation of sediments and encroachments. Rejuvenation of tanks through clearing the waterways in the catchment, nala stabilization by planting trees, de-siltation, strengthening of tank bund and weirs etc., should be made mandatory.

Eviction of encroachment of tanks and catchment area should be done on priority. Also, recharge shafts can be additional measures to enhance groundwater recharge. Recharge shaft can be created either through a) drilling borewell in the tank and desilted water should be provisioned to enter the casing from the height of 1 feet below the crest / weir; b) Filter bed system can be created using boulders, jelly and sand at 4-5 points in the tank to encourage percolation. The local Taluk or Gram Panchayaths should be entrusted with the task of periodic maintenance.

Expected Outcomes:

i. **Improved Water Security:** Increased groundwater recharge will bolster water security, ensuring reliable access to clean water for drinking, sanitation, and agricultural needs, thereby enhancing livelihoods and socio-economic well-being.

ii. **Ecological Restoration:** Restoring groundwater levels will contribute to the rejuvenation of ecosystems, preserving biodiversity, and enhancing ecosystem services vital for the health and resilience of rural communities.

iii. **Climate Resilience:** Building resilience to climate change impacts by conserving and effectively managing groundwater resources, thereby mitigating the adverse effects of droughts, floods, and other extreme weather events.

In rural areas, rainwater harvesting is taken up considering watersheds as a unit. Surface spreading techniques are common since space for such systems is available in plenty and the quantity of recharged water is also large. The following techniques may be adopted to save water going to waste through slopes, rivers, rivulets, and nalas.

6.2 Urban Areas

Population densities in the urban areas were increased due to congestion and over-crowding after an increased employment opportunity, especially in Bengaluru city. The increase in population has led to expansion in other supportive sectors such as real estate, hotels, hospitals, shops and shopping malls, etc. Increase in water demand due to elevated life style is causing great stress on the water supply. Higher water consuming places like swimming pools in hotels, resorts, apartments, bathing tubs in hotels and housing apartments, car wash at home and at water jet vehicle wash outlets, maintaining extensive gardens etc., are all contributing to water stress. Vertical growth in urban areas, particularly high-rise housing apartments coming up in any and all localities without a study on 'Carrying capacity' is leading to greater stress on all civic amenities including water supply. Hence, the city is facing water stress and can be addressed through following measures:

Rain water harvesting: Rain water collection is intended largely to meet domestic needs and augmenting groundwater urban areas. Reuse of harvested rainwater directly by collecting in the sump is a costlier affair considering the sump cost. However, its use for groundwater recharge and subsequent utilization indirectly by pumping with borewells has greater potential. The important strategies to harvest rainwater in urban areas include;

Roof top harvesting: 90-95 per cent of the intercepted rainfall on the terrace of the concrete / pucca house can be harvested with gutter. A small terrace of 30 ft x 40 ft can generate 1.1 lakh liter water in Bengaluru annually, which can meet the domestic need of the same for about 200 days in a year. Gutter harvested water can be either stored in the sump or utilized for borewell recharge directly with filter bed system or indirectly groundwater recharge using recharge pits. Although, regulations are formulated for rooftop rainwater harvesting, many people create the infrastructure for getting permission/ occupancy certificate, but divert harvested water to the drainage system thinking it may affect the building foundation. Hence, awareness to be increased and regulation should be imposed strictly.

Parks can be used as sink: Lot of area in the cities are earmarked for beautification with parks. These areas are the potential sinks for diverting runoff in the residential areas and using the same for groundwater augmentation. Although, many parks in Bengaluru city are implemented with recharge system, their maintenance and diversion of runoff is not being followed properly. The lower soil profile below 1 m depth should loosely be filled with jelly and sand at least in 25-30 per cent park area and storm water should be diverted to the recharger structure.

Recharge pits and filter bed in the drainage line: Recharge pits in the foot path and filter bed of 1 m depth below the storm drainage filled with boulders, jelly and sand need to be made mandatory in the layouts.

Modified paved ways: Paved way need to be designed with a mechanism to infiltrate rainwater by including shaft or filter bed system at subsurface layer and interlocking tiles in the surface.

Borewell recharge filter bed system: The runoff flowing on the road and vacant spaces can be diverted for borewells' in the community land for recharge.

Greening of the residential area: Trees penetrate the roots deeper in the soil and facilitate ease of flow of surface water into deeper depth. It should be made compulsory to plant trees in all the residential areas with a concept of at least 1 tree per house. Even the Government and community spaces may be made use for planting trees and greening the cities to bring back the glory of garden city, which is the solution for many problems related to health, ecosystem, weather, water etc.

Tank rejuvenation: Similar to the rural areas, tanks in the urban areas also needs rejuvenation by clearing vegetation, silt, strengthening bunds, weirs, planting trees around etc.

Promotion of usage of treated water for parks, flushing and gardening: The treated water can be supplied in alternative pipeline and can be used for flushing, gardening and maintenance of parks, which can reduce burden on groundwater pumping.

Filling tanks with treated water: Bangalore city alone generate around 14 TMC waste water, which can be properly treated at least to secondary stage and can be used for filling tanks.

Reduce, recycle and reuse: Many Apartments are operating Sewage Treatment Plants and a few of them have surplus treated water. This excess treated water could be used in industries, constructions, etc. A system is to be planned to use this treated water by the local bodies and industries.

Establishment of infiltration galleries: During rainy days, the rain water flows along its original path and slopes. In urban areas these water paths are obstructed, narrowed down or closed down for land reclamation. Due to such obstructions, it creates water pools at several locations in the city. Infiltration galleries could be constructed for harvesting this rain water at such identified locations.

Utilization of drinking water reverse osmosis filters rejected water: Owing to deteriorating quality in potable water, use of RO filters has become a common practice among citizens. There are countless RO filters in residences, and for the benefit of those who cannot afford such filters, public RO units have come up at a number of locations depending on the increasing demand. All these RO filters reject about 60 per cent of the input water. At present this 60 per cent water is going waste. The present situation is demanding that this water be also utilized wherever it is suitable. This reject water from RO filters could be collected and reused for cleaning vessels, gardening, washing, toilet flushing etc., in the residence while, public RO rejected water can be utilized for groundwater augmentation with filter bed system.

6.3 Peri-Urban areas

6.3.1 National and International Status

It is estimated that 17 % of India is overexploited due to excessive extraction of groundwater (GW) (58–65 % in 2020), reducing annual recharge from 447 billion cubic meters to 432 BCM. To prevent further depletion, long- term water management strategies are crucial, with artificial GW recharge methods such as the use of rainwater and treated wastewater for improving the GW table. Managed aquifer recharge (MAR) is a common technique for preserving GW by intentionally infiltrating water from the surface into GW and addressing freshwater scarcity. MAR is achieved through techniques such as percolation tanks, rainwater harvesting, soil aquifer treatment (SAT), and infiltration basins. SAT is a globally practiced wastewater recycling method under MAR that converts wastewater into high-quality recharge effluent by removing contaminants as wastewater infiltrates through soil layers. Successful GW recharge schemes based on SAT are summarised in Table 21. The reported GW recharge rate, soil type, and changes in GW quality are also tabulated in Table 21.

Table 21. Summary of SAT based groundwater recharge studies									
Sl. No	**Country**	**Climate**	**Soil type**	**Aquifer type**	**Wet/ Dry ratio**	**GW recharge rate (mm/d)**	**Impact on GW quality**	**Remarks**	**Reference**
1.	Israel	Arid-semiarid	Sandy loamy	Sandy	0.5	13.3	70% removal efficiency for TSS, COD, BOD, ammonia, nitrogen, phosphorous, and turbidity 100% removal of Coliform	Recharged water a reliable source of irrigation	Icekson-Tal *et al.*, 2003
2.	Egypt	Dry-deserted	Sandy	Unconfined	0.5	25-35	COD reduction by 95% BOD reduction by 70- 80%	Constant hydraulic rate increases recharge rate by 40%	El Arabi and Dawoud, 2012
3.	South Africa	Arid-semiarid	Sandy loamy	Sandy	-	26	Not reported	The numerical model MODFLOWfogroundwater flow and contaminant transport	Jovanovic *et al.*, 2017
4.	Australia	Semiarid/ desert	Sandy-clay	Alluvial	0.33	107	Improvement in recharged water quality in terms of EC, OC, TN, and CaCO3	Infiltration rates per basin varied from 0.1 to 1 m/day	Barry *et al.*, 2017
5.	Belgium	Maritime	Sandy	Dune (saline)	-	110	Improved water quality in terms of EC, TOC, hardness, chlorides, nitrates, phosphates,and heavy metals. Absence of total coliforms and pathogens.	A unified conceptual model was developed, making a framework for forecasting long- term groundwater sustainability	Van Houtte and Verbauwhede, 2012
6.	Phoenix (USA)	Dry-deserted	Sandy	One layer, alluvial	0.75	Not reported	Reduction in N by 65%, faecal coliform by 99%, TOC by 93%	Hydraulic loading rate 60-100 m/yr	Crites *et al.*, 2005; Bauwer, H., 1991

Source: Adapted from Verma et al. (2023)

As can be seen from Table 21, GW recharge rates vary significantly even in sandy and sandy loamy soils, from 13.2 mm/day to 110 mm/day, with varying degrees of GW quality improvement. GW recharge rates and changes in GW quality are influenced by many factors such as soil type, soil permeability, local hydrogeology, heterogenicity, topography, land use, and management practices including GW pumping, and climatic conditions. Very few studies investigated the effect of GW recharge through surface tanks in India on GW levels and quality. There is a lack of quantitative information in the literature on recharge rates in hard aquifers, effect on GW quality, and agricultural impact, especially for crystalline aquifers characterized by hard rock with fractured gneiss, granites, schists, and highly fractured weathered rocks of peninsular India.

6.3.2 Koramanagala-Challaghatta (K&C) Valley project in Kolar and Chikkaballapur Districts

All major towns and cities these days produce a lot of treated sewage which is expected to comply to the reigning discharge standards to water bodies including Ground Water Recharge. A city such as Bengaluru produces about 1500 million liters per day (MLD) of sewage, most of which is treated and can form yet another good source of water for irrigation when recharged to the ground and used judiciously during the appropriate season. In the case of Bengaluru, this above quantity of discharge is equivalent to providing five 50ha.mm crop irrigations in about a quarter of a million hectares and is therefore an important consideration for all future approaches to augment ground water. The case of the KC Valley project that treats and fills ~140 irrigation tanks in Kolar District of Karnataka is discussed here in detail about its potential impact on ground water security as well as various other related impacts. The K&C Valley recycling project is the result of the extensive efforts of two state government organizations, namely the Bangalore Water Supply and Sewerage Board (BWSSB) (Water utility board) and the Minor Irrigation Department (MI) to combat persistent drought in Kolar district, Karnataka.

Kolar district falls under a partial rain shadow zone, and due to the topography and physiography, there are no perennial sources (rivers) of water. The soil is distributed in the range of red loamy to red sandy and lateritic soil. Kolar predominantly has fractured multi-aquifer systems with gneiss/granite/schist rocks. Bedrock is peninsular gneiss of the archean age and the area can be classified as "hard rock terrain" with a semiarid climate. Kolar district had approximately four thousand unlined cascading man-made tanks or water reservoirs for capturing rainwater and were used for various purposes along with GW recharge. With little or no rains over the last 10 years, numerous tanks and borewells had gone dry and the GW table declined at alarming levels due to over- exploitation. The depth of irrigation borehole wells had reached ~250–300 m from the surface. Thus, to provide relief to the droughts, for effective management of the limited GW resources, and to ensure its long-term sustainability, in 2018, the Minor Irrigation and Groundwater Development Department, Government of Karnataka implemented K&C Valley project in Kolar district. This initiative aims to benefit 24,000 hectares of agricultural land, boosts water security, stimulates the rural economy, and enhances socio-economic conditions for ~ 2 million people.

The K&C Valley project is based on SAT method and under this project 440 MLD secondary and tertiary treated water (STTW) from Bengaluru's STPs is pumped into Lakshmisagara tank (LT) in Kolar district through a closed network of channels for 53 kilometres. The water from this tank flows by gravity in open channels for a distance of 2 km to the Narsapura tank (NT) and from this tank, it flows from several ridge points to the rest of the other tanks including Kolar tank (KT). This interconnected system allows for efficient water distribution. Excess water from any tank exceeding its capacity can naturally flow downstream through these open channels. Additionally, pumping stations can be activated in specific uphill sections to supplement gravity flow when needed. As of January 2024, over 147 surface tanks have been successfully refilled, and the secondphase of the project is underway to revive more than 100 additional tanks. The K&C Valley project is showed in a conceptual representation in Fig. 25.

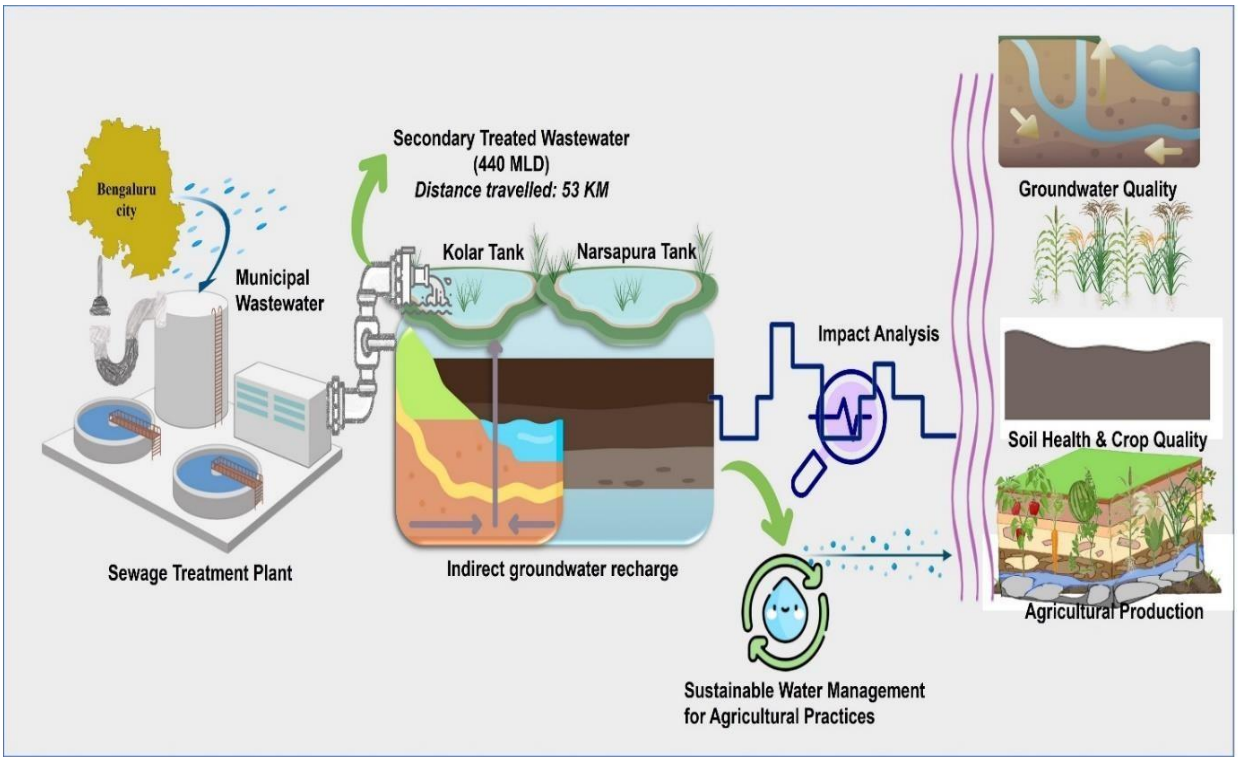


Fig. 25. Conceptual representation of K&C Valley project: A model for indirect groundwater recharge with treated wastewater, leading to increased agricultural production. (Source: Adapted from Manisha *et al*. 2024)

6.3.2.1 Objective and Intent

There are currently no large-scale field level studies documented in India that utilize the concept of managed aquifer recharge (MAR) to augment GW resources in water stressed areas such as the Maidan areas of Karnataka through filling up of existing local water bodies such as manmade tanks (called Kere in Kannada language) with additional water resources including STTW from major cities to rejuvenate existing surface tanks and facilitate indirect GW recharge in drought- prone, semi-arid rural districts. The Government of Karnataka (GoK) addressed this gap by taking up the first-ever such a task that is described in various studies based on K&C Valley project. These studies specifically aimed to:

- Quantify GW recharge rates in the aquifers of Peninsular India, characterized by fractured hard rock and weathered rock formations, using the AMBHAS_1D GW modelling approach.
- Changes in GW quality due to the improved recharge from this project are also quantified.
- Additionally, the impact on socio-economic status is quantified by analyzing the impact on agriculture, fisheries, milk production, and income. Impacts of the K&C Valley project on GW quality and socio-economic status was quantified by comparing areas receiving STTW (impacted area) to those not receiving it (non-impacted areas).

6.3.2.2 Methodology

6.3.2.2.1Water quality analysis

The study by Verma et al. (2023) analyzed the impacts of K&C Valley recycling on surface water quality by selecting two surface tanks namely i) NT and ii) KT as model tanks to represent 137 tanks. The tanks selected in the study were identified as having received STTW at the start of the recycling. The NT was 2 km away from the very first tank i.e., LT whereas the KT was 16 km away from the NT. A detailed water quality analysis as per the Hon'ble National Green Tribunal (NGT) standards (National Green Tribunal, 2019) which includes the specific eight parameters pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen (NH_4-N), total nitrogen (TN), phosphate phosphorus (PO_4-P), and faecal coliform was performed for the STTW and surface water tanks. All the water samples were tested in triplicates and average values are represented with standard deviation as avg.±std. dev. Other than the NGT parameters a detailed analysis for heavy metals and up to 10 emerging contaminants was also carried out for the STTW and surface water of the first tank (LT) receiving the treated water. ICPMS (Quadrupole ICPM- Thermo X series II) that can operate in both analog and pulse counting modes was used for heavy metal analysis, and LCMS (Dionex

Ultimate 3000 (Thermo), micro-LC equipped with C18, 150 × 4.6 mm, 5 µm reversed phase column for the analysis of emerging contaminants. The instrument sensitivity ranges between <10 ppb to <1 ppt (parts per thousand).

6.3.2.3 Measured outputs and outcome of the K&C Valley indirect GW Recharge Project

6.3.2.3.1 Impact on surface water quality

The water quality in the tanks was monitored frequently to assess the nature and quality of water that would be the source for GW recharge. Table 22 presents the water quality of the STTW coming from Bengaluru and surface tank water identified for the study. The test results were compared with the NGT standards. Firstly, it is important to establish that the water being used to augment and recharge GW meets an accepted set of standards and therefore in turn is likely to improve the high salt and mineral bearing GW extracted from deeper underground aquifers, typically characterized both by higher total dissolved solids content (TDS) on the one side and the potential for various forms of geogenic pollutants or harmful constituents such as fluoride, arsenic, etc.

Table 22: Water quality of secondary and tertiary treated wastewater and surface tanks

Parameters	Unit	Hon'ble NGT discharge standards (NGT, 2019)	Sampling Points			
			STTW from outlet of STP	Lakshmisagara tank (LT)	Narsapura tank (NT)	Kolar Town tank (KT)
pH	-	6.5-9.0	7.6	7.6	7.8	7.7
BOD5	mg/L	10	9 ± 1.0	6.2 ± 1.5	7.2 ± 2.0	6.4 ±1.4
COD	mg/L	50	48 ± 4.0	42 ± 8.0	50 + 4.0	42 ± 2.0
TSS	mg/L	10	8 ± 2.2	6.8 ± 2.0	7.2 ± 2.8	6 ± 1.5
NH4 -N	mg/L	5	4.6 ± 0.8	3.7 ± 0.3	2.8 ± 0.8	2.4 ± 0.2
TN	mg/L	10	7.8 ± 2.5	5.3 ± 1.4	6.9 ± 1.0	5.2 ± 0.8
PO4- P	mg/L	1.0	0.8 ± 0.3	0.3 ± 0.1	0.6 ± 0.2	0.4 ± 0.1
Faecal Coliform	MPN/ 100 mL	< 230 allowable	280 ± 20	220 ± 16	240 ±30	230 ± 25
Source: Adapted from Verma et al. (2023)						

As can be seen from Table 22 the STTW coming meets all the norms set by the NGT (2019) for the treated wastewater to be disposed into surface water bodies or for land disposal /applications with minor exception with regards to the faecal coliform (FC) levels, which marginally exceeded the above the NGT standards.

However, when the water augmented into open water bodies such as the “Keres” of Karnataka, the standing water here increases the extent of GW recharge. Also, it is well known that during GW recharged through increased infiltration as a result of higher water maintained in these Keres, such microbial population (measured as FC), will rapidly reduce as the recharged water flows through multiple tanks on the one side and more so during infiltration through the long soil column to reach the GW. As per NGT norms pH should range from 6.5 to 9 as most aquatic organisms prefer this as the acidic nature of water (pH < 7) enhances the proliferation of algae.

Water used to recharge GW, in this case STTW often contains a few undecomposed organic substances that tend to undergo slower biological decomposition in the waterbody (BOD) and also interfere with the chemical oxidation of substances (represented by the COD) values of the water used for filling up the tanks/lakes and facilitate indirect GW recharge and therefore augmentation of the local GW resources for agricultural use. The BOD and COD predominantly represent the rapidly decomposable and more recalcitrant organic loads in the treated water and that should not exceed 10 and 50 mg/L, respectively.

The average COD/BOD are within permissible limits and the quality for this parameter falls around NGT limits. An even higher level of self-purification by algal photosynthesis and natural purification may be expected due to STTW having undergone many days of open flow exposed to air and subject to aerobic degradation. COD/BOD in Lakshmisagara and Kolar tank water bodies, remained unchanged although within acceptable limits leading to a possible conclusion that residence time in these lakes is less than expected or additional inputs have occurred to the openly flowing channels that transfer water from one lake to another.

The discharge limits for total nitrogen TN are <10 mg/L and PO_4-P is <1 mg/L which is meant to restrict autotrophic algal growth; sometimes leading to algal blooms. High values of soluble P levels in excess can sometimes lead to high algal populations that not only overproduce photosynthetic oxygen at mid-day leading to supersaturation of dissolved oxygen (DO) at mid- day superseding the general solubility limit of ~8mg/L to reach up to 20mg/L, a condition most suitable for achieving a higher level of water purification. Also, this can also lead to hypoxia (DO <3mg/L) at pre-dawn hours from excessive algal respiration leading to fish death. Yet, algal growth performs an important function of becoming a sink for nutrients and thereby making the water a lot more suitable for recharge.

On the other hand, since this water is reused for crop cultivation, stripping the water free of plant nutrients becomes questionable from the perspective of long-term sustainability, but is not addressed here. The total suspended (TSS) values were lower than the discharge limit of 10 mg/L. A low TSS in the receiving waterbody indicates completeness of the treatment system on the one hand and also for potential light penetration into the waterbody for the essential photosynthetic activity of the native algae and resulting higher levels of "water purification". Table 22 also presents the water quality of the first tank (LT) receiving the STTW. It may be observed that the water quality in the LT has slightly improved relative to STTW. The marginal improvement in TSS levels between the STTW and its receipt at LT is suggestive of a small role of the nearly 22-h residence time for treated water to travel 53 km through pipes and its contribution to improved water quality.

Yet, as shown in Table 22, it was observed that the water quality of the NT has marginally deteriorated, most likely due to human activities such as fertilizer runoffs from agricultural land and fugitive discharges of domestic sewage by houses on the tank shore (discussed above).

Figure 26. STTW being transported to Lakshmisagara Lake ~60km from the City showing discharge point and the lake while the inset shows the water quality (c.2022)

When the overflow from the NT travels to the KT by covering a distance of 16 km, while also spending a large residence time in open tanks, it can be observed that the water quality of the KT has improved relative to the NT. It is indicated that in addition to the long periods of residence time spent by STTW during its flow through a cascade of surface water tanks as well as through the connecting water channels, this treated water is subject to a long residence time within the tanks that it passes through which leads to natural treatment. The water quality of KT when compared with that of the STTW, it was observed that there was almost 25 to 50% improvement for all the parameters studied.

Such an observation where the treated water encounters multiple treatment opportunities but still show small changes in quality indicates that the treatment systems are functioning to their near ideal levels and leave behind very little treatable substances. The results presented in such studies are also supported by other reports in literature Amin et al. (2022); CGWB, (2020); Sharma and Kennedy (2017) where the water quality of treated water improved due to the self-purification mechanisms when subject to a flowing state and also through dilution as an impact of GW recharge.

Eslamian et al. (2018) reported the removal of dissolved organic compounds during GW recharge through SAT system as an impact of microbial biodegradation and absorption. El Arabi and Dawoud (2012) reported the removal of suspended solids, biodegradable materials, bacteria, and other microbes from treated wastewater through the vadose zone as it acts as a natural filter in SAT systems. The presence of heavy metals in mixed sewage (domestic, commercial and industrial wastewaters) is often a concern in various regions cities of the world largely because there is inadequate separation of the domestic and industrial wastewater sources.

Table 23 presents the water quality in terms of heavy metals. As can be seen from Table 23, the STTW and LT's water surpass the even the stricter standards meant for drinking water (BIS 10500, 2012) with respect to heavy metals content. This suggests three possibilities: firstly, there is very low contamination of urban runoffs, and secondly, the anaerobic stages experienced by wastewaters generally cause heavy metals to precipitate and separate out, even if they are present and finally, there is little industrial wastewater contribution. From this above perspective, the wastewaters are treated and rendered safe for discharge to surface water bodies.

El Arabi and Dawoud, 2012 reported the removal of heavy metals and other inorganic contaminants from wastewater during GW recharge as an impact of geochemical reactions such as mineral precipitation, dissolution, adsorption, and redox reactions. Detailed studies on the presence of emerging contaminants in STTW and surface water in the study area are underway by many groups now and this is spread to many other watersheds and river basins. Results presented in Table 23 clearly indicate absence of heavy metals in STTW and subsequently in the first surface tank (LT) receiving STTW. This is because the STTW undergoes different levels of natural treatment as it experiences a long residence time (>14 days) in tanks.

Table 23: Analysis of heavy metal in secondary and tertiary treated wastewater and Lakshmisagara tank

Sl.No.	**Metals, metalloids, and heavy metals**	**IS 10500 (mg/L)** (BIS 10500, 2012)	**STTW (mg/L)**	**Lakshmisagara tank (LT) (mg/L)**
1	Iron (Fe)	3	0.36 ± 0.02	0.26 ± 0.001
2	Manganese (Mn)	2	0.02 ± 0	BDL ± 0
3	Zinc (Zn)	5	BDL ± 0	BDL ± 0
4	Cadmium (Cd)	2	BDL ± 0	BDL ± 0
5	Lead (Pb)	0.1	BDL ± 0	BDL ± 0
6	Arsenic (As)	0.2	0.001 ± 0	0.001 ± 0
7	Chromium (Cr^{+5})	0.1	<0.1 ± 0	<0.1 ± 0
8	Nickel (Ni)	3	0.028 ± 0	0 ± 0
9	Copper (Cu)	3	0.00 ± 0	0 ± 0
10	Aluminium (Al)	0.2	BDL ± 0	0 ± 0
11	Barium (Ba)	0.7	0.045 ± 0	0.01 ± 0
12	Boron (B)	0.5	0.021 ± 0	0.001 ± 0
13	Selenium (Se)	0.01	BDL ± 0	BDL ± 0
14	Silver (Ag)	0.1	BDL ± 0	BDL ± 0
15	Mercury (Hg)	0.001	BDL ± 0	BDL ± 0
16	Molybdenum (Mo)	0.07	0.001 ± 0	BDL ± 0

Source: Adapted from Verma et al. (2023):
***Note:** BDL is below the detection limit of $1x10^{-6}$ mg/L*

Emerging Contaminants of environmental concerns (EC) have also posed some challenges and it is critical to establish their possible presence in water sources used for augmented ground water recharge using various techniques and, in this case, using surface tanks and water bodies filled with STTW. Some of the early results for the K&C Valley indirect GW recharge project is presented in Table 24 which firstly indicate the absence emerging contaminants in the augmentation water source, namely STTW and subsequently in the first surface tank (LT) receiving STTW.

Table 24: Analysis of emerging contaminants in secondary and tertiary treated wastewater and Lakshmisagara tank

Test Parameter	Type	STTW (mg/L)	Lakshmisagara tank (LT), (mg/L)
Fluoroquinolones	Antibiotics	BDL	BDL
Ciprofloxacin		BDL	BDL
Azithromycin		BDL	BDL
Tetracycline		BDL	BDL
Norfloxacin		BDL	BDL
Acetaminophen	Pain killers	BDL	BDL
Ibuprofen		BDL	BDL
Diclofenac		BDL	BDL
Sulfamethoxazole		BDL	BDL
Cetirizine		BDL	BDL
Xylenol	Pharma-ceutical and Personal Care Products	BDL	BDL
Triclosan		BDL	BDL

Source: Adapted from Verma et al. (2023):

Note: *BDL is below the detection limit of $1x10^{-6}$ mg/L*

6.3.2.2.2 Impact on groundwater levels

The static ground water levels for the two impacted towns, namely Narsapura and Kolar from various sources have been observed along with rainfall data to segregate the influence of rainfall from the increased indirect GW recharge effects in the vicinity of these two towns and their large water bodies (Lakes). It can be observed from Fig. 27 that the GW levels before recycling STTW (March 2018) were around 18 mbgl (meters below ground level) which improved to 7.5 mbgl for NB and for KB it was 33 mbgl in Aug 2018 which rose to 9 mbgl in September 2018. A clear rapid recharge and positive impact on GW levels can be observed as the levels increased by 58% and 73%, respectively, in the impacted boreholes studied.

Figure 27: Singehalli (top) and Kolarammani (mid and bottom) Lakes full and overflowing

Reports in Literature indicate a linear relationship between GW recharge and rainfall. However, it may be observed from the historical precipitation data (KSNDMC, 2020) presented in (Fig. 27) that 2018–2019 was a rain deficit period and yet the GW levels increased significantly which in turn confirms direct impact of indirectly recycled water (STTW) filled in the existing surface tanks towards improving GW availability. This approach to MAR has resulted mainly because surface water from rejuvenated tanks has infiltrated through soil layers and percolated vertically downward deep in the soil through the unsaturated zone towards the ground water table.

The movement of water also depends on soil permeability or hydraulic conductivity. Pore space in the soil serves as the storage compartment for water. It is reported that the Karnataka state is underlain by peninsular gneisses, and granites. The surface tanks studied are also located at such highly fractured and weathered rock and have a sufficient thickness of permeable vadose zone which helps for speedy GW recharge (Fig. 28 (a) presents maps showing low water levels in Kolar district before commencement of the recycling and Fig. 28 (b) presents increased water levels immediately after commencement of the K&C Valley indirect GW recharge project.

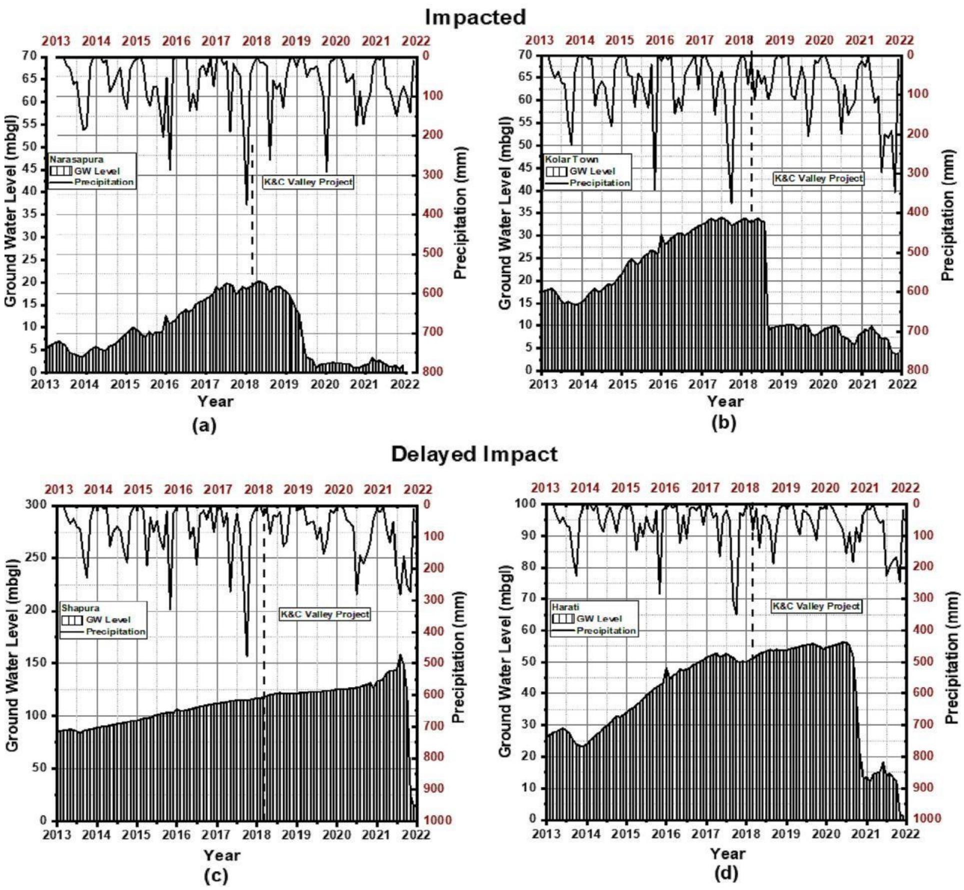


Fig. 28. Change in groundwater levels between before and after recycling of STTW for impacted boreholes (a and b) and non-impacted boreholes (c and d) Source: Adapted from Verma *et al*.

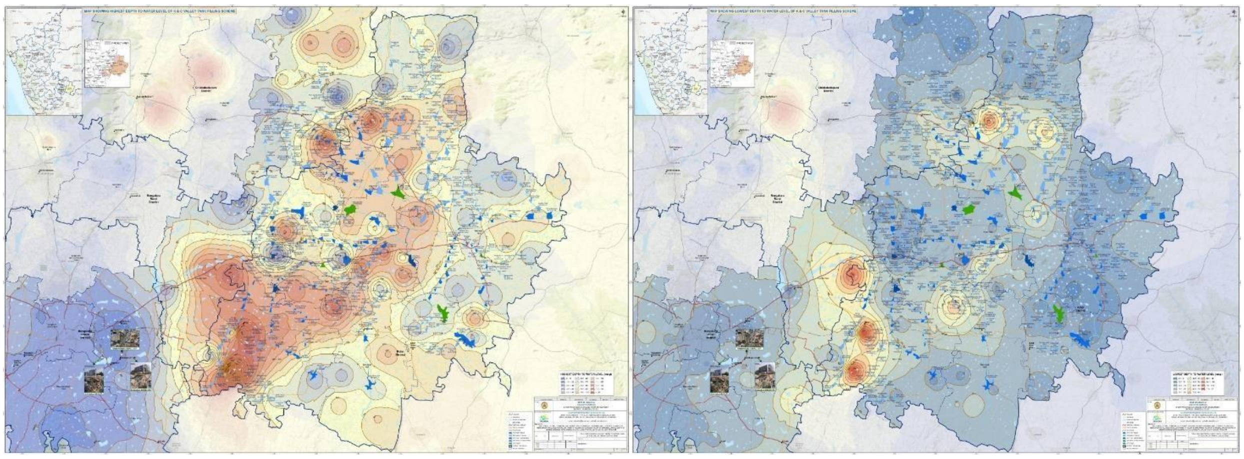


Fig. 29 (a) & (b): Map presenting water levels in Kolar district before and after the K&C valley project implementation. Source: Adapted from Varma et al. (2023)

As discussed in the earlier section, the soil type in Kolar district ranges from red loamy soil to red sandy lateritic soil which is also characterized by low water holding capacity and increased hydraulic conductivity. This soil has an infiltration rate of >10 in. per hour (CGWB, 2020) thus, such high infiltration rates can explain an immediate response that can be seen in the impacted boreholes which were in the nearby vicinity of the rejuvenated surface tanks. Therefore, it may be concluded that indirect artificial recharge of the GW as in the above case has a significant role in the development and management of drought prone semi-arid areas as it boosts the GW level and also provides a greater water security. Nandan et al. (2021) also reported improved GW levels through indirect GW recharge methods.

Water levels of two boreholes namely Shapur (SB) and Harti (HB) with delayed impact presented in Fig. 28 (c) and (d), where it can be observed that in both the boreholes there is no immediate improvement in the GW levels after recycling. It is thus concluded that treated water has not reached to these areas which are far away (at 10 to 14 km from the KT) until 2020. Whereas it can also be observed that the water levels have increased in both SB and HB after 2020. At SB, the water level increased by 80% from October 2021 to November 2021 whereas at HB it increased by 48% from October 2020 to November 2020. This is attributed to the fact that these two boreholes have shown a delayed impact with respect to 2018 post recycling and may be attributed to lateral movement of percolated underground water over a long period. In order to confirm these findings GW modelling was carried out.

Figure 30. S Agrahara, Chowdenhalli and Ammerhalli Lakes brimming with water (c.2022)

To model the source and impacts of rainfall and other influences on ground water recharge and extent of extraction, a physically lumped unconfined model AMBHAS_1D was used to model the GW level fluctuation in two steps considering the GW recharge, discharge, and pumping. In the first step model calibration was carried out for a period of 5 years from 2013 to 2017 during which the GW levels were representative of long-term GW balance in the non-impacted region. The annual water budget for each location is tabulated and provided in Table 25. Daily recharge rate before 2018 is in the range of 0.1 to 0.48 mm for all four boreholes studied. The daily recharge rates of NB and KB reflect the impact of recycling stating from year 2018 as the daily recharge rate is almost 2–10 times higher for 2018 and 2019. The sharp rise in the observed GW levels at impacted locations in range of 20m to >100m within 4–6 months duration supports the higher recharge estimates because of contribution of rejuvenated tanks. Since 2019, these two borehole sites exhibit low seasonal GW level variability (around 5 m) as these sites are in the vicinity of the tanks which act as constant head boundary condition. The other two boreholes (SB and HB), experience 5–10 times rise in daily recharge rate in 2020 and 2021, respectively confirming a delayed impact with respect to 2018. Net pumping to recharge ratio at all locations before the recycling was >1 signifying unsustainable GW pumping in the region. The daily recharge rate improved significantly post 2018 because of the extra recharge from the tanks which is much higher than the direct recharge from rainfall. The increased recharge compensates for pumping and the ratio of net pumping to total recharge drop below 1. The GW recharge estimates based on GW modelling indicate that this large-scale recycling of STTW has enhanced the GW recharge in the region resulting in rapid recovery of GW storage.

6.3.2.3.3 Impact on groundwater quality

GW quality as presented in Fig 31 to 36. Fig. 31-36 illustrate that, the GW quality in the impacted boreholes has improved across all parameters studied when comparing the data from before and after the recycling period. Observations indicate that in the case of NB, there was no significant change in pH value. However, a notable improvement in water quality parameters was observed, characterized by the reduction of 55% hardness, 23% TDS, 12% in EC, 46% in Ca^{+}, 62% Na^{+}, 22% Cl^{-}, and 84% NO3. Similarly, for KB, no change in pH value was observed, but there was a significant improvement in water quality parameters, characterized by a reduction of 70% hardness, 76% TDS, 85% EC, 88% Ca^{+}, 88% Na^{+}, 96% Cl^{-}, and 93% NO_3. Fig. 31 and 28 presents reduction in Mg, K, SO_4, and F when compared for before and after recycling period. Clearly the hard waters of deep aquifers (before recycling) with a lot more dissolved salts have transformed into a more agriculture friendly water

Table 25. Annual water budget and contribution of groundwater recharge from rain and tanks

Bore holes	Particulars	2013	2014	2015	2016	2017	2018	2019	2020	2021
Narsapura	Net Pumping (mm)	150	150	150	150	150	150	150	150	150
	Total Recharge (mm)	90	67	139	69	120	352	966	181	284
	Recharge from Rain (mm)	90	67	139	69	120	89	80	109	109
	Recharge from Lake (mm)	0	0	0	0	0	263	886	73	175
	Daily Recharge Rate (mm/day)	0.25	0.18	0.38	0.19	0.33	0.97	2.65	0.50	0.78
	Net Pumping to Total Recharge ratio	1.6	2.2	1.0	2.1	1.2	0.4	0.1	0.8	0.5
Kolar	Total Recharge (mm)	67	68	88	56	108	1101	358	293	429
	Recharge from Rain (mm)	67	68	88	56	108	53	71	87	150
	Recharge from Lake (mm)	0	0	0	0	0	1048	287	206	279
	Daily Recharge Rate (mm/day)	0.18	0.19	0.24	0.15	0.30	3.02	0.98	0.80	1.18
	Net Pumping to Total Recharge ratio	2.2	2.2	1.7	2.6	1.3	0.1	0.4	0.5	0.3
Shapur	Total Recharge (mm)	89	90	123	66	173	56	81	138	1647
	Recharge from Rain (mm)	89	90	123	66	173	56	81	138	184
	Recharge from Lake (mm)	0	0	0	0	0	0	0	0	1463
	Daily Recharge Rate (mm/day)	0.24	0.25	0.34	0.18	0.48	0.15	0.22	0.38	4.51
	Net Pumping to Total Recharge ratio	1.6	1.6	1.2	2.2	0.8	2.6	1.8	1.0	0.0
Harati	Total Recharge (mm)	71	37	87	39	106	65	47	1217	640
	Recharge from Rain (mm)	71	37	87	39	106	64	45	84	119
	Recharge from Lake (mm)	0	0	0	0	0	1	2	1134	520
	Daily Recharge Rate (mm/day)	0.19	0.10	0.24	0.11	0.29	0.18	0.13	3.33	1.75
	Net Pumping to Total Recharge ratio	2.1	4.0	1.7	3.8	1.4	2.3	3.1	0.1	0.2

Source: Adapted from Verma et al. (2023)

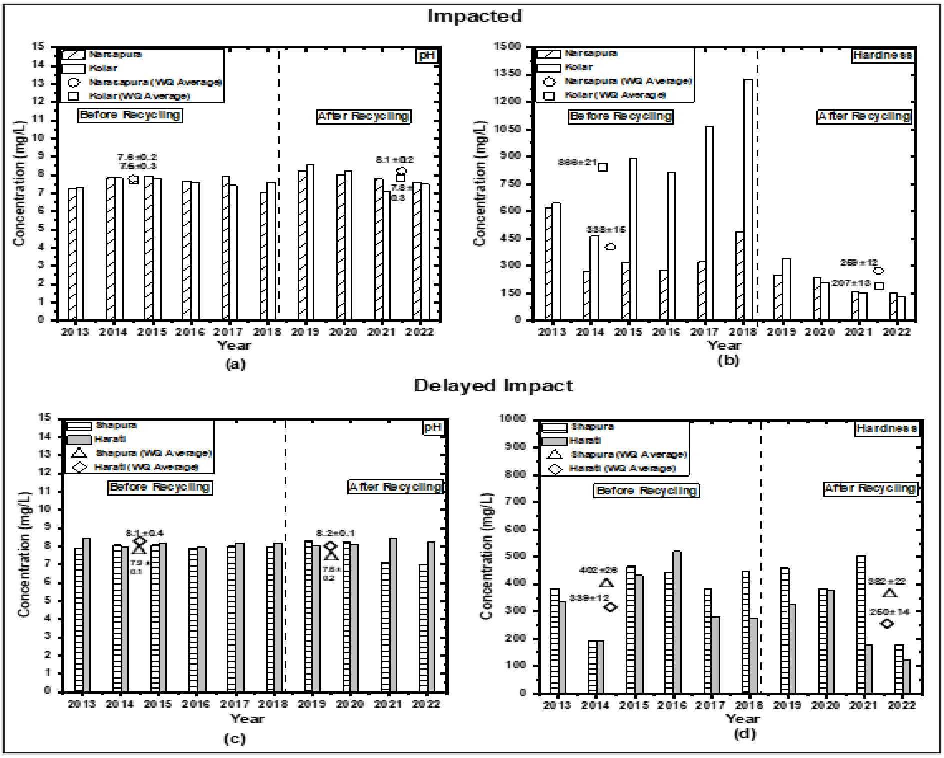


Fig. 31: Impact on groundwater quality (physical parameters)

Source: Adapted from Verma *et al*. (2023)

Note: Before recycling period is 2013-2017 whereas after recycling period is 2018- 2022

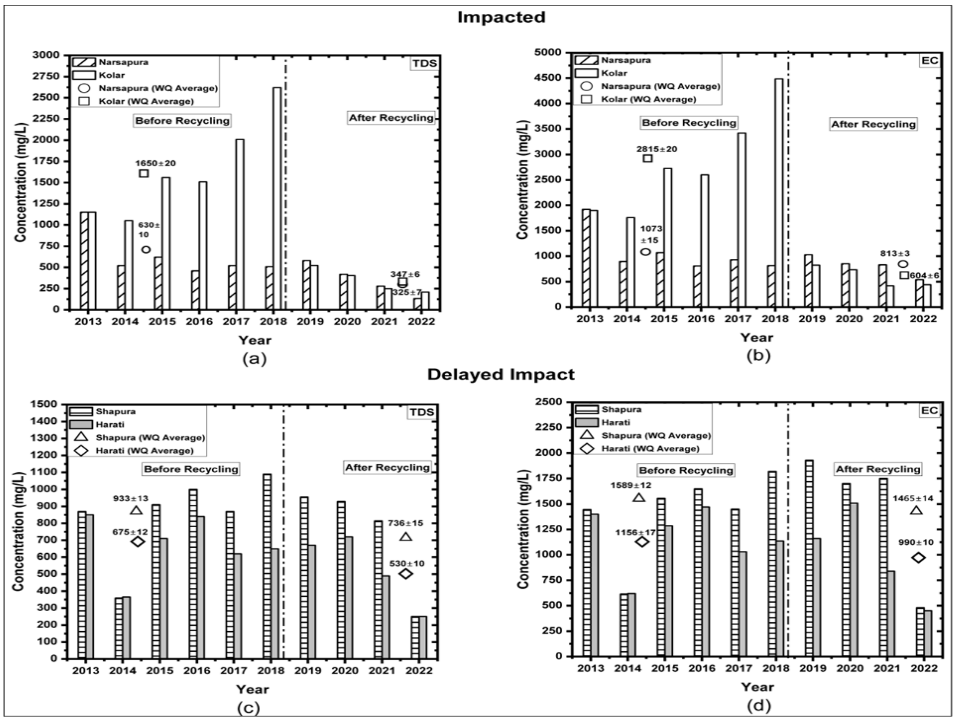


Fig. 32 Impact on groundwater quality (physical parameters)

Source: Adapted from Verma *et al*. (2023)

Note: Before recycling period is 2013-2017 whereas after recycling period is 2018- 2022

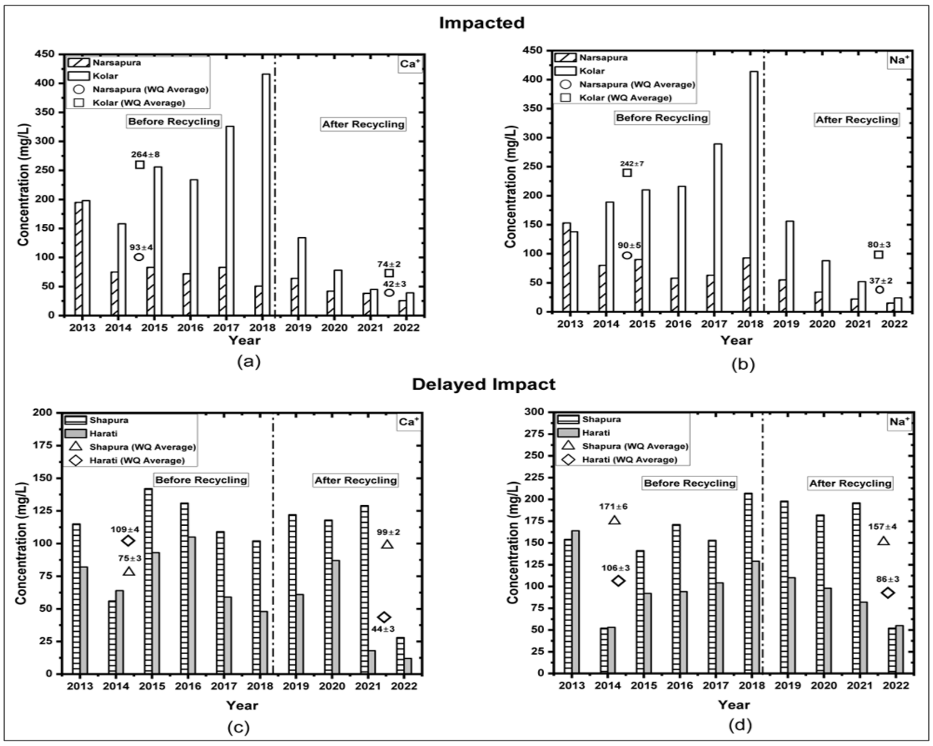


Fig. 33 Impact on groundwater quality (Cations)

Source: Adapted from Verma *et al.* (2023)

Note: Before recycling period is 2013-2017 whereas after recycling period is 2018- 2022

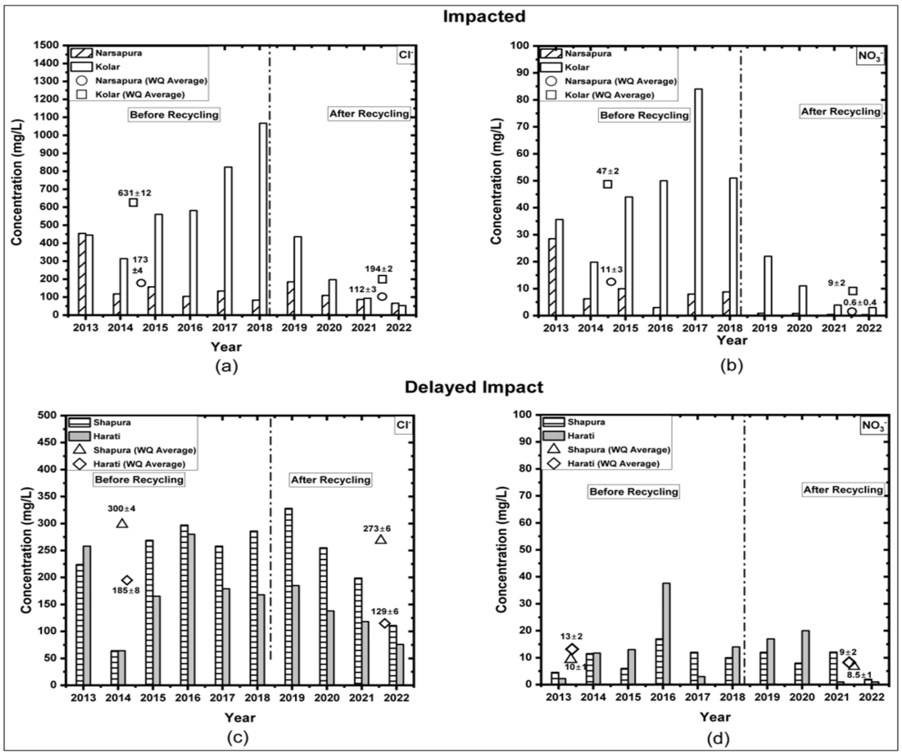


Fig. 34 Impact on groundwater quality (Anions)

Source: Adapted from Verma et al. (2023)

Note: Before recycling period is 2013-2017 whereas after recycling period is 2018- 2022

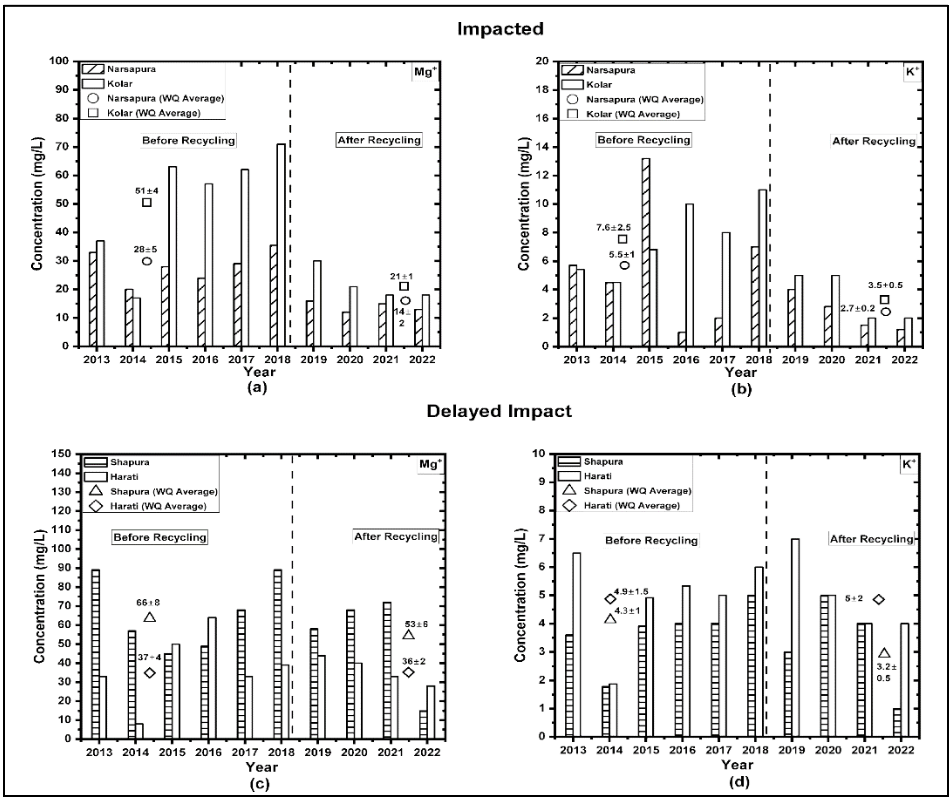


Fig. 35 Impact on groundwater quality (Cations)

Source: Adapted from Verma *et al*. (2023)

Note: Before recycling period is 2013-2017 whereas after recycling period is 2018- 2022

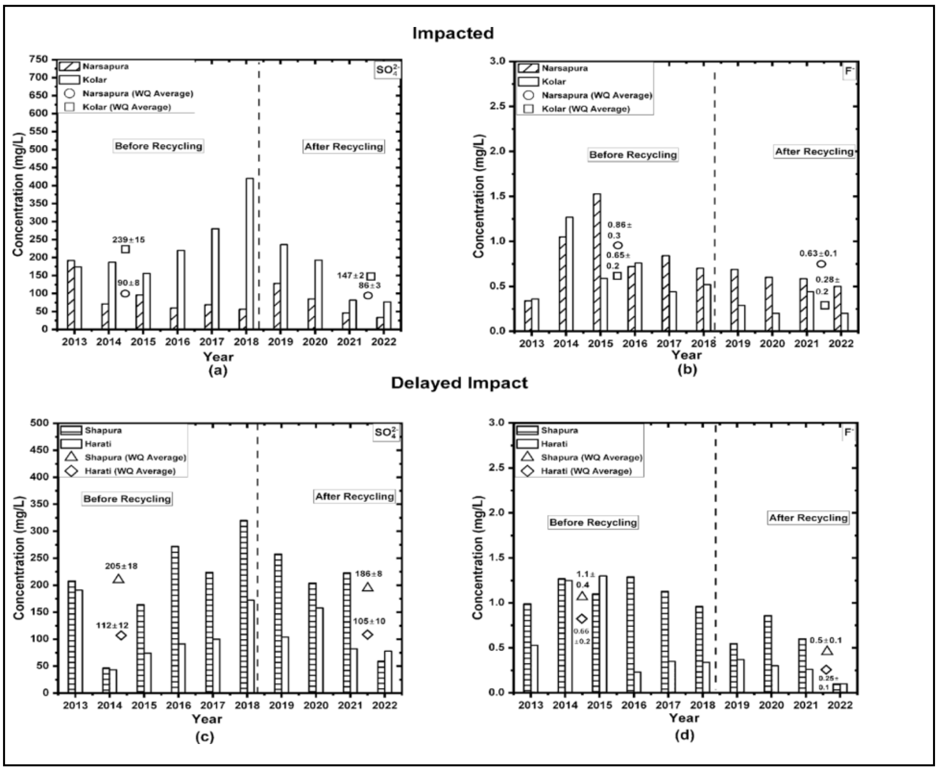


Fig. 36 Impact on groundwater quality (Anions)

Source: Adapted from Verma *et al*. (2023)

Note: Before recycling period is 2013-2017 whereas after recycling period is 2018- 2022

Dilution effect on the water quality parameters resulting from the recharge of recycled water into the deep aquifer. As discussed earlier, the STTW held in tanks infiltrates into the subsurface and deeper aquifers rapidly, and percolates vertically through the unsaturated zone towards the water table. This infiltration process through the soil is slow, which results in the purification of any residual chemicals that may have escaped the wastewater treatment process. Moreover, this filtration process occurring over months starves the potential pathogens, ensuring their rapid die-off.

The removal mechanisms involved in the recycling process include physical filtration, biodegradation, adsorption, chemical precipitation, ion exchange, and dilution. Microbial action typically converts organic contaminants into simpler compounds, while filtration through various soil layers removes suspended matter and pathogens confirming the safety of the recharged GW for reuse. The delayed impact of recycled water on GW recharge in SB and HB resulted in no significant impact on water quality before 2019, but a significant improvement was observed in 2020–2021 due to dilution. The results of this study are reported to be consistent with the other findings in literature such as that of Zhang et al. (2018), who reported improved groundwater quality with a standard of class 1 WQ Index in a laboratory experimental setup using reclaimed water for GW recharge. The removal of suspended solids, biodegradable substances, nitrogen, phosphorus, and heavy metals due to the vadose zone acting as a natural filter. Bekele et al. (2011) reported 66% removal efficiency for fluoride, 62% for iron, 51% for total organic carbon (TOC), and 30% for phosphorus through a MAR system when treated wastewater was used for GW recharge.

The large-scale recycling of secondary treated wastewater effectively rejuvenated existing surface tanks and recharged GW in neighbouring villages of Bangalore city. The GW recharge rates in hard rock aquifers with fractured gneiss, granites, schists, and highly fractured weathered rocks, and the results demonstrated recharge rates up to 3 mm/day, which is 10 times the otherwise recharge rates. The positive impacts of this recycling effort on GW levels and quality are also observed. Due to additional recharge coming from the recycling STTW, the GW levels increased by 58 to 73%. Also, due to infiltration through the tank soil and strata, the GW hardness improved by 50–70%.

6.3.2.4 Impact of indirect groundwater recharge using STTW on socio-economic status

This section presents the overall impacts of the K&C valley project in different socio-economic sectors studied by Manisha et al. (2023). To quantify the impact of the K&C Valley project on socio-economic status, a two-step data collection process was followed i.e., (i) approaching farmers of impacted and non-impacted areas

Figure 37: Lotus, Water lily and aquatic birds indicate acceptable water quality in recharged lakes

(covered 12 villages in the Kolar district comprising 6 villages from impacted areas and 6 from non-impacted areas.) through a structured household survey and (ii) reaching out to different government organizations such as the department of agricultural & horticulture, department of veterinary sciences, Kolar-district co-operative milk producer's societies union ltd., Department of Fishery Sciences and District Surveillance Office, Kolar. Consecutive data for a 6-year period, between 2016-2021, were collected from these organizations. Data between 2016-2018 were categorized as 'pre-recycling' and that between 2019-2021 as 'post-recycling' data.

6.3.2.4.1 Impact on land use and land coverage (LULC)

Increased water availability in the form of recharged GW allows for higher intensities and greater area of land use in typical drought prone or arid /semi-arid areas. The Fig. 38 indicates the topographical view of land use and land coverage in the Kolar district. The analysis shows almost 6 times improvement in the water spread area of water bodies from 9.01km^2 in 2017 to 61km^2 in 2022. It was observed that area under trees increased from 124 km^2 to 177 km^2 and cropping land increased from 2477km^2 to 2584 km^2 during the same period. A major change was observed in the area under flooded vegetation indicating a 67 times improvement from 0.07 km^2 in 2017 to 4.8 km^2 in 2022. The data for fallow land and rangeland indicated a decrease of 41% and 32% during the same period. Fig. 38 establishes the contribution of filled water bodies and minor tanks in the improvement of areas of agricultural or productive land.

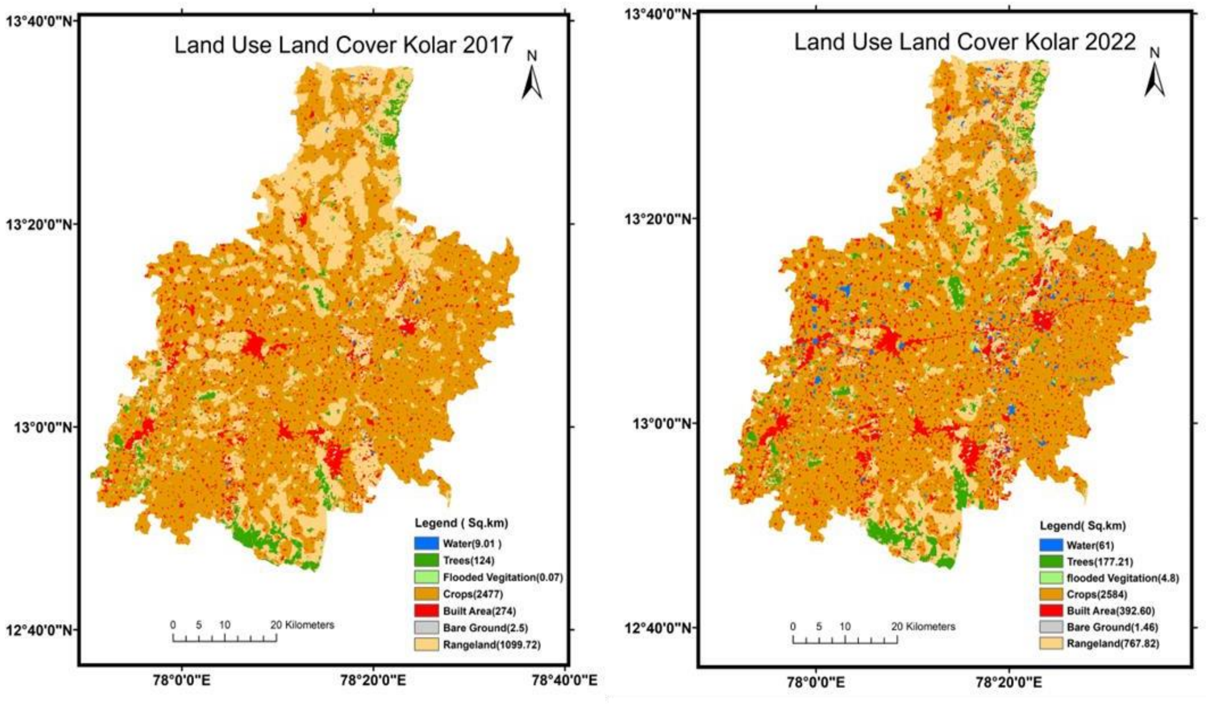


Fig. 38 Change in land use and land cover between 2017 and 2022 in the Kolar district

Source: Adapted from Manisha *et al.*, (2023)

6.3.2.4.2 Impact on agricultural land

Droughts, erratic rainfall, and declining GW levels are forcing farmers to abandon agriculture. Fig. 39 (a) presents that the area under cultivation of vegetables for the year 2021 was relatively higher in impacted areas (57 ha) compared to non-impacted areas (29 ha). It was observed that the area under plantation and pulses was also high in impacted areas compared to non-impacted areas, but a significant difference was not found. Fig. 39 (b) indicates a change in agricultural land between pre and post recycling period. It was observed that in Kolar district the average area under cultivation of vegetables increased from ~20,000 hectares (ha) to ~33,000 ha from the pre- to post- recycling period which indicates an increase of 65%. During the same period average area under cultivation of flowers, fruits, and plantation and spices & aromatic (SP & Aroma) crops increased by 68%, 50%, 42%, and 33% respectively. A minimum increase of 10%, 9%, and 7% was observed for areas under cultivation of pulses, cereals, and oil seeds, respectively. It is obvious that due to the assured availability of water the cropping pattern was changed from low water requiring crops (e.g., pulses, oil seed) to high water requiring and water-intensive /water sensitive crops (vegetables, flowers, etc.).

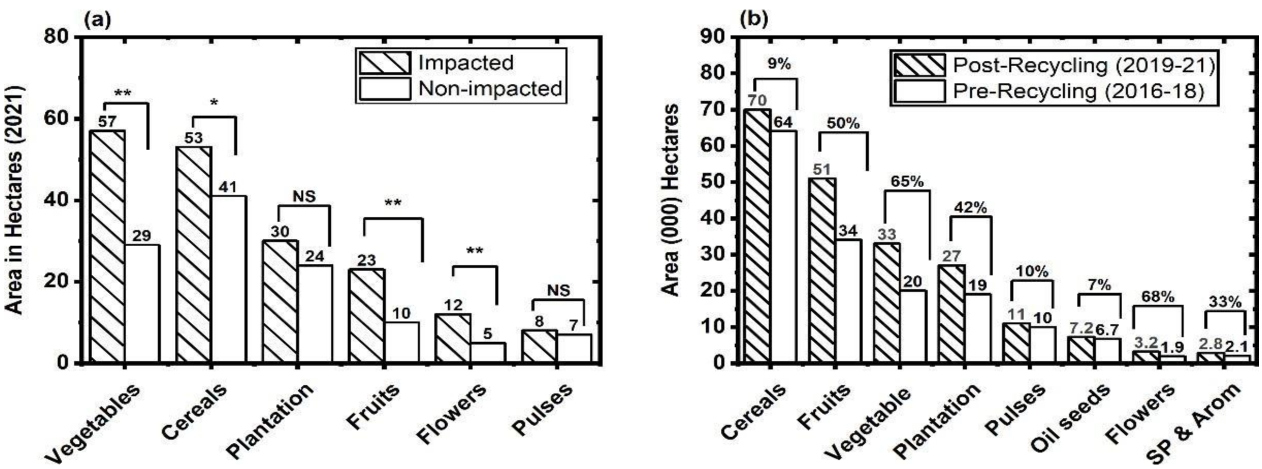


Fig. 39. Change in agricultural land (a) Comparison between impacted and non-impacted areas (b) Comparison between pre- to post-recycling period in Kolar district.

Source: Adapted from Manisha *et al*. (2023)
[Fig. (a) based on household survey (b) Department of Agriculture & Horticulture, Kolar]

*Note: NS- not significant for $p > 0.05$, *$p < 0.05$, **$p < 0.01$. Plantation- cashew, silver oak, eucalyptus, coconut, areca nut, tamarind, and mulberry; Vegetables- tomato, potato, beans, cabbage, green chili, capsicum, carrot, etc.; Fruits- mango, banana, sapota, guava, grapes, watermelon, pomegranates, papaya, etc.; Cereals- ragi, paddy, maize, jowar, minor millets, etc.; Flower- marigold, chrysanthemum, jasmine, rose, crossandra etc.; Pulses-red gram, field bean, toor, cowpea, horse gram, green gram, etc. Oil seed – ground nut, sunflower.*

6.3.2.4.1 Impact on agricultural (crop) production

Fig. 40 (a) presents that the production of different plantation crops was relatively higher for the year 2021 in impacted areas (23 metric tons (MT)/ha) compared to non-impacted areas (15MT/ha). Fig. 40 (b) indicates improvement in crop production from the pre-to-post recycling period where the average production of flowers, vegetables, plantation, fruits, spices, and aromatic plants and pulses increased by 80%, 70%, 36%, 35%, 28%, and 12%, respectively. While during the same period production of cereals and oil seeds increased by 11% and 7% only. It is visible that agricultural production has increased significantly as a result of the assured availability of irrigation water throughout the year, due to revival of the GW table. The greater availability of GW in the impacted area as well as its availability at much lower depths due to vastly improved water tables not only made it possible to achieve increased the cropping intensity but also changed some of the land use pattern wherein fallow lands and that planted with eucalyptus were brought back under the plough. This was a clear case of the reversal of land alienation, improved agricultural outputs as well as greater water security.

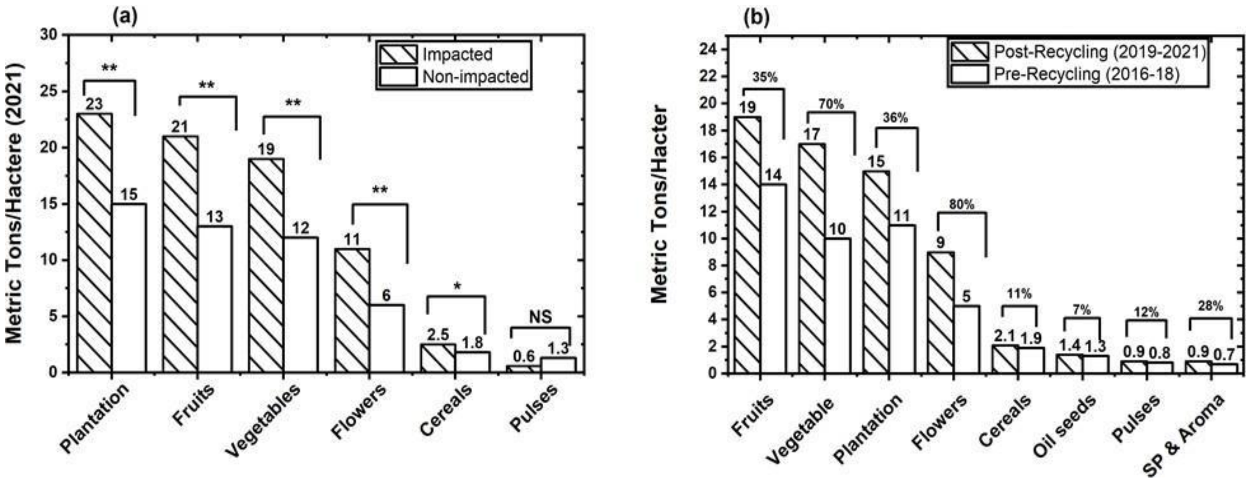


Fig. 40: Change in agricultural production; (a) Comparison between impacted and non- impacted areas (b) Comparison between pre- to post-recycling period in Kolar district.

Source: Adapted from Manisha et al. (2023)

[Fig. (a) based on household survey (b) Department of Agriculture & Horticulture, Kolar.

*Note: NS- not significant for p > 0.05, *p < 0.05, **p < 0.01. Plantation- cashew, silver oak, eucalyptus, coconut, areca nut, tamarind, and mulberry; Vegetables- tomato, potato, beans, cabbage, green chili, capsicum, carrot, etc.; Fruits- mango, banana, sapota, guava, grapes, watermelon, pomegranates, papaya, etc.; Cereals- ragi, paddy, maize, jowar, minor millets, etc.; Flower- marigold, chrysanthemum, jasmine, rose, crossandra, etc.; Pulses-red gram, field bean, toor, cowpea, horse gram, green gram, etc. Oil seed – ground nut, sunflower.*

6.3.2.4.1 Impact on livestock rearing pattern and milk production

Fig. 41 (a) indicates that the number of sheep, goats, cows, and buffalo was higher in impacted areas compared to non-impacted areas in 2021. The extent of milk production in impacted and non-impacted areas is presented in Fig. 41 (b). The total milk production per day was significantly ($p<0.01$) higher in impacted areas compared to non-impacted areas at 2141L and 1394 L. (c) shows that the average number of livestock was relatively increased during the post-recycling compared to the pre-recycling period, however, there was no change observed in the pattern of livestock rearing. Other livestock such as pigs, sheep, goats, and poultry also witnessed an increase from the pre-to-post recycling period with a reported growth of 100%, 37%, 33%, and 27% respectively. Milk production was increased by 37% from 0.08 million litres /day to 0.11 million litres /day at Bangarpete. Similarly, an increase of 25%, 17%, and 12% in average milk production was reported at Mulbagal, Kolar, and Mular taluks, respectively. Farmers also revealed that the quality and quantity of milk have been improved due to the increased use of green fodder in the daily ration of animals. It is evident from the results that the availability of water has a positive impact on livestock rearing along with milk production.

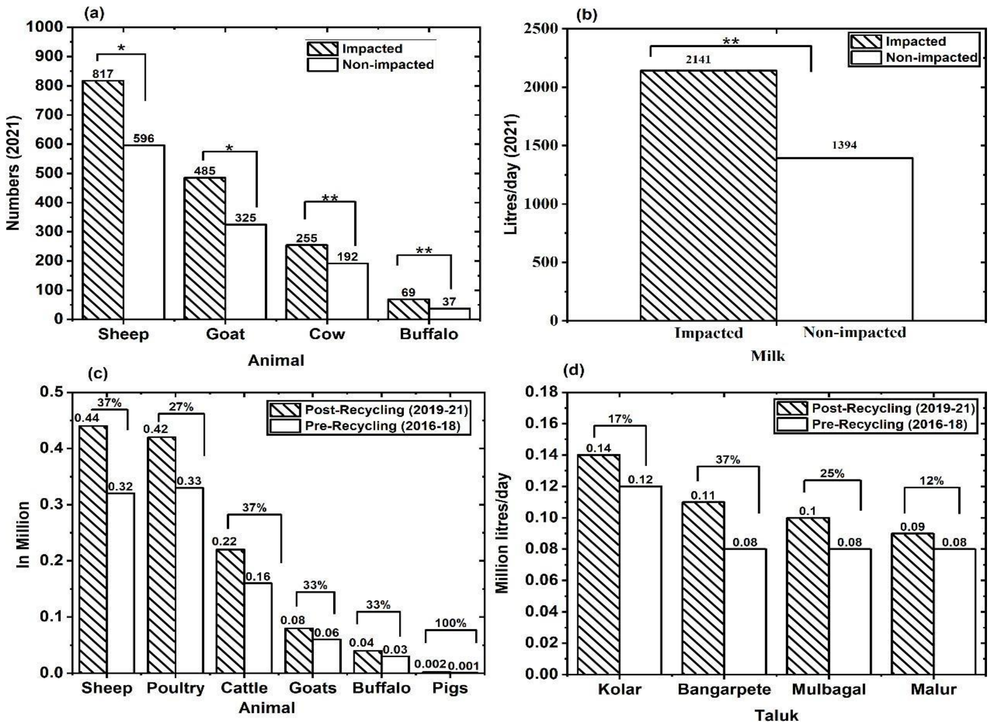


Fig. 41 Change in livestock pattern and milk production (a) Comparison between impacted and non-impacted areas in pattern of livestock (b) milk production (c) Comparison between pre to post recycling period in the pattern of livestock (d) milk production.

Source: Adapted from Manisha et al. (2023) *[Fig. (a & b) based on household survey; (c) Department of animal husbandry and veterinary services, Kolar; (d) Kolar-Chikkaballapur District Co-operative Milk Producer's, Societies Union Ltd. Kolar.*

Note: Significant for p < 0.05, **p < 0.01.*

6.3.2.4.2 Impact on fish production

Fig 42 (a) indicates a steep rise in fish farming during the post-recycling period in all taluks of the Kolar district. The highest increase of 300% was observed at KGF followed by Bangarpete (221%), Kolar (133%), Mulbagal (49%), and Malur (29%) from the pre- to post-recycling period. Fish farming is one of the most important allied sectors in the Kolar district and occupies an important place in socio-economic development. It could be observed from Fig 42 (b) that the average fish production increased by 133% from 647MT to 1510MT from the pre- to post- recycling period in impacted areas whereas only an 8% increase was reported from non-impacted areas.

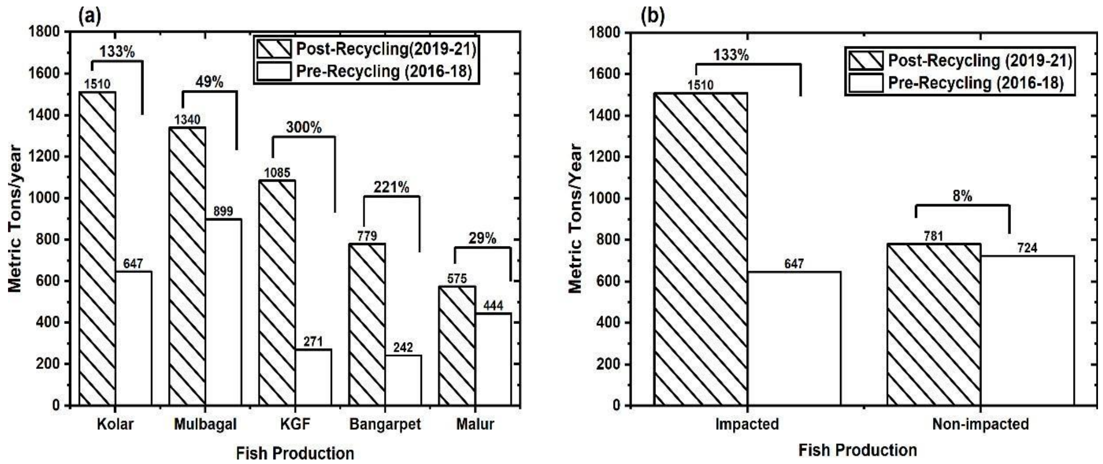


Fig. 42 : Change in fish farming (a) Comparison between pre- to post-recycling period (b) Comparison between impacted and non-impacted areas.

Source: Adapted from Manisha *et al.* (2023)

Note: Impacted-Kolar taluk and Non-impacted: Srinivaspur taluk

The assessment of the food web starting from phyto-plankton and zooplanktons, indicate that the aquatic flora (phytoplankton) and fauna (zooplankton) required to support good fish populations are present in adequate numbers in the tank water (STTW). The increased availability of plankton required nutrients such as ammonia, nitrite, nitrate, calcium, and potassium have now clearly improved and is supported by the food web analysis worked out for Puttenahalli, Yelahanka. Similarly, such additional nutrients are generally used for fertilization of fishponds in aquaculture which is also a known practice around the World.

6.3.2.4.3 Impact on land values

The mean price of agricultural land was substantially higher (Rs.2.4 million/ha) in the impacted areas compared to the non-impacted areas (Rs.1.1 million/ha). From the pre- to post-recycling period land value in impacted areas observed a sharp escalation where prices increased by 118% compared to a mere 25% increase in non-impacted areas. Assured availability of water throughout the year resulted in fertile and productive land and has caused this change.

Fig. 43: Visual water quality as seen in Chowdenhalli, Mulahalli and terminal Dandupalya Lakes

Fig. 44: Seasonal streams have becoming perennial increasing ground water recharge period and as reflected in an open well being revived near Chowdenhalli

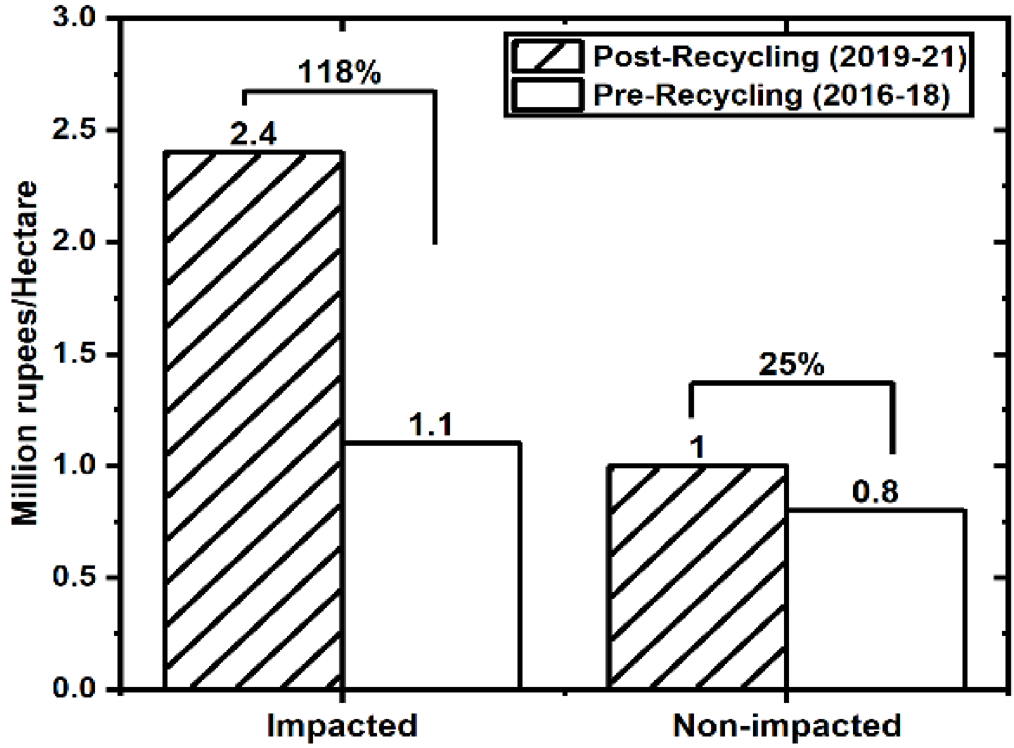


Fig. 45: Change in the value of agricultural land between pre- to post-recycling period

Source: Adapted from Manisha *et al.* (2023)

6.3.2.4.4 Impact on overall income

It could be observed from Table 26 that the average net income of farmers was relatively higher in impacted areas compared to non-impacted areas. For instance, the average income from flower cultivation was Rs. 2,27,893/ha in impacted areas Vs. Rs. 75,345/ha in non-impacted areas, indicating an increase of 202%. Similarly, average income from vegetable, plantation and cereals cultivation was also relatively high at Rs. 6,54,672/ha, 3,72,583/ha and 49,372/ha in impacted areas compared to Rs. 2,62,143/ha, 1,93,790/ha and 32,352/ha at the non-impacted areas, indicating increase of 150%, 92% and 53% respectively. Recourse to multiple cropping as well as increased agricultural crop yields is together responsible for this increase.

It was noted that the average income from livestock was substantially high at 1,29,200/farm in impacted areas compared to Rs. 93,245/farm in non-impacted areas, indicating an increase of 38%. Similarly, it was observed that average income from non-farm activities was also relatively higher in impacted areas. Data from multiple sectors reveals that water availability and the increased GW table are playing an important role in the radical improvement of the agro-economic system.

Fig. 46: Increased water availability duration has increased fish catch over 5 times as seen by fish nets (top), casual fishing (mid) and typical fish catch (0.5-1kg), bottom increasing food security.

Table 26: Change in income from different units of production between impacted and non-impacted areas

Sl.No.	Income source in 2021	Impacted farmers (₹/ha)	Non-impacted farmers (₹/ha)	Percentage change (%)
I	Crops			
	Cereals	49,372	32,352	53
	Vegetables	6,54,672	2,62,143	150
	Pulses	98,027	93,552	5
	Plantation	3,72,583	1,93,790	92
	Flowers	2,27,893	75,345	202
II	Livestock	1,29,200	93,245	39
III	Non-farm income			
	Service	48,725	35,213	38
	Rental Income	62,352	27,822	124
Source: Adapted from Manisha et al. (2023)				

The research carried out by Nandan et al. (2021) supports the study of Manisha *et al*. (2023) and reported positive impact on GW, agricultural sector, and socio-economic conditions in water-scarce regions through managed aquifer recharge (MAR). The rejuvenated tanks are home to a variety of birds, such as fish eagles, herons, and various types of ducks, indicating the presence of a large fish population, which serves as their primary food source. Large and smaller fish were also observed in these tanks, starting from the LT, indicating successful breeding. These observations suggest that the recharged water quality is suitable for aquatic life and supports fish growth and reproduction, which was previously a concern when selecting fish for commercial cultivation in these tanks.

In the past, it was challenging for fish to breed in what was perceived as "hard/polluted" water. However, these observations demonstrate that the approach of recharging water in the tanks allows for successful fish breeding and growth, eliminating the need for separate breeding programs and seeding with fingerlings. These observations, showing fish in various stages of breeding and growth, clearly indicate the suitability of this approach not only for fish cultivation but also for their breeding and the long-term sustainability of surface tank water.

Fig. 47: Perennial water flowing in the interconnected lakes indirectly recharging ground water greatly increases the effective recharge zones seen in three such channels

Table 27. Categorization of Taluks based on GW exploitation

Sl no.	Name of District	Semi-Critical Taluks	Critical Taluks	Over-exploited Taluks
1	Bagalkot	Guledagudda, Hungund, Mudhol, Rabakavi, Banahatti	Badami	Bagalkote
2	Belagavi	Athani, Chikodi, Gokak, Hukkeri, Yeragatti	Kagavada, savadatti	Bailahongal
3	Bengaluru Rural			Nelamangala
4	Bengaluru Urban			Anekal, Bengaluru City, Bengaluru-East, Bengaluru-North, Bengaluru-South, Doddaballapura, Devanahalli, Hosakote
5	Bidar	Bhalki, Hulasuru		
6	Chamarajanagara	Hanur, Kollegala, Yalanduru	Chamarajanagara	Gundlupet
7	Chikkaballapura			Bagepalli,, Chikkaballapura, Chintamani, Gudibande, Gauribidanuru, Sidlaghatta
8	Chikkamagaluru			Ajjampura, Kaduru
9	Chitradurga			Challakere, Chitradurga Hiriyuru, Holalkere, Hosadurga
10	Davanagere		Davanagere	Channagiri, Jagaluru
11	Gadag	Gadag, Mundargi	Rona	Gajendragada
12	Hassan		Channarayapatna	Arasikere
13	Haveri	Byadagi, Hirekerur, Rattehalli		
14	Kalburgi	Afzalpur		
15	Kolara			Bangarpet, Kolara, KGF, Malur, Mulabagilu, Srinivasapura
16	Koppal	Kanakagiri, Yelburga	Kukanuru	
17	Mandya	Malavalli		
18	Raichur	Sirivara		
19	Ramanagara	Channapatna, Kanakapura	Magadi, Ramanagara	Harohalli
20	Tumakuru	Pavagada	Koratagere	Chikanayakanahalli, Madhugiri, Sira, Tiptur, Tumkur
21	Vijayanagara	Hadagali	Harapanahalli	Hagaribommanahalli, Kotturu
22	Vijayapura	Nidagundi		
23	Yadgir	Gurumitkal, Yadagir		

7. Agriculture and allied sectors

The state comprises of ten agro-climatic zones. Rainfall shows very high spatial and temporal variability. About 70% of the geographic area falls in arid and semi-arid zones. Annual rainfall varies between 500 mm in the northern region and around 4,000 mm in coastal regions with an average of 1,151 mm. About two thirds of the state receives less than 750 mm of rainfall. Agumbe in the Sahyadri hills is ranked as India's second highest rainfall location receiving about 7,600 mm per annuum. Karnataka has on an average of 55 rainy days in a year during monsoon. However, Monsoons have experienced some changes in recent years that are attributed to climate change and variations in the El Niño southern oscillation.

Rainwater management: *In-situ* rainwater conservation, which involves capturing and managing rainwater where it falls, is crucial for sustainable agricultural practices, especially in rainfed areas. This approach helps to maximize the use of available water, improve soil moisture, reduce soil erosion, and enhance groundwater recharge. Compared to large-scale irrigation infrastructure projects, in-situ rainwater conservation techniques are often more cost-effective and easier to implement. They can be tailored to local conditions and do not require significant financial investment or complex technology.

7.1 Agronomic measures

Contour cropping: is a conservation farming used on slopes to control soil loss due to water erosion. Contour cropping involves planting crops across the slope. It protects the valuable top soil by reducing the velocity of runoff water and inducing more infiltration. On long and smooth slope, contour cropping is more effective as the velocity of flow is high under such situation and contour cropping shortens the slope length to reduce the flow velocity. Contour cropping is most effective on slopes between 2 and 10 percent.

Strip Cropping: is the practice of growing strip of erosion permitting crops such as root crop, cereals, etc., alternated with strips of erosion resistant crops such as fodder crops, legumes grasses, etc., which are closely spaced. Strip cropping is a more intensive farming practice than contour farming. The farming practices that are included in this type of farming are contour strip farming, cover cropping, farming with conservation tillage and suitable crop rotation. Close growing crops act as barriers to flow and reduce the runoff velocity generated from the strips of intertilled crops, and eventually reduce soil erosion. Strip cropping is laid as

i) **Contour strip cropping:** alternate strips of crop are sown more or less following the contours, similar to contouring. Suitable rotation of crops and tillage operations are followed during the farming operations.

ii) **Field strip cropping:** strip of uniform width are laid across the prevailing slope, while protecting the soil from erosion by water. To protect the soil from erosion by wind, strips are laid out across the prevailing wind direction. Such practices are generally followed in areas where the topography is very irregular and the contour lines are too curvy for strict contour farming.

iii) **Buffer strip cropping:** is practiced where uniform strip of crops are required to be laid out for smooth operations of the farm machinery, while farming on a contour strip cropping layout. Buffer strip of legumes, grasses and similar other crops are laid out between the contour strips as correction strips. Buffer strips provide very good protection and effective control of soil erosion.

Mulching: Mulches are used to minimize rain splash, reduce evaporation, control weeds, reduce temperature of soil in hot climates, and moderate the temperature to a level conducive to microbial activity. Mulches help in breaking the energy of raindrops, prevent splash and dissipation of soil structure, obstruct the flow of runoff to reduce their velocity and prevent sheet and rill erosion. They also help in improving the infiltration capacity by maintaining a conductive soil structure at the top surface of land. Organic mulches viz., cut grasses or foliage, straw materials, wood chips, saw dusts, stonesetc and synthetic mulches viz., plastics, resins, asphalt emulsions, latex, cut back asphalt, canvas etc are commonly used. Conventional organic mulchesare more effective than the synthetic mulches. The tree branches, twigs, leaves, leaf litter, grasses, weeds etc. are used as organic mulch to cover the soil surface.

Stone mulching involves the spreading of stone pieces on the ground surface to conserve the moisture and also to reduce the wind erosion. It is a very old practice, followed in arid zones. Soil under the stones tends to be in moist condition, but the temperature of that soil becomes slightly higher. The soils lying below the stones, harbor small animals and involve higher nitrification. The stone mulching is also used for trapping the dew, particularly in those locations where significant dew fall takes place. ICAR-Central Arid Zone Research Institute Jodhpur, has reported the use of rubble mulch, which is simply combination of small fragments of stones and bricks. This mulch provides better results on moisture conservation compared to the stone mulching, synthetic mulching and mulching made by straw materials.

Grassed waterways: Grassed waterways are natural or manmade channels established for the transport of concentrated flow at safer velocities from the catchment using adequate erosion resistant vegetation which cover the channels. These channels are used for the safe disposal of excess runoff from the crop lands to some safe outlet, namely rivers, reservoirs, streams etc. without causing soil erosion. Terraced and bunded crop lands, diversion channels, spillways, contour furrows, etc. from which excess runoff is to be disposed of, preferably use constructed grassed waterways for safe disposal of the runoff. The grassed waterways outlets are constructed prior to the construction of terraces, bunds etc. because grasses take time to get established on the channel bed. The vegetative cover slows the water flow, minimizing channel surface erosion.

7.2 Promotion of good agricultural practices:

Agriculture is the largest consumer of fresh water (>82 percent), having the potential to minimize water use and reduce the dependence on groundwater. Groundwater supports more than 60 percent of the irrigation needs. Efficient water management practices in agriculture savea huge quantum of water (about 30-50 percent in different crops) and minimize groundwater exploitation. The dependence on groundwater for agriculture can be reduced by increasing the proportionate usage of harvested rainwater and treated water conjunctively.Efficient utilization of water through scientific soil and crop management practices is crucial for optimizing water resources, reducing water wastage, and maximizing crop productivity. By implementing the following practices, farmers can enhance water-use efficiency and minimize water losses. The important strategies to wise water management in agriculture are

Solar paneling on open canal system: Solar panels covered on the open canal serve the dual purpose of minimizing evaporation losses from the open can and contribute for the energy security in the state. Solar paneling on the open canals improve conveyance efficiency and reduce weed menace in the canals and increase the relative proportion of water for field application in turn reducing groundwater exploitation.

Proper irrigation scheduling for increasing water use efficiency: Proper irrigation scheduling ensures required amount of water in right time to achieve higher crop productivity. Monitoring soil moisture levels, weather conditions, and crop water requirements determines the optimal time and duration for irrigation activities. Avoiding over-irrigation and supplying water when the crop is most in need increases water-use efficiency. It allows farmers to schedule water rotation over many fields to reduce crop water stress and enhance yield. It generates additional returns by reusing "saved" water to irrigate non-cash crops that would not otherwise be irrigated during water shortages.

Water requirement for different crops: It is defined as the quantity of water regardless of its source, required by a crop or diversified cropping pattern in a given period of time for its normal growth & development under field conditions at a given place. In other words it is the total quantity of water required to mature an adequately irrigated crop. It is expressed in depth per unit time. Water requirement, if considered as a demand, it includes the quantity of water needed to meet the losses due to evapotranspiration (ET), plus the losses during the application of irrigation water (unavoidable losses) and the additional quantity of water required for special operations such as land preparation, transplanting, leaching of salts below the crop root zone, frost control etc. We should provide only the required quantity of water and avoid excess irrigation of crops.

Water requirement of various crops

Crop	Water requirement (mm)	Crop	Water requirement (mm)
Rice	1200	Tomato	600 – 800
Wheat	450 – 650	Potato	500 – 700
Sorghum	450 – 650	Pea	350 – 500
Maize	500 – 800	Onion	350 – 550
Sugarcane	1500 – 2500	Chillies	400 – 600
Sugarbeet	550 – 750	Cabbage	380 – 500
Groundnut	500 – 700	Banana	1200 – 2200
Cotton	700 – 1300	Citrus	900 – 1200
Soybean	450 – 700	Grapes	700 – 1200
Tobacco	400 – 600	Mango	1000 – 1200
Beans	300 – 500	Turmeric	1200– 1400

The water requirement of crops varies across different growth phases. Irrigation schedule need to be planned according the stage of the crop to minimize water wastage and achieve higher water productivity.

Adoption of micro-irrigation: Drip irrigation envisages the maintenance of optimum moisture by irrigating directly to the rhizosphere and minimizes evaporation, reduces water wastage through seepage and percolation losses. Drip irrigation saves 30 to 60 percent water over surface irrigation method in different crops. Similarly, sprinkler irrigation economizes water in closely spaced, short statured crops. Indeed, the micro irrigation policy of Govt of Karnataka emphasizes for enhancing the area under micro irrigation to 35 lakh hectares.

Drip irrigation in the State can be promoted through, (a) making mandatory under bore well-irrigated situation, (b) promotion of sub-surface drip irrigation in perennial crops like mulberry and sugarcane, (c) piped supply of water in the canal command areas save water by blocking seepage and percolation loss, besides creating opportunity for the farmers to adopt drip irrigation, (d) support construction of water storage ponds at farmer level. A water storage tank of 250-500 m^3 capacity per ha can save water sufficient for 10-15 days to irrigate under drip. This helps to impose canals on & off system and save greater proportion of water, (e) relaxation of area ceiling for extending incentives to adopt micro-irrigation. Presently, a ceiling of 5 ha area is prevailing for availing the benefits of micro-irrigation. Relaxing this can help farmer to minimize water use and government to expand area under micro-irrigation and, (f) implementation of recommendations of Karnataka Antharaganga Micro Irrigation policy.

The irrigation efficiency under drip irrigation system is around 90-95% against 35-40% in surface irrigation. Different micro-irrigation methods suitable are:

Surface drip irrigation: The application of water to the soil surface as drops or tiny streams through emitters with discharge rate for point-source emitters less than 8 L/h for single outlet emitters and for line-source emitters less than 4 L/h. Surface drip irrigation need to be promoted in widely spaced annual crops like maize, vegetables, flowers etc and should be made mandatory under groundwater irrigated situations as the extraction of groundwater can be reduced to nearly half because of higher efficiency.

Subsurface drip irrigation: The application of water below the soil surface through emitters, with discharge rate generally in the range of 0.6 to 3 L/h. Subsurface drip irrigation can be promoted in perennial crops viz., mulberry, sugarcane etc where laterals having pressure compensating mechanisms need to be laid at a depth of 7.5-10 cm inside the soil.

7.3 Promoting efficient surface irrigation in areas with limited applicability of micro-irrigation:

In the areas where surface irrigation is inevitable, water savings can be done through

a) **Widening irrigation interval**: Gradual widening of irrigation interval by increasing the days of next irrigation can minimize water application and reduce the burden on groundwater. In a weekly surface irrigated crops, the irrigation interval can be gradually increased to once in 10 days, later once in 12 days, 14 days can minimize number of irrigation and save water without compromising yield as the crop could adopt to changed moisture regimes.

b) **Ridges and furrows in widely spaced crops**: The widely spaced crops with spacing higher than 2 feet viz., maize, chilli, potato etc should be brought under ridges and furrow method of irrigation to minimize the quantity of irrigation.

c) **Alternative furrow irrigation**: In widely spaced ridges and furrow irrigated crops, irrigating in alternative furrows / skip furrow techniques to be promoted to save water and reduce the dependence on groundwater. Alternate furrow irrigation can be adopted with alternating the irrigation rows in each irrigation. For instance, if rows 1, 3, 5, 7…………….. were irrigated in first irrigation, rows 2, 4, 6, 8………….. are to be considered in the next irrigation. This can save water and keep soil conditions conducive throughout crop season.

d) **Pitcher irrigation and Plant tissue irrigation:** In widely spaced plantations, mud pots punched and plugged with cotton can be placed in the root zone and are filled with water. The hole with cotton trickles water drop by drop and reduce water application. The pots are only irrigated to save water considerable. Advancement is made on plant tissue irrigation in crops like coconut, where water is injected directly to plant xylem tissue with syringe fitted to small pot, tied in the plant stem.

e) **In rice ecosystem, water saving can be promoted through alternate wetting and drying techniques:** Irrigation to the rice field under check basin may be switched to application only when airline cracks appear make alternate wetting and drying to save water and reduce methane emissions.

Direct seeded rice and aerobic system of rice cultivation has the potential to reduced crop water requirement to an extent of 30-35%. These practices can be promoted in mid and tail end reach of the command.

The following agro-techniques can be promoted as good agricultural practices both under surface and micro-irrigation conditions to minimize water application and reduce the groundwater draft.

7.4 Conservation agriculture:

It is a resource-saving agriculture crop production technology that aims to achieve sustained production with the conservation of natural resources while maintaining water balance in the field. Conservation agriculture practices, such as minimum soil disturbance and maintaining permanent soil cover, help reduce soil erosion. When soil erosion is minimized, less sediment is carried into water bodies, reducing sedimentation and improving water quality. Sedimentation can adversely affect groundwater recharge by filling in streambeds and reducing infiltration rates. By mitigating erosion, Conservation Agriculture supports groundwater recharge by allowing rainwater to percolate through the soil and replenish aquifers. The practice of maintaining permanent soil cover, such as crop residues or cover crops, helps improve soil structure and porosity. This allows water to infiltrate into the soil more easily rather than running off the surface. As a result, more water can percolate downward to recharge groundwater aquifers. Additionally, reduced tillage practices minimize soil compaction, which can improve soil permeability and enhance infiltration rates, further facilitating groundwater recharge.

Minimum Soil Disturbance: This principle advocates for reducing or minimizing mechanical soil disturbance, such as ploughing or conventional tillage. Instead of turning over the soil through intensive tillage, conservation agriculture promotes techniques like no-till or reduced tillage. These methods leave crop residues on the soil surface and disturb the soil minimally, preserving its structure and organic matter content. Crop residues left on the soil surface decompose slowly, contributing organic matter to the soil. The increased organic matter and reduced soil compaction with reduced tillage improves infiltration to increase available soil moisture in the rhizosphere, support greater percolation to augment groundwater recharge and minimize groundwater extraction.

Permanent Soil Cover: The principle of permanent soil cover involves keeping the soil surface covered with residues from previous crops, cover crops, or mulch throughout the year. This practice helps protect the soil from erosion, conserve moisture, suppress weed growth, and promote soil health. This can also support for reduced evaporation and minimize crop water needs.

Crop residue management: Incorporation of crop residues into soil or retention on the surface has several positive influences on physical, chemical and biological properties of soil. Leaving substantial amounts of crop residues evenly distributed over the soil surface reduces wind and water erosions, increases water infiltration and moisture retention, and reduces surface sediment and water runoff. The crop residues play an important role in amelioration of soil acidity through the release of hydroxyls especially during the decomposition of residues with higher C:N ratio, and soil alkalinity through application of residues from lower C:N ratio crops, including legumes, oilseeds and pulses. The role of crop residues on carbon sequestration in soils would be an added advantage in relation to climate change and GHGs mitigation.. Yield response with residues management varies with soil characteristics, climate, cropping patterns, and level of management skills.

7.5 Mulching:

Covering the soil minimizes evaporation and maximize *in-situ* rain water conservation. Mulching has to be promoted both under rainfed and irrigated situation by covering soils with organic residues (crop residues, unflowered weeds, tree leaves etc.) and polythene sheets. Polythene mulching can be made mandatory in widely spaced high value vegetables and flowers with drip irrigation. The base of widely spaced trees should be mulched with organic residues. The efficiency of mulch depends on various factors such as the type of mulch used, application method, climate, soil type, and maintenance practices. Generally, mulching is highly efficient in conserving water, suppressing weeds, moderating soil temperature, and improving soil health when applied correctly

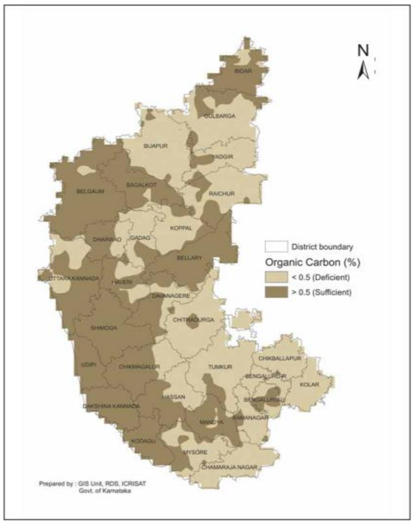
7.6 Nutrient Management:

Nutrient management is pivotal in safeguarding groundwater quality and sustainability within agricultural systems. Proper management practices are essential to prevent the leaching of nutrients such as nitrogen and phosphorus into groundwater. These nutrients, vital for crop growth, can pose environmental risks if they infiltrate aquifers unchecked. Effective nutrient management involves precise application timing and rates, alongside the use of slow-release fertilizers and techniques like precision irrigation to minimize runoff and leaching. By promoting soil health through practices such as cover cropping and crop rotation, nutrient management enhances the soil's ability to retain nutrients, reducing the likelihood of groundwater contamination. Monitoring soil nutrient levels and groundwater quality allows farmers to adjust their practices accordingly, ensuring optimal nutrient use efficiency while protecting water resources. Ultimately, nutrient management not only supports agricultural productivity but also plays a crucial role in preserving groundwater quality and sustainability for future generations.

Nutrient management in relation to water saving agriculture can be addressed through Encouraging the application of organic manures viz., FYM, compost, vermicompost, oilcakes etc. These will help for improvement of soil health with favourable physical and chemical properties supporting infiltration, water retention and percolation to augment groundwater recharge and minimize its extraction.

Green manuring is a practice where a specific crop is grown with the intention of incorporating it into the soil while still green or shortly before maturity. This technique aims to enhance soil quality and provide benefits to subsequent crops. By plowing or turning in undecomposed green plant tissues into the soil, farmers improve both the physical condition and fertility of the soil. Green manuring serves as a cost-effective and environmentally friendly approach to soil improvement, supporting long-term agricultural sustainability and resilience against climate variability. Green manuring can be promoted as substitute / alternative to above organic manures considering the pre-season rains and nursery time in paddy crops. Indeed, collection and incorporation of green leaves and tender twigs collected from shrubs and trees grown on bunds / waste lands / nearby forest areas and weeds before flowering help to support soil physical and chemical properties to promote water saving agriculture.

7.7 Soil health improvement:



Increasing soil organic carbon content helps to improve water holding capacity, conserve rain water by increasing infiltration rate and minimize evaporation loss.The organic carbon content in the soil is to be increased to 0.75 per cent through (a) promotion of organic and natural farming practices, (b) green manuring can be encouraged with pre monsoon rain, (c) promotion of pulses in the cropping system, (d) incorporation of green leaf wastes *viz*., tree biomass, unflowered weeds etc., and (e) avoiding burning of crop residues *viz*., sugarcane/maize trash, paddy residue etc

7.8 Redesigning of cropping system:

The water requirement and productivity largely varies with the crops and cropping system. Cropping system to be redesigned based on water availability, climate and soil. Efficient crop zoning to be made based on Land Resource Inventory (LRI) and should be promoted highly suitable crops for the domain considering water budget of the location. The following crops cane be promoted in different geographical situations with good agricultural practices.

Coastal Karnataka:

Main Crops: Paddy, coconut, areca nut, black pepper, cashew nut

Pattern: Predominantly paddy followed by pulses or vegetables

Northern Karnataka:
Main Crops: Jowar, bajra, maize, pulses (tur, chickpea), oilseeds (groundnut, sunflower), cotton, sugarcane
Pattern: Mixed cropping with cereals and pulses or oilseeds, double cropping in irrigated areas

Southern Karnataka:
Main Crops: Ragi, paddy, maize, pulses (green gram, black gram), oilseeds (groundnut, sunflower)
Pattern: Crop rotation with ragi and pulses, double cropping in irrigated areas

Central Karnataka:
Main Crops: Maize, ragi, groundnut, pulses, cotton, sugarcane
Pattern: Intercropping and mixed cropping with cereals and pulses

These cropping systems and patterns are adapted to optimize the use of available resources, maintain soil health, and maximize productivity and profitability for the farmers in Karnataka. Presently, the cropping system followed in many parts of the State is not water efficient. Crop violations are to be viewed seriously through restrictions imposed on supportive services *viz*., subsidy on seeds, fertilizers, imposing higher tax etc. Redesigning of cropping system in the State to be done considering (a) efficient crop zoning i.e., by identify the efficient crops to the zone using LRI/ scientific basis and impose restrictions strictly. Need to work out water budget and cropping system is to be redesigned considering water budget, (b) high water requiring crops like rice, sugarcane need to be discouraged under borewell, and tail ends regions of the command area, (c) areca is expanding geometrically across the State outside the traditional area even in low rainfall and groundwater grey areas like Pavagada, Challakere is to be strongly discouraged and, (d) agronomic practices like soil test based nutrient management and cultural practices minimizes water requirement and maximize water productivity.

7.9 Precision farming technologies:

Offer a suite of innovative tools and practices designed to optimize agricultural inputs and improve the efficiency of water use, thereby enhancing groundwater content. These technologies leverage data, advanced machinery, and sensor systems to make precise and informed decisions about crop management, which can significantly impact groundwater recharge and conservation. Here are several key precision farming technologies and how they contribute to improving groundwater content:

Soil Moisture Sensors: are devices placed in the ground to monitor the moisture content of the soil in real time. These sensors provide accurate data on the amount of water available to crops at various soil depths. By using this information, farmers can precisely manage irrigation schedules, applying water only when and where it is needed. This targeted approach reduces over-irrigation, minimizes water waste, and prevents excessive water extraction from groundwater sources. Consequently, more water remains available for natural infiltration and groundwater recharge.

Geographic Information Systems (GIS) and Remote Sensing: GIS and remote sensing technologies use satellite imagery and aerial photography to monitor crop health, soil conditions, and water use over large areas. These technologies can identify variations in soil moisture, crop stress, and areas with potential waterlogging or drought. By analyzing this spatial data, farmers can make informed decisions about water management, targeting specific areas that need attention. This precision reduces unnecessary water application, promotes efficient water use, and supports groundwater recharge by ensuring water is distributed according to actual field conditions.

Variable Rate Technology (VRT): VRT allows for the variable application of inputs such as water, fertilizers, and pesticides based on the specific needs of different field zones. By using detailed field maps and sensor data, VRT systems adjust the application rates in real time. For irrigation, this means water can be applied more precisely, reducing excess use and promoting efficient water distribution. The reduction in over-application helps prevent water runoff and leaching, thus protecting groundwater quality and enhancing recharge.

Crop Modelling and Decision Support Systems (DSS): Crop modelling and DSS use algorithms and simulation models to predict crop water requirements, growth stages, and yield outcomes under varying conditions. These tools integrate data from weather forecasts, soil moisture sensors, and historical crop performance to provide recommendations on optimal irrigation scheduling. By using these models, farmers can anticipate water needs more accurately and apply water strategically, minimizing unnecessary extraction and promoting groundwater sustainability.

Drones and Unmanned Aerial Vehicles (UAVs): Drones equipped with multispectral and thermal cameras can survey fields to assess crop health, soil moisture levels, and irrigation system performance. The high-resolution data collected by drones enable precise monitoring and management of water use. For instance, drones can identify areas of the field that are over-irrigated or suffering from water stress, allowing for targeted adjustments to irrigation practices. This precise monitoring helps conserve water and supports efficient groundwater recharge.

Integrated Water Management Systems: Integrated water management systems combine multiple precision farming technologies to create a holistic approach to water use. These systems coordinate data from soil sensors, weather stations, and irrigation controllers to manage water resources comprehensively. By optimizing water distribution and reducing wastage across the entire farm, integrated systems enhance water use efficiency and promote groundwater recharge.

Promotion of protected cultivation: The potential of protected cultivation needs to be harnessed considering its higher yield potential almost near 3 times the open cultivation. Indeed, rainwater harvesting to an extents of 90-95% is possible by implementing roof water harvesting, which can supplement the water need at least 200 days and sustain high value crops for 2 seasons in an area receiving above 700 mm rainfall annually. This can reduce the dependence on groundwater for irrigation. Automation needs to be promoted for protected cultivation comprising weather, water, nutrient and pest control system.

Ground Water management: Though groundwater is considered ubiquitous, it is not uniformly available. Weathered hard rocks account for 97% of the aquifers, the great majority being granite (90%) and the remainder Deccan trap basalts. Alluvial coastal flood plains account for only 2% of aquifers and other formations for just 1%. Tube and bore wells irrigate a net area of 12.5 lakh ha, contributing 37% to the state's net irrigated area. The replenishable groundwater is 15.9 billion m^3 and annual groundwater availability 15.3 billion m^3. The groundwater draft stands at 10.7 billion m^3 out of which 91% is for irrigation alone. The increasing dependence on groundwater has already led to a 70% of groundwater development against 58% in the country.

Minimization of groundwater exploitation: Efforts must be made to minimize groundwater usage across agricultural, domestic, and industrial sectors through the adoption of efficient practices. This can be achieved by raising awareness, implementing regulated water supply, and imposing charges for usage exceeding specified standards. Furthermore, rural areas should focus on adopting practices such as conjunctive use of treated water and rainwater harvesting, alongside enforcing strict regulations on water usage by industries. Industries in rural regions must prioritize water-efficient practices and invest in rainwater harvesting, groundwater recharge, and wastewater treatment for reuse. It is imperative to rigorously enforce regulations governing water use by industries. To accurately monitor groundwater extraction, all borewells must be equipped with digital water meters, with data collected in real-time. Effective groundwater management strategies are essential in situations where demand surpasses availability or contamination threatens quality. Given the extensive use of groundwater for irrigation in the study area, the uneven distribution of resources exacerbates demand. Thus, there is an urgent need to develop sustainable and scientifically-driven groundwater management approaches to ensure resource longevity and equitable distribution.

Central ground water board recommended Ground water issues, manifestation and management plans

Issues	Manifestation	Management plans
Long term declining trends in Ground water	Lowering of water levels in about 50% of wells analyzed during pre and post monsoon periods	1. Recycling & Reuse through water treatment. 2. Implementation of artificial recharge projects through construction of water conservation structures viz., Check dams, sub-surface dykes, etc at scientifically selected locations
	Declining rate is not significant	1. Adoption of water use efficiency methods like Drip irrigation and Sprinkler needs to be adopted for Irrigation 2. Artificial recharge structures should be periodically cleaned
Ground water quality issues	High fluoride concentration in ground waterin some pockets	1. Can be tackled through installation of Defluoridation plants 2. Dilution of fluoride concentration by Construction of Artificial recharge structures

Participatory groundwater management: The groundwater data sets are required to be gathered frequently each year for updating aquifer condition in the micro-watershed. Devising a suitable participatory framework of gathering soft/ hard data sets of groundwater by stakeholders will address not only sustainable data gathering but also empower/ educate the stakeholders about groundwater system. Several successful experiments were carried out on participatory approaches and these can be dovetailed to the watershed programs for proper groundwater management of the micro-watershed by the stakeholders themselves.

Farmers should be encouraged to involve themselves in village level participatory groundwater management, wherein they will assess the water availability after the monsoon season, and plan for optimum utilization among themselves. They decide on the extent of area to be irrigated and the type of crops to be grown etc., with the available resource during that year. They also measure hydrological parameters and maintain a record of the readings. In this regard, suitable legal framework need to be developed in consultation with National Law School of India University and related departments.

7.10 Water management in forest area:

Forests play a crucial role in maintaining ecological balance, supporting biodiversity, and providing numerous ecosystem services. One of the key aspects of forest management is the conservation of soil and water resources. Soil and water conservation in forest areas is vital for sustaining forest health, productivity, and ecological functions.

Soil and water conservation practices in forest area

I. Reforestation including plantation, rehabilitation, and agro-forestry development

II. Non-structural measures: Land use regulation, public awareness for forest, livelihood assistance/poverty alleviation, etc.

III. Structural measures:

Catchment conservation works other than water harvesting structures: These are implemented to minimize the soil erosion around the structures. In addition, those are also implemented to prolong the life span of water harvesting structures (check dams). Representative conservation works viz., Gully plugging works, contour trench works, terrace works, contour bunding works, mulching, plantation and filter strip works along the river, river/stream bank protection works (bandalling), etc.

Water harvesting structures: check dams (construction of embankment)

Gully Plugging Works: The gully plugging works are the barriers installed across the gully to reduce the runoff velocity of the gully, to retain the sediment behind them, and to reduce the gully erosion of the micro watershed.The gully plugging works consist of the barrier and the optional downstream and upstream aprons.

Contour Trench Works: The contour trench works are the method of constructing the trenches along the contour lines of the slope with 10 - 30%. Objectives of the trench works are to retain water and sediment on the slope, to increase the water infiltration, to improve local soil moisture, and as the result, to reduce the runoff discharge and sediment to the downstream watershed. There are three (3) types of the contour trenches, that is, continuous trenches, and interrupted (line and staggered) trenches. The continuous contour trenches are essentially used for moisture conservation in low rainfall areas. The staggered trenches are commonly constructed in annual 1,500-2,500 mm rainfall condition.

Fig 48 : Gully plugging works

8. Integrated action plan for implementation

1. The department wise responsibilities for implementation of integrated action plan for augmenting groundwater are presented in Table-5. In the following paragraphs summary of activities to be taken by the relevant departments are presented for immediate action by the Government of Karnataka.

2. **Watershed Development Department:** Groundwater assessments are carried out operationally each year in India by Department of Water Resources, River Development & Ganga Rejuvenation (Ministry of Jal Shakti). However, these assessments are done at a coarser scale of block/taluk based on long term groundwater observation network of about 1 well in about 80 to 100 km^2. The watershed programs in the country are managed for interventions at the scale of approximately 5000ha and hardly possess suitable groundwater level/ stock maps. In recent years, watershed programs (Sujala-3/ REWARD) are supported by detailed project reports involving digital data/ atlas related to several variables such as soil, topography, drainage, land use & land cover, hydrology etc., at 1:4000 scale required for treatment of micro-watersheds (~500ha). However, the groundwater related data have not been available at a such finer scale and hence specific targeted investments for infrastructure to augment groundwater recharge using managed aquifer recharge methods have not been addressed.

3. Hence, the first step would be to create a groundwater level map for each micro-watershed/ sub-watershed (500 - 5000ha) with at least two season maps such as pre-monsoon (e.g. April) and post-monsoon (e.g. November), which will provide areas with depleted groundwater stock in the micro-watershed. Combining this data with an estimates of groundwater balance (recharge and draft) are needed. Along with this water balance for the micro-watershed during various seasons is needed using hydrological models. The additional recharge structures taking into account of the volume of storage and number of such structures then can be devised including point well recharge structures adjacent to check- dams. The groundwater in most parts of Karnataka occurs in hard rock areas and as such designing artificial recharge structures are tightly linked to the structural maps of the underlying rock formation. Towards this aquifer maps generated under National Project on Aquifer Management program of CGWB at 1:50000 scale is used for downscaling them to 1:5000 scale through additional geological & geophysical surveys at the micro-watershed.

4. Further, the responsibility of Watershed Development Department for augmenting groundwater in the State will be as follows; (a) promotion of *in-situ* rainwater harvesting practices in collaboration with the departments of Groundwater, Agriculture, Horticulture, Sericulture, and Forestry, (b) construction of appropriate *ex-situ* rainwater harvesting structures in watershed development

projects and sharing LRI and hydrology data to RDPR for implementation of MGNREGA and Forestry departments, (c) development of a legal framework for the minimization of groundwater exploitation in collaboration with National Law School India University and the Law Department, GoK, (d) promotion of mulching practices among farmers in collaboration with the departments of agriculture, horticulture, and sericulture departments (e) Soil health improvement initiatives to be taken jointly with the departments of agriculture, horticulture, and sericulture, (f) redesigning cropping systems based on crop suitability as indicated in LRI and its promotion in the watershed area in collaboration with the departments of agriculture, horticulture, sericulture and water resources, (g) incorporating conjunctive water use plan while developing watershed wise water budget plans in collaboration with the line departments and , (h) developing a strategy for implementing water credit system in collaboration with the departments of minor irrigation, RDPR, finance, industries, law, agriculture, horticulture, and other relevant departments

5. **Rural Development and Panchayat Raj Department:** (a) Implementation and regulation of rooftop rainwater harvesting initiatives in rural areas, (b) monitoring regulated drilling of borewells and mandatory borewell recharge, (c) creating awareness on minimization of groundwater exploitation, (d) regulated supply of water and to imposing water charges to minimize groundwater exploitation and, (e) participatory groundwater management initiatives through collaborative efforts between the Watershed Development Department and the Groundwater Department (f) Gram Panchayaths to construct point recharge structures for all Drinking water supply Borewells in their jurisdiction. Panchayaths be encouraged to claim Water credit after point recharge structures operate successfully.

6. Minor Irrigation Department: Rejuvenation of tanks in collaboration with RDPR Department and installation of shafts in the tanks at appropriate places for recharge of groundwater. For Tank rejuvenation, accumulated silt to be removed (a thin layer be removed at a time) , Feeder streams/nalas to the Tank have to be cleaned for smooth flow of runoff water, encroachment of nalas and tank beds be made free and restored.

7. Groundwater Directorate: Issue permission for drilling new borewells as per the norms to ensure regulated drilling of borewells. To undertake 'Demand-Supply' studies in selected panchayaths, Town Municipalities and irrigated areas to assess excess draft if any. Advising Groundwater Authority to bring in Recharge component mandatory for all Borewell owners irrespective of 'Over-exploited' or 'Safe' taluks.

8. **Pollution Control Board:** Regulation of industrial water usage to minimize groundwater exploitation in collaboration with the department of industries and commerce. Control free flow of domestic sewage water and industrial effluents to

natural streams/nalas. UGD to be enforced/insisted in areas where it is not operating to achieve this.

9. **Karnataka Antharaganga Micro Irrigation:** As part of promotion of good agricultural practices, expansion of area under drip irrigation and precise irrigation techniques in collaboration with the departments of agriculture, horticulture, and sericulture

10. **Forest Department:** (a) as part of afforestation, revival of forest areas and agro-forestry initiatives in collaboration with Watershed Development Department, agriculture, horticulture, and sericulture departments and, (b) construction of shallow and sloped ponds in the forest area in collaboration with Watershed Development Department. (c) In collaboration with Groundwater Department, undertake Hydrogeological survey in Forest areas to decipher the Groundwater prospect areas, and also zones suitable for Recharge and Rainwater harvesting. This will be a positive step towards arranging drinking water for the wild animals, and recharge to aquifer in general.

11. **Urban Development Department / Bruhat Bengaluru Mahanagara Palike/BWSSB and Municipal Corporation:** (a) enforcement of adoption of rooftop rainwater harvesting in urban areas in collaboration with Bangalore Development Authority and Urban Development Department, (b) greening of residential areas in collaboration with BDA, Urban Development Department and forest Department, (c) tank rejuvenation in urban areas in collaboration with BDA, Urban Development Department, Forest Department and Minor Irrigation, (d) promotion of the usage of treated water for parks, flushing, and gardening in collaboration with BDA, Urban Development Department and BWSSB, (e) filling tanks with treated water in urban areas in collaboration with BDA, Urban Development Department and BWSSB, (f) reduction, recycling, and reuse of water in collaboration with BDA, Urban Development Department and industrial stakeholders, (g) establishment of infiltration galleries in collaboration with BDA, Urban Development Department and relevant stakeholders and, (h) utilization of reverse osmosis filter rejected water in collaboration with the BDA, Urban Development Department (i) Expanding UGD facility to all area where it is not available now, and stop flow of domestic sewage to natural streams. Natural streams converted as Raja Kaluves to be reversed to carry only storm water flows.

9. Strengthening of Institutions

1. **Strengthening State Ground Water Authority:** The State GWA should be strengthened with executive powers at the earliest on priority. The GW Authority should have dedicated technical staff of its own with executive powers. With its own technical staff equipped with executive powers, it would be possible to check further decline in resources and depth to GW levels, manage the resources for sustainability. In a recent publication – Groundwater Law and Management in India, Groundwater Management and the Law from 14 States and one union territory are discussed. 'Groundwater rights came to be recognized as an incident of the right of ownership of the overlying land since long'. With regard to Karnataka, the authors have said that the law governing groundwater in the State limits its scope to the operation of the system in Notified areas.

   The authors opine that the model represented by the Andhra Pradesh water law, that integrates water, forest, and soil management (Jal, Jungle, Jameen) as a more appropriate model worthy of emulation in Karnataka. Groundwater regulation has to be linked to Soil conservation, the revival of tank system and afforestation. Also, the Groundwater Law should be made applicable over the entire state which will be effective for control and management of the resource.

2. **Creating mass awareness:** General public should be imparted awareness on methods of water recharge and water conservation. In the first instance, 'Training of Trainers' is to be done. After the trainers are trained, they can organize mass awareness camps in rural and urban areas an enlighten the participants on the different aspects of groundwater such as its availability, usage, Artificial Recharge Structures, Roof rain water harvesting, economy in water use, etc.

3. **Repository of all artificial recharge structures:** Several departments of the State government and NGOs are constructing artificial recharge structures in different parts of the State. There is no proper directory of such structures constructed till now. This hampers a proper assessment of recharge from these structures. Any department like Minor Irrigation Dept or Watershed Development Department should be made as the nodal department for this. Any departments or NGOs should seek permission for constructing a particular structure, with Geo coordinates. This will help to estimate the recharge through such structures accurately, and plan for locations for new structures. The Structures constructed till now should be inventoried and recorded and a directory be prepared and made available online for the interested departments, research scholars etc.

4. **Industrial water use planning:** Latest data on how much water is used by the industries in the State is not available. There is a need to undertake a detailed inventory of industries using water for the daily needs of its employees, water required in the processing of the products, and also industries which use water as the raw material like bottled water and aerator manufacturing industries. It will also collect information on source of water, effluents released per day and how it is disposed, and also information on solid wastes.

5. **Hydro-geological wings in other departments:** Domestic water supply is a major task before the government. Rural water supply is taken care by the Rural Development Engineering Department, in the Zilla Panchayats of the Districts, Bangalore Water Supply and Sewerage Board in Bangalore city, city corporations and town municipalities in other urban and semi urban localities. The RDED has its own group of Hydro-geologists at head office and district RDED offices. The BWSSB need to have its own technical wing with sufficient number of geologists who can monitor the groundwater status in entire Bangalore urban area limits and render advise to the board. They will monitor and execute the roof rain water harvesting in the city. They can also under take studies on demand, availability and supply position of drinking water for different locations.

6. There are several reservoir command area offices in the State. They should also have a hydro-geological wing which will study the water-logged areas within the command area and suggest methods for conjunctive use of surface and groundwater. This will result in extending the canal flow in the tail end, and land reclamation in the water-logged areas in the command.

10.Water credits

Water credits for improving water use efficiency: Karnataka being an upper riparian state is facing severe water crisis specially during deficit rainfall years. Though the average annual rainfall in the state exceeds 1150 mm, its spatial distribution vary from 350 mm to 4000 mm. The temporal distribution is also affected in recent time attributing to climate change. Climate change added undesirable dimension to rainfall in the state interms of increased rainfall intensity and ill distribution. This has created pressure on water resources affecting water security. Further, the water demand in the state is increasing from all the sectors associated with increased temperature, urbanization and industrialization. Indeed, the proportion of fresh water in the total is declining with the increased water pollution. This has resulted in extraction of groundwater to meet the demand of domestic, agricultural and industrial sectors leading to over-explotation. This over-extraction has drastically reduced per capita water availability, with nearly 54 per cent of assessment units in water stress. All these together raising concern on efficient water use to support water security and prosperity of the human being.

The Comptroller and Auditor General (CAG) report of 2021 highlighted that groundwater extraction exceeds recharge rates, threatening about 80 per cent of freshwater sources over the next two decades. Agriculture accounts for almost 85 per cent of freshwater usage, so efficient management practices in this sector can significantly affect groundwater conservation. The Government of India launched Mission LiFE (Lifestyle for Environment) in 2023 as a global mass movement to drive actions to preserve the environment. The rewards for these actions, to be traded like carbon credits, are being developed through frameworks and trading platforms. Mission LiFE proposes a transition to a circular economy, driving changes in demand, supply, and policy, with water conservation being one of its seven focus areas.

Water credits are a market-based mechanism such as carbon credits, incentivising water conservation and quality improvement. Individuals and entities can earn tradable credits by adopting water-saving measures. These credits can then be sold to others needing to offset their water usage or improve their water management practices. Water credits can enhance water use efficiency in agriculture, promote sustainable water management practices, and foster investment in water-saving technologies and infrastructure, addressing Sustainable Development Goal 6 (Clean Water and Sanitation).

Defining baselines for water credits is more complex than for carbon credits due to the localised nature of water resources. Factors such as rainfall, groundwater availability and current consumption levels need to be considered. Assessing the water footprint involves evaluating virtual water—the total water consumed during the production process of agricultural commodities, compared to the place of cultivation.

Virtual water is the total volume of water consumed in the production process of agricultural commodities, from crop cultivation through to the final product. This includes both direct water usage (irrigation) and indirect water usage (water embedded in inputs such as fertilizers and pesticides), helping to determine the water needs for different crops and indicating the water usage efficiency and sustainability of agricultural practices. Due weightage and consideration is needed to be given for the source of water in the water credits. The source of water to be considered are green, blue and grey water in giving weightage as the cost of deriving these vary considerably.

Green water: Rainwater stored in the soil and used by plants, forming the part of virtual water derived from natural precipitation. Unlike irrigated agriculture, rainfed systems depend entirely on green water.

Blue water: Freshwater sourced from surface and groundwater for irrigation, representing the managed portion of water resources used in agriculture. Greater weightage needs to be given for blue water in the water credit system.

Grey water: The volume of freshwater required to dilute pollutants (e.g., fertilizers and pesticides) resulting from agricultural production, and restore water to usable quality. Grey water should fetch highest weightage as the cost of it is higher.

To reward conservation through water credits, it is important to define overall water footprint baselines, including virtual water and tracing its location and stages of use. Conservation efforts rewarded with water credits should consider local rainfall, groundwater availability, and water quality. A water-intensive agricultural activity in a water-scarce region should incur a water scarcity penalty. This comprehensive approach ensures that water consumption is evaluated holistically, factoring in the overall context, not just the water efficiency of the specific agricultural activity. Water efficient crops, water prudent irrigation practices and technology are the need of the hour. Water credits can motivate farmers to adopt practices to improve water use efficiency in agriculture and monetize the savings. A robust framework for water credits is essential for effectiveness and scalability. This should define eligible water-saving activities, set measurement and verification standards, and create a marketplace for credit trading. Successful water credit systems require regional adaptation to address varying rainfall levels, water scarcity, and water quality challenges.

11.Success stories

Israeli Technology:

Israel's leadership in sustainable water management began with finding solutions to the country's first and foremost problem: the uneven distribution of freshwater throughout the country. To supply the growing demand, Israel's national water company Mekorot, began constructing the National Water Carrier. This water transportation network was designed to pump water from the northern Lake Kinneret (Sea of Galilee) and transfer water from existing regional water projects to central and southern Israel. But upon its completion in 1964, 80% of the water transported by this system was allocated for agriculture. Clearly, the National Water Carrier alone could not satisfy both agriculture and household needs. Luckily, a solution was already in development thanks to the innovative genius of Simcha Blass and his son Yeshayahu, who began developing a drip irrigation technology in 1959. Their revolutionary method slowly applies water directly to the roots of crops through a network of tubes, valves and drippers. Israeli engineers realized it's not just about conserving available freshwater but also taking advantage of water sources previously considered unusable, such as treated municipal wastewater and stormwater. In 1985, Israel began sending treated, recycled wastewater through its National Water Carrier to farms, greatly reducing the gap between consumer demand and available water. By 2015, Israel had managed to treat and recycle 86% of its wastewater for agricultural operations, leading the world in wastewater reclamation. Second to Israel in that same year was Spain, recycling just 17% of its wastewater.

Gujarath model:

With only 2% of the country's water resources and 5% of the country's population, Gujarat is typically reckoned as a water deficient state. Its rocky terrain and coastal topography make ground water withdrawal unfeasible, while the supply of surface water is limited. This is due to the fact that it lies on the leeward side of the Western Ghats and by the time, the Bay of Bengal branch of the South West Monsoon reaches Gujarat, it does not have adequate moisture left with to cause rain. It is known to receive less than 60 cm of rainfall annually. One such noteworthy initiative by the Gujarat government is the Sujalam Sufalam Yojana, a water conservation scheme by the Gujarat government. The scheme revolves around the twin objectives of deepening of water bodies before monsoons and enhancing water storage for rainwater collection. It entails desilting of water bodies across the state through a participative approach. In its first year (*2018*), the scheme succeeded in achieving the targets of increasing water storage capacity by 11,000 lakh cubic feet through deepening of 13,000 lakes, check dams, and reservoirs. On the back of this success, the state earmarked its financial contribution to 60% for programme activities, requiring private entities to pay only the remaining 40%. Another benchmark initiative by the state is a water management system that injects and stores excess rainfall water underground and later uses it for irrigation during summers. This programme, Bhungroo, was carried out by a number of Gram Panchayats. It encompassed training farmers in installation of sub-surface storage and a piezometer for water level monitoring on a day-to- day basis. By augmenting ground water through harvesting water on around 10 rainy days, farmers were able to continue farming for more than half of the year. Not only did this programme contribute towards establishing food security and improving the state's agricultural output, it also reduced drudgery of women, thus making them the chief owner and expert of this practice.

In India, the Narmada Basin has a sub-tropical climate. Rainfall over the basin is monsoon-driven, i.e., a majority of annual rainfall over the basin is contributed by the monsoon season, prevailing from mid-June to mid-October. A Linear Programming Optimization model has been developed to operate the multi-purpose multi-reservoir system in the Narmada River basin. The objective of this is to allocate water to the command area of the Narmada Main Canal (NMC) in Gujarat and Rajasthan during the low flow year by curtailing the hydropower demands. As per the Water Policy of India, irrigation demands have a higher priority than hydropower demands. The optimization model developed for the integrated reservoir operation of the multipurpose multi-reservoir system has been applied for the Sardar Sarovar Project (SSP) to allocate water optimally among various demands based on water availability. Inflows and releases for domestic, irrigation, environmental flow, and hydropower generation were considered as decision variables. Stage capacity curve, initial storage, and target storage that need to be maintained at a certain time period were constraints bound for reservoir release.

Kumudvathi River Rejuvenation in Karnataka:

Kumudvathi watershed is located on the left bank of river Cauvery. The total area covered is 462 Km^2. The major part, 330 Sq. Km, of the watershed is covered by Nelamangala Taluk of Bangalore Rural District and the rest of it is covered by Magadi Taluk of Ramanagara District. The entire watershed is further divided into 18 mini watersheds, ranging in size from 12 Km^2 to 40 Km^2. 'The catchment area of Kumudvathi is declared as overexploited in Karnataka'. The Managed Aquifer Recharge (MAR), part of holistic river rejuvenation framework evolved by The Art of Living, are being carried out for the last 8 years by the Art of Living River Rejuvenation team and recharge structures have been built across the entire stream network. This has been undertaken with an objective of resuming the flow in Kumudvathi river has embarked upon a program of River Rejuvenation through managed aquifer recharge and increasing the natural vegetation. The program has been implemented in association with local farmers and volunteers and with support from Hindustan Aeronautics Limited (HAL), Bosch (RBEI), HDB Financials Services Ltd, ALTAIR Engineering, CISCO, Intel, etc,.

Karnataka Antharaganga Micro Irrigation Corporation Limited:

It is a Public Limited Company, incorporated under the Companies Act as a Company limited by Shares. It is classified as State Govt company and is registered at RoC-Bangalore. It was established on 05-12-2018. The authorized share capital of the company is Rs. 50,000,000 and its paid up capital is Rs. 500,000. Its balance sheet was last filed on 31-03-2020. Karnataka Antharaganga Micro Irrigation Corporation Limited Corporate Identification Number (CIN) is U01100KA2018SGC119162 and its registration number is 119162. By promoting micro-irrigation, the corporation address water scarcity issues while enhancing agricultural productivity and resilience. KAMICL conducts awareness and educational programs for farmers to promote the benefits of micro-irrigation, such as drip and sprinkler systems. The corporation provides training sessions to farmers on the efficient use of water resources through micro-irrigation techniques. KAMICL is involved in planning and implementing various micro-irrigation projects across Karnataka, ensuring that these systems are set up in a cost-effective and timely manner. In summary, KAMICL initiatives contribute significantly to sustainable agricultural practices, improved water management, and economic benefits for farmers in Karnataka.

12.Policy measures

1. In-situ moisture conservation is an essential component in the rainfed dominated state of Karnataka. The net cultivated area of the state is around 11 million ha, should be used as a site of moisture conservation to reduced the dependence on ground water for crop production and also to augment percolation to recharge the ground water. Bunding should be a continuous activity in the state, since over a period of time the bunds get damaged with intense rainfall and cultivation activity. Annually, bunding should be taken at least in 1 m.ha area by providing a budget outlay of Rs 150 Crores.

2. Tanks are lifeline in the rural ecosystem in the state as they provide water for all human welfare activities including irrigation besides, augmenting groundwater. Hence, tank rejuvenation should be taken on priority in a phased manner covering atleast 2500 tanks annually starting from vulnerable taluks indicated in the Dr. Nanjundappa's report. Tank rejuvenation can be promoted in PPP approach involving CSR funds with an annual state share of Rs. 250 Crores.

3. Agronomic measures are essential in drought proofing and encouraging of these practices conserves rainwater and reduces the dependence of groundwater for protective irrigation. Hence, farmers incentives from the government should be linked with the adoption of good agricultural practices.

4. Krishibhagya is a successful model in the state of Karnataka. This needs to be further promoted in the entire state by providing at least Rs. 500 crores annually.

5. Watershed development department should undertake ex-situ rainwater conservation programs and non-arable land treatment continuously with an annual budget outlay of Rs. 500 crores.

6. Piped conveyance of irrigation saves greater quantum of water by minimizing seepage, percolation and evaporation losses. The saved water in the piped conveyance system can help for expanding area under irrigation and reduce dependence on groundwater. Pilot studies on piped irrigation system in each command needs to be demonstrated with an annual budget outlay of Rs. 200 crores.

7. Enhancing soil health by improving soil organic carbon is necessary in water saving agriculture. Alternative practices such as green manuring should be promoted through supplying green manure seeds on subsidy basis with a annual budget outlay of Rs. 100 crores.

8. Encourage ODOP program to promote efficient crop zoning concept in order to achieve higher water productivity besides, ensuring better income.

9. Protected cultivation with automation and roof water harvesting needs to be promoted for reducing the dependence on groundwater and livelihood of farming community with an annual budget outlay of Rs. 200 crores.

10. Convergence of various schemes for implementing the above activities for improved groundwater conservation, extraction and utilization. This needs systematic research and development activities from the State Agricultural Universities and line departments, to be undertaken by proving the required budgetary support of Rs. 100 crores.

11. Need for future watershed improvement programs to replicate such potential in all peri-urban areas to collect, treat and recharge ground water around the towns and cities and augment the existing ground water resources.

12. Current wastewater treatment methods /regulations require stripping the treated water free of nitrogen and phosphorus content and is generally a non-sustainable approach. Methods to capture these nutrients and reuse them on farmland need to be evolved.

13. Long term ground water budgeting using recharge from all available sources would be key towards sustainable agriculture in the climate-variable future for which techniques and farm friendly options need to be evolved.

- **Ensuring equitable access**: Small farmers and large enterprises should have equal access to water credits, preventing wealthier entities from dominating the market.
- **Harmonizing regulatory frameworks**: Water rights and regulations vary widely across states, necessitating harmonization for a standard water credit market.
- **Verification processes**: Ensuring that reported water savings are genuine and not overstated requires robust verification processes through third-party audits and digital tracking systems.
- **Economic valuation**: Establishing an economic value for water credits requires comprehensive studies to set baselines.
- A systematized framework and standard operating procedure need to be developed for implementation of water credit system inline with carbon credit system

13. Conclusion

The climate change induced vagaries of rainfall, dwindling groundwater resources, increasing water demand are well established realities. Now it is required to create more awareness among the stakeholders and convince with latest technologies available for efficient water use and augment groundwater. The success of an artificial recharge structure depends on the local field conditions such as soil type, nature and disposition of subsurface rock type, depth of weathering, availability of surplus water for recharge etc.

An integrated action plan for groundwater recharge and management includes efficient rainwater harvesting, its use for groundwater augmentation with different recharge mechanisms, wise use of water in agriculture, industry and domestic sector, afforestation, rejuvenation of tanks, institutional mechanisms. These should be adopted by the respective departments of the Government by converging various schemes to augment groundwater. It can be a guiding document for future planning. Structures can be constructed depending on the field requirement, field suitability and availability of funds, from executive field departments, etc.

Appendix 1. District Wise GW Recharge, Exploitation and Balance available for 2022-23

ANNEXURE- VIA: DISTRICT WISE GROUND WATER RESOURCE ASSESSMENT OF KARNATAKA (in TMC) - GWRA 2023

Sl. No	District	Annual Ground water Recharge (TMC)	Annual Extractable Ground Water Resource (TMC)	Annual Ground Water Extraction for Domestic Use (TMC)	Annual Ground Water Extraction for Industrial Use (TMC)	Annual Ground Water Extraction for Irrigation Use (TMC)	Total Annual Ground Water Extraction for all uses (TMC)	Stage of Ground Water Extraction (%)	Allocation of Ground Water Resource for Domestic Utilisation for projected year 2025 (TMC)	Net Annual Ground Water Availability for Future Use (TMC)
1	Bagalkot	25.45	22.91	1.55	0.01	17.16	18.72	81.72	1.63	9.63
2	Ballari	24.29	21.86	0.68	0.13	5.19	6.00	27.46	0.74	15.92
3	Belagavi	44.47	40.31	4.37	0.08	22.85	27.29	67.71	4.92	14.46
4	Bengaluru (Rural)	7.30	6.64	0.91	0.29	9.03	10.23	154.00	0.98	0.00
5	Bengaluru (Urban)	8.38	7.54	1.25	2.83	7.29	11.37	150.84	1.29	0.00
6	Bidar	13.29	11.97	1.51	0.00	5.51	7.02	58.63	1.56	4.91
7	Chamarajanagara	14.10	12.80	0.95	0.01	11.39	12.35	96.53	1.12	1.37
8	Chikkaballapura	12.30	11.07	1.06	0.03	15.94	17.03	153.82	1.12	0.00
9	Chikkamagaluru	24.66	22.19	0.87	0.00	10.93	11.81	53.20	0.93	11.08
10	Chitradurga	16.41	14.77	1.37	0.03	18.13	19.54	132.25	1.44	0.33
11	Dakshina Kannada	25.90	23.31	1.82	0.01	8.61	10.44	44.78	1.94	12.74
12	Davanagere	22.11	19.90	1.28	0.08	16.33	17.69	88.91	1.32	6.53
13	Dharwad	11.41	10.27	0.60	0.03	5.15	5.78	56.24	0.62	4.47
14	Gadag	12.50	11.40	0.23	0.01	8.27	8.51	74.62	0.26	3.10
15	Hassan	28.00	25.20	1.07	0.00	16.91	17.98	71.35	1.11	9.99
16	Haveri	23.24	20.91	0.69	0.03	12.04	12.76	60.99	0.77	8.93
17	Kalburgi	25.42	23.06	2.52	0.02	6.93	9.47	41.06	2.70	13.58
18	Kodagu	8.71	7.84	0.33	0.03	2.81	3.17	40.39	0.34	4.66
19	Kolara	16.06	14.46	1.45	0.05	23.48	24.98	172.80	1.52	0.00
20	Koppal	23.02	20.87	0.97	0.02	11.92	12.91	61.84	1.03	9.28
21	Mandya	25.92	23.38	1.39	0.02	12.79	14.20	60.75	1.41	10.19
22	Mysuru	22.03	19.91	1.50	0.03	9.48	11.01	55.30	1.59	8.97
23	Raichur	27.30	24.66	1.14	0.06	9.82	11.03	44.73	1.27	14.13
24	Ramanagara	15.98	14.39	1.09	0.26	12.43	13.78	95.77	1.16	1.49

Sl. No	District	Annual Ground water Recharge (TMC)	Annual Extractable Ground Water Resource (TMC)	Annual Ground Water Extraction for Domestic Use (TMC)	Annual Ground Water Extraction for Industrial Use (TMC)	Annual Ground Water Extraction for Irrigation Use (TMC)	Total Annual Ground Water Extraction for all uses (TMC)	Stage of Ground Water Extraction (%)	Allocation of Ground Water Resource for Domestic Utilisation for projected year 2025 (TMC)	Net Annual Ground Water Availability for Future Use (TMC)
25	Shivamogga	37.61	34.10	0.95	0.09	12.82	13.85	40.62	0.97	20.87
26	Tumakuru	29.32	26.39	2.02	0.03	22.17	24.21	91.77	2.11	5.10
27	Udupi	18.50	16.65	0.74	0.01	4.87	5.62	33.75	0.76	11.01
28	Uttara Kannada	32.81	29.63	1.10	0.00	8.41	9.51	32.11	1.13	20.09
29	Vijayanagara	14.45	13.05	0.78	0.01	10.11	10.90	83.49	0.82	2.83
30	Vijayapura	40.22	33.69	1.77	0.01	11.87	13.65	40.50	1.85	20.36
31	Yadgir	19.98	18.08	1.01	0.31	5.55	6.87	37.99	1.07	11.50
	Total(TMC)	671.15	603.20	38.98	4.53	356.16	399.66	66.26	41.50	257.51

Appendix 2: Existing policies, acts, rules and regulations on groundwater in Karnataka

Year	*Policy/ Act/ Rule*	*Purpose*
1965	Karnataka Groundwater Act	Regulation and management of groundwater extraction to prevent overexploitation and depletion.
1972	Water (Prevention and Contro of Pollution) Act	Regulating and preventing water pollution to safeguard groundwater quality.
1999	Karnataka Groundwater (Regulation and Control of Development and Managemen Act	Further regulation of groundwater extraction management, and conservation.
2002	Karnataka Groundwater (Regulation and Control of Development and Managemen Rules	Detailed rules specifying procedures for groundwater extraction permits, monitoring, and enforcement.
2011	Karnataka State Water Policy	Setting guidelines for sustainable water resource management, including groundwate to ensure equitable distribution and conservation.
2014	Karnataka State Groundwater Policy	Providing a framework for sustainable groundwater management, addressing issues like over-exploitation, quality degradation, an promoting recharge measures.
2020	Karnataka Groundwater (Regulation and Control of Development and Managemen Amendment Act	Amendments to strengthen regulations, streamline processes, and enhance enforceme mechanisms to prevent illegal extraction and promote sustainable use.
2020	Jal Jeevan Mission	To provide operational water supply to every household in the rural areas, providing a capacity of 55 lpcd of clean drinking water every day.
2022	Karnataka State Water Policy	To promote re-cycling and reuse of treated waste water and rainwater harvesting

Appendix 3: Department wise responsibilities for implementation of the integrated action plan

	Actionable points	*Department Responsible*
I. Rural Areas		
A. Rain Water Harvesting:		
i	*In-situ* rainwater harvesting	WDD, Agriculture, Horticulture, Sericulture, Forestry, RDED
ii	*Ex-situ* rain water harvesting	WDD, RDPR, Forestry
iii	Rejuvenation of tanks and installation of shafts for recharge	Minor Irrigation and RDPR, Gram Panchayaths
iv	Roof top rain water harvesting	RDPR
B. Regulated Drilling of Borewells:		
i	Permissions for new borewell	Groundwater Directorate
ii	Monitoring the borewells	RDPR
iii	Mandatory borewell recharge	RDPR
C. Minimization of Groundwater Exploitation:		
i	Creating awareness	RDPR
ii	Regulated supply of water	RDPR
iii	Imposing water charges	RDPR
iv	Industrial water regulation	Industries and Commerce, PCB
v	Participatory Groundwater Management	RDPR, WDD, GWD
vi	Legal frame work	WDD, NLSIU, Law Department
D. Promotion of Good Agricultural Practices		
i	Adoption of drip irrigation	KAMIC, Agriculture, Horticulture, Sericulture
ii	Precision Irrigation	KAMIC, Agriculture, Horticulture, Sericulture
iii	Mulching	WDD, Agriculture, Horticulture, Sericulture
iv	Soil health improvement	WDD, Agriculture, Horticulture, Sericulture
v	Redesigning of Cropping system	WDD, Agriculture, Horticulture, Sericulture and Water Resources Department

	Actionable points	***Department Responsible***
E. Conjunctive use of water		WDD, Agriculture, Horticulture, Sericulture Aad Urban Development
F. Afforestation		
i	Revival of forest area	Forest Department,
ii	Agro-forestry	Forest Department, WDD, Agriculture, Horticulture and Sericulture
iii	Construction of shallow and slopy ponds in the forest	Forest Department and WDD
G. Water Credit		WDD
II. Urban Areas		
a	Rooftop rainwater harvesting	BBMP, BDA, Urban Development Department
b	Greening of the residential area	BBMP, BDA, Urban Development Department, Forestry Department
c	Tank rejuvenation	BBMP, BDA, Urban Development Department, Forestry Department, Minor Irrigation
d	Promotion of usage of treated water for parks, flushing and gardening	BBMP, BDA, Urban Development Department, BWSSB
e	Filling tanks with treated water	BBMP, BDA, Urban Development Department, BWSSB
f	***Reduce, Recycle and Reuse***	BBMP, BDA, Urban Development Department, Industries
g	***Establishment of Infiltration Galleries***	BBMP, BDA, Urban Development Department
h	***Utilization of Reverse Osmosis (RO) filters rejected water***	BBMP, BDA, Urban Development Department

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