Ministry of Irrigation

Integrated Watershed and Water Resources Management Project (IWWRMP) Project Management Unit (PMU)

CONSULTING SERVICES FOR DEVELOPMENT OF GROUNDWATER MANAGEMENT PLAN FOR MALWATHU OYA, DEDURU OYA, KUMBUKKAN OYA, MADURU OYA, MI OYA, MAHA OYA, KELANI BASIN AND JAFFNA PENINSULA

Contract No. LK-MOMDE-330742-CS-QCBS

DRAFT REPORT ON IDENTIFICATION OF GROUNDWATER USER GROUPS AND THE ABSTRACTIONS OF GROUNDWATER RESOURCES

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Integrated Development Consultants (Pvt) Ltd
No. 50/3, Old Kesbewa Road,
Rattana[itoya, Boralesgamuwa

Global Research Foundation
No 108 A, Stanley Thilakaratha Mwatha,
Nugegoda

Version	Originator	Checked by	Date	Observations
1.0	Sydney de Silva Ananda Dissanayake	Sunidha Senaratne		

Disclaimer

This Report has been prepared to fulfil Task 2 of the Terms of Reference of the Consultancy assignment "Development of Groundwater Management Plans for Malwathu Oya, Deduru Oya, Kumbukkan Oya, Maduru Oya, Mi Oya, Maha Oya, Kelani Basin and Jaffna Peninsula (WRB)". It is to identify the different user groups of groundwater and to quantify the amount of abstractions utilized for particular uses in the study areas. The outcome will be directly used in the rest of the tasks, leading to the preparation of Groundwater Management Plans as per the Consultancy Contract Agreement.

The data and information presented herein have been obtained from various sources, including reports, publications, and databases maintained by Governmental and non-governmental organizations. Further to obtaining the secondary data, the consultant team spent a considerable amount of time collecting field-level data and also engaged in field verification programs to scrutinise data recorded in the databases of some of the institutions.

The findings, interpretations, and recommendations are based on the data available at the time of preparation and are subject to change as new information becomes available.

Acknowledgement

The Consultancy Team would like to thank the Project Director and the staff of the PMU of the IWWRMP, and the officials of the Water Resources Board for the initial guidance provided to the Team. The Team appreciates all the officers in the relevant organisations and colleagues who shared their information and insights with the Team, and hopes to do justice to their valuable inputs.

List of Abbreviations and Acronyms

ASR	Aquifer Storage and Recovery
BOI	Board of Investment
CBO	Community Based Organization
CEA	Central Environment Authority
CCSL	Climate Change Secretariat Sri Lanka
DAD	Department of Agrarian Development
DEM	Digital Elevation Model
DI	Department of Irrigation
DMC	Disaster Management Centre
DNCWS	Department of National Community Water Supply
EA	Environmental Assessment
GRF	Global Research Foundation (JV Partner of the Consultant)
GSMB	Geological Survey and Mines Bureau
GMP	Groundwater Management Plan
GRPM	Groundwater Potential Map
HH	Household
INGO	International Non-Governmental Organization
IDC	Integrated Development Consultants (Pvt) Ltd (Lead Partner of the Consultant)
IWRM	Integrated Water Resources Management
lpcpd	Litres per Capita per Day
LC	Land Cover
LU	Land Use
MAR	Managed Aquifer Recharge
MWS	Ministry of Water Supply/Ministry of Housing, Construction and Water Supply
MET	Meteorology Department
NBRO	National Building Research Organization
NGO	Non-Government Organization
NWSDB	National Water Supply and Drainage Board
O&M	Operation and Maintenance
PHDT	Plantation Human Development Trust
PS	Pradeshiya Sabha (Local Government)
RWSS	Rural Water Supply and Sanitation
UDA	Urban Development Authority
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization
WMO	World Meteorological Organization
WSS	Water Supply and Sanitation
WSSs	Water Supply Schemes

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CHAPTER 1. INTRODUCTION AND BACKGROUND

1.1 This Report

This report, "Report on Identification of Groundwater User Groups and the Abstractions of Groundwater Resources – D 4" is a contractual output under Task 2 of the study, which is aimed at identifing groundwater user groups and the abstractions of groundwater resources. The outcome of the task is expected to be:

- User groups of groundwater identified
- Uses of groundwater identified
- Areas with water stress identified
- Areas with deterioration of water quality identified

1.2 Consultancy Assignment

The Project Management Unit (PMU) of Integrated Watershed & Water Resources Management Project (IWWRMP) invited proposals for consultancy services for the Development of Groundwater Management Plans for Malwathu Oya, Deduru Oya, Kumbukkan Oya, Maduru Oya, Mi Oya, Maha Oya, Kelani basin and Jaffna Peninsula in February 2024. The two consultancy firms, Integrated Development Consultants (Pvt) Ltd (IDC) and Global Research Foundation (Pvt) Ltd (GRF), as a Joint Venture (JV) submitted proposals in March 2024. After evaluation of the proposals, PMU awarded the consultancy assignment to IDC-GRF JV in March 2024.

Accordingly, IDC-GRF JV signed the consultancy agreement on 29th April 2024. The period of the consultancy assignment was 12 months. Accordingly, the assignment was due to be completed on 29th April 2025. Due to reasons beyond the control of the Consultant, the execution of the consultancy was delayed, and the time period was extended by an Addendum till 29th November 2025. Due to the continued issues encountered, a further extension is expected to be approved.

1.3 The Consultants

The joint venture between Integrated Development Consultants (IDC) and Global Research Foundation (GRF) is the consultant, while IDC is functioning as the lead partner with the authority to deal with the Client.

1.4 Overview of the Study

1.4.1 Introduction to the Project

The Government of Sri Lanka (GOSL) is implementing the Integrated Watershed and Water Resources Management Project (IWWRMP) under the Ministry of Irrigation (MI) of Sri Lanka, with the assistance of the World Bank. The Project Development Objective is to improve watershed and water resources planning and enhance the functionality of water resources infrastructure. The overall project consists of four main components with further divisions under Component 1, as shown in Figure 1.1.

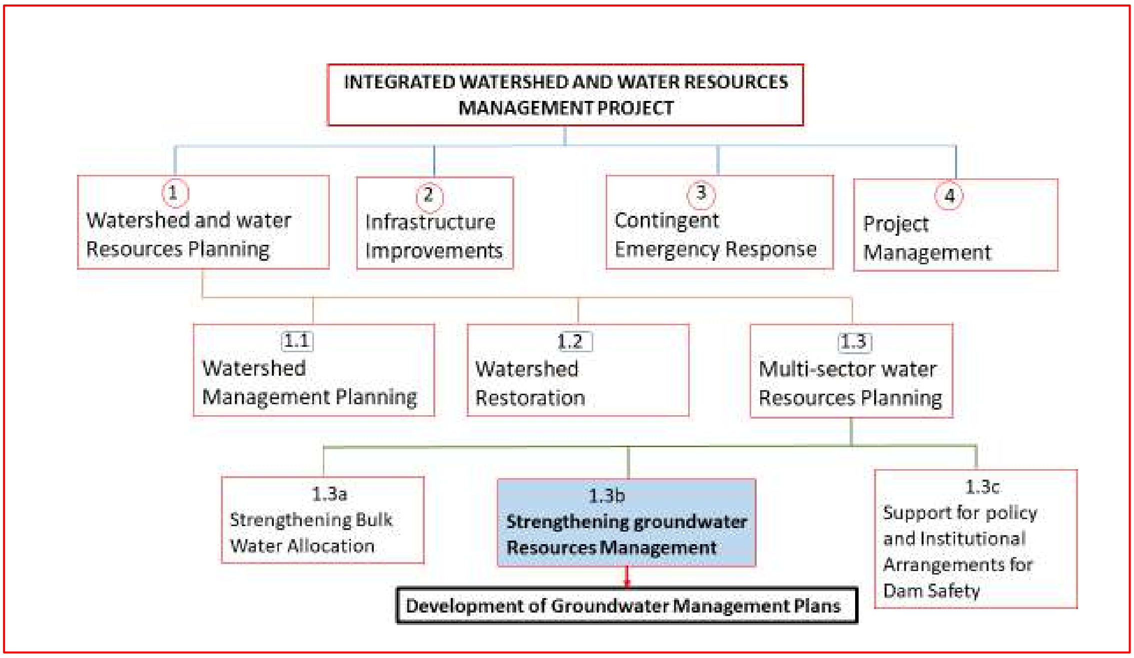


Figure 1.1: Overall Project Structure

Under the division of 1.3b in the above, eight hydrologic Units have been identified for the initial assessment by carrying out several activities to finalize four Units for the development of Ground Water Management Plans as specified in the TOR. The identified Units for the initial study are Mi Oya, Maha Oya, Deduru Oya, Kelani, Malwathu Oya, Kumbukkan Oya, and Maduru Oya river basins and Jaffna Peninsula. The distribution of these hydrologic Units as per the climatic zones as shown in Figure 1.2.

Hydrologic units(Study areas)	Climatic zone			Drainage area (Sq. km)
	Wet	Intermediate	Dry	
Malwathtu oya			√	3291
Daduru oya	√	√		2623
Kelan river	√			2282
Mi oya		√	√	1516
Maha oya	√	√		1528
Kumbukkan oya		√	√	1218
Maduru oya		√	√	1487
Jaffna Peninsula			√	1018

Figure 1. 2 : Basins Selected for the Study

1.5 Overall Objective and Tasks of the Assignment

The overall objective of the project is to strengthen Groundwater Resources Management in Sri Lanka by performing eight tasks that are outlined in Figure 1.3, and described later in the report.

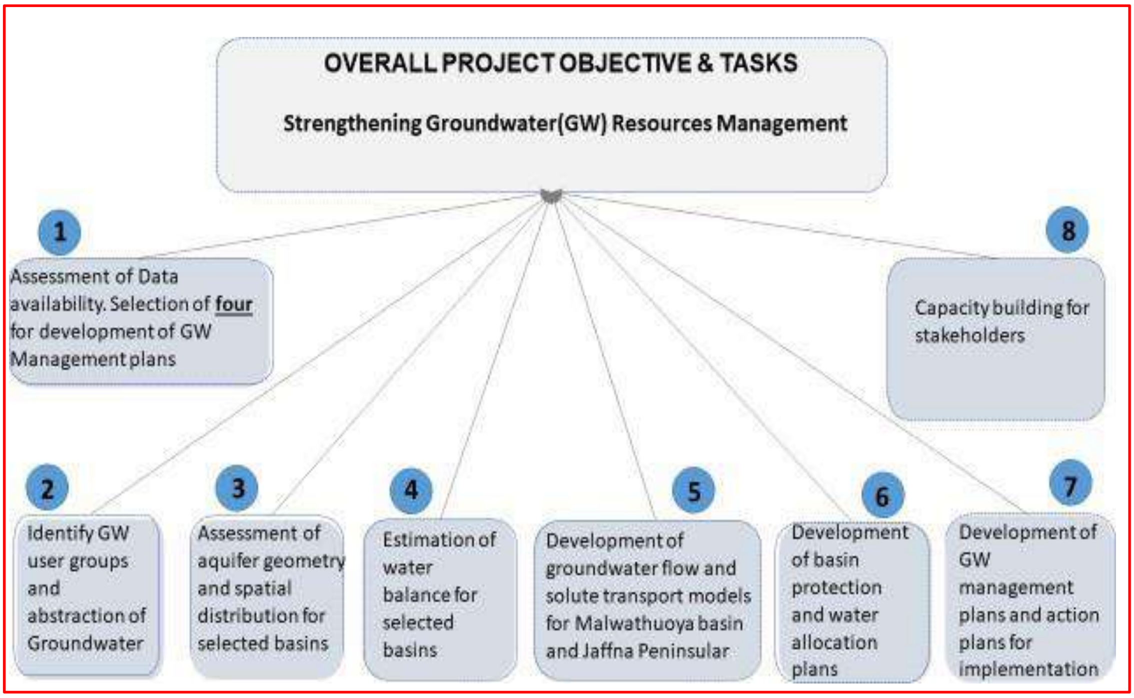


Figure 1.3 :Overall Project Objective and Tasks

1.6 The Present Status of the Project

Deliverable 1 was submitted. The following hydrologic units were finalized as the most suitable hydrologic Units for the development of Groundwater Management plans (Figure 1.4).

- Keleni River Basin
- Malwathu Oya Basin
- Deduru Oya Basin
- Jaffna Peninsula

Figure 1.4: Selected Hydrologic Units

CHAPTER 2: APPROACH AND METHODOLOGY

The Tasks assigned to the consultant leading to the preparation of Groundwater Management Plans are as follows. Seven key tasks are prescribed, with an additional task for providing training on identified topics to the staff of WRB and for the other key stakeholders.

Table 2. 1: Tasks of the Study

Task No	Task
1	Assessment of the availability of data/ information for the selected eight river basins and identify the most appropriate four river basins for developing the groundwater management plans, focusing on Task 2 to Task 8.
2	Identify groundwater user groups and the amounts of abstraction
3	Development of aquifer maps-Hydrogeological maps
4	Prepare water balance for each river basin
5	Development of numerical flow models for Malwathu Oya and Jaffna peninsula. ***(Note: At the request of WRB, PMU instructed the Consultant to develop the numerical groundwater model for Kelani River basin, instead of for the Malwathu Oya Basin as required in the TOR.)***
6	Development of Basin protection and water allocation plans
7	Preparation of Groundwater Management Plans
8	Capacity Development activities

This report addresses the following as per the scope of work of Task 2, which will provide a broad overview of the availability of groundwater resources in sufficient quantity and suitable quality for different uses and the abstraction pattern accordingly.

- Assessment of the present hydro-geochemistry of the river basin
- Assessment of temporal & spatial, quantity and quality requirements of present and future groundwater demand and use
- Identify the major user groups within the basin and their abstraction volumes and distribution of abstraction, spatial and temporal abstraction behaviours.
- Present stresses on aquifers in quality and quantity due to over-abstractions and other anthropogenic activities or geogenic nature.
- Assessment and identification of recharge zones with potential for the recharge volumes and the runoff or rainfall collecting storage availability.
- Identify the recharge scheduling or lagging period after rainfall if the rainfall-recharge phenomenon cannot be coexistence due to groundwater level is too shallow during the natural recharge by the rainfall and evaluation of the relative importance in collaborating with the basin surface water planning team and propose the requirement of the type of groundwater artificial recharge structure/s & conceptual structural design/s with necessary guidelines for implementation and follow ups.
- Identification and assessment of the contaminant sources and their threats to groundwater quality.

- Assessment of future aquifer stresses and groundwater conditions under different patterns of water demand and water use, recharge availability, rainfall patterns, contamination, etc.

In the preparation of this report, a thorough assessment of the study areas was conducted in different aspects, as given in the succeeding chapters.

2.1. Methodology

The availability of groundwater is basically linked to the hydrological cycle, which shows how each element contributes to the occurrence of groundwater. The groundwater use is partially referred to the outflow that is related to the water balance formulae.

Identification of the groundwater uses and the extent to which the water is utilized is of great importance from the groundwater management perspective in a sustainable manner. The study highlighted how the users cope with the demand and supply related to water quality and quantity. Further to this, it is important to identify the over-abstraction across basins by various users, exerting additional stresses on aquifer/s, resulting in further deterioration of water quality and depletion of groundwater storage. The identification of groundwater user groups and the patterns of abstraction of groundwater resources will help develop proper groundwater management plans for the relevant basins.

The quantity of groundwater abstracted daily by dominant users such as NWSDB and large private industries/ soft drink producers/farmlands is usually controlled and recorded. In contrast, almost all self-supplied small-scale industries, domestic-level manufacturers, medium-scale cultivators, animal husbandry owners and domestic users are not legally obligated to measure their groundwater extractions. The methodology we propose to adopt has a wide range of coverage to identify and account for non-recorded uses and users to fulfil the requirements of the task.

The outcomes of this Task are as follows:

- User groups of groundwater identified
- Uses of groundwater identified
- Areas with water stress identified
- Areas with deterioration of water quality identified
- Site with potential for artificial recharge identified

2.1.1. Field Program

Field activities are vitally important under this task as most of the small to medium level users go unnoticed, or records with respect to groundwater uses and quantities are not properly maintained. Planning of a field program needs to be properly programmed to obtain good results.

Prior to the field program, a thorough assessment of the data and information obtained during the literature survey was conducted to gain an insight into the overall aspects of water resources in the basin in general and the Present Status of the Groundwater Resources in particular.

Table 2.2 illustrates the required data and information in the process of characterization of the basin in terms of geomorphological, demographical, meteorological, hydrological, geological and hydrogeological, water quality and hydrochemical settings that influence the use and abstraction by different users. A detailed description of elements in Table 2.2 is presented in Chapter 3 of the report.

Table 2.2- Data and Information that Influence the Groundwater Uses

Task No	Task Description	Data and Information Requirement
2	Identify groundwater user groups and the abstractions of groundwater resources	i. Physical characteristics of the Basin ii. Population distribution and projections iii. Land Cover and Use: (a) Forestry (b) Agriculture iv. Water quality analysis across the Basin with distribution maps v. Standards for drinking and other uses such as agriculture, recreation, etc. vi. Annual overall Water demand of the Basin vii. Aquifer/s characteristics (Petro) viii. Aquifer/s dimensions (physical) ix. Aquifer/s distribution maps- x. Pumping test data xi. Water level monitoring data xii. Demand and supply - water stress

2.1.2. Data Selection and Acquisition

In general, a river basin typically comprises several Divisional Secretariats (DS) or parts, each is further divided into smaller administrative units known as Grama Niladhari (GN) Divisions, facilitating effective governance at the village level. Figure 2.1 illustrates the DS and GN divisions within the Deduru Oya basin, where approximately 38 DS divisions are subdivided into 1,116 GN divisions.

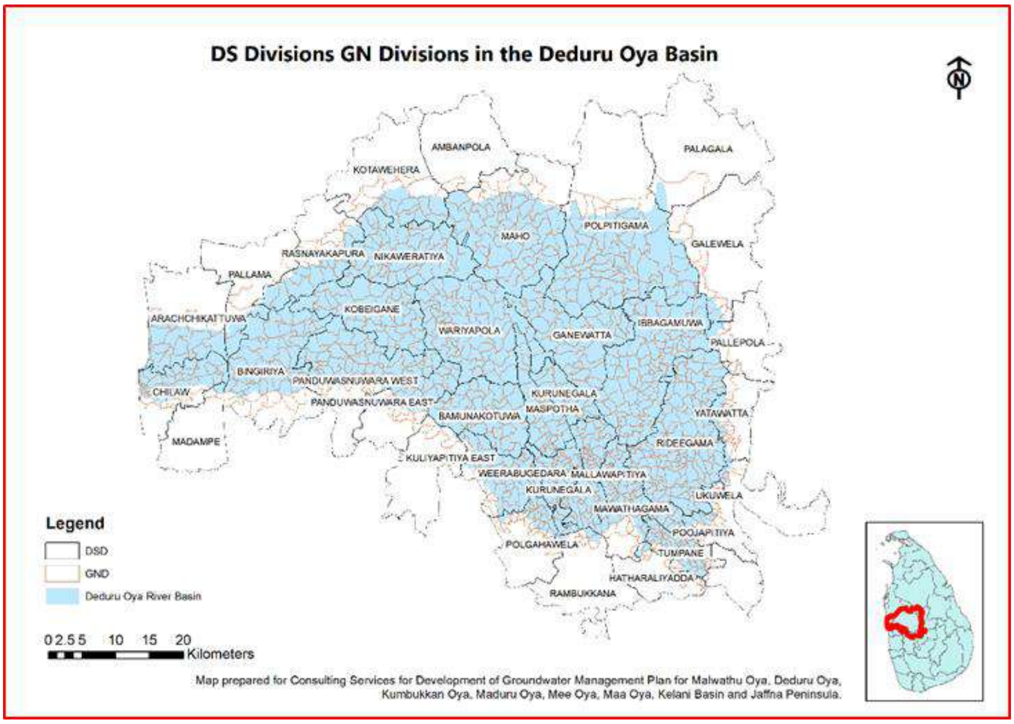


Figure 2.1: DS and GN Divisions within Deduru Oya Basin

Requirements of data needed to identify groundwater uses in the basins are attributed to the characteristics of the basin listed in Table 2.2. For example, the water quality heavily governs the domestic use of water. The water quality also affects the watering for crop types, as the use of low-quality water affects the harvest. Physical characterization of the basin and information gathered from proper Key Informants (KI) are vital in the process of realistic assessment of the nature of groundwater abstraction and its application.

Table 2.3 provides the institutions and the availability of data and information for the assessment of the water availability and utilization.

Table 2. 3: Institutions and Data Availability

Institution	Data Package and Form of Availability	Data that could be Acquired
WRB (Water Resources Board)	Groundwater database and real-time data	Geology, land use, surface geophysical profiles, hydrogeology and hydrochemical data
NWSDB (National Water Supply and Drainage Board)	Groundwater database	Tube well data, both surface and groundwater abstraction data, water quality data, pumping test data, groundwater monitoring data
DNCWS (Department of National Community Water Supply)	General Database	General data on rural WSS managed by CBOs, water abstraction and some hydrochemistry information
Irrigation Department (ID)	Hydrology database	Basin and hydrology, River flows, reservoir capacities, water quantities released for

Institution	Data Package and Form of Availability	Data that could be Acquired
		irrigation
Department of Agrarian Development (DAD)	Agrarian Database	Agro wells & minor irrigation tank capacities
Meteorological Dept.	Meteorology database	Climate data
Climate Change Secretariat (CCSL)	Climate change forecasting at basin level	Climate change impacts
Maheweli Authority of Sri Lanka (MASL)	Database on Water availability	Reservoir data, water diversion data between basins, reservoir capacities, water quantities released for irrigation
Central Environmental Authority (CEA)	Water quality (Soft & Hard copies)	Water quality data, Effluent dischargers
National Disaster Management Centre (DMC)	Database of disaster management	Flood and drought events
National Survey Dept (NSD)	Maps	Digital topo maps
Geological Survey and Mines Bureau (GSMB)	Geological and mining database	Geological maps, Mining locations
Local Govt. Authority (LA)	Data on potable water and solid waste	Water supply data, Waste disposal sites
Lanka Rainwater Harvesting Forum (LRHF)	Data on rainwater harvesting	Rainfall harvesting data at the domestic level
NGOs & INGOs	Well Data Data on specific projects (GW Recharge)	Rural water supply GW Recharge in Jaffna peninsula
Drilling companies	Hard copies	Borehole data

2.1.3 Identification of Key Informants at the Basin Scale

After reviewing the existing data, maps, and other information, we initiated stakeholder consultations and interviews with Key Informants (KI) with the intention of identifying water use at the local scale.

Key Informant Interviews (KIIs) with various categories of groundwater users are particularly helpful in assessments, since they allow obtaining in-depth information about the groundwater users, level of groundwater use and users' attitudes and knowledge on the extraction of groundwater.

Figure 2.2 illustrates the approach that we used to obtain accurate and reliable information to identify the groundwater uses in the basin.

KIIs were conducted using semi-structured interview formats to assess the level of groundwater use by stakeholders.

The figure illustrates the flow diagram to show how KIIs are effective in gathering information at field level.

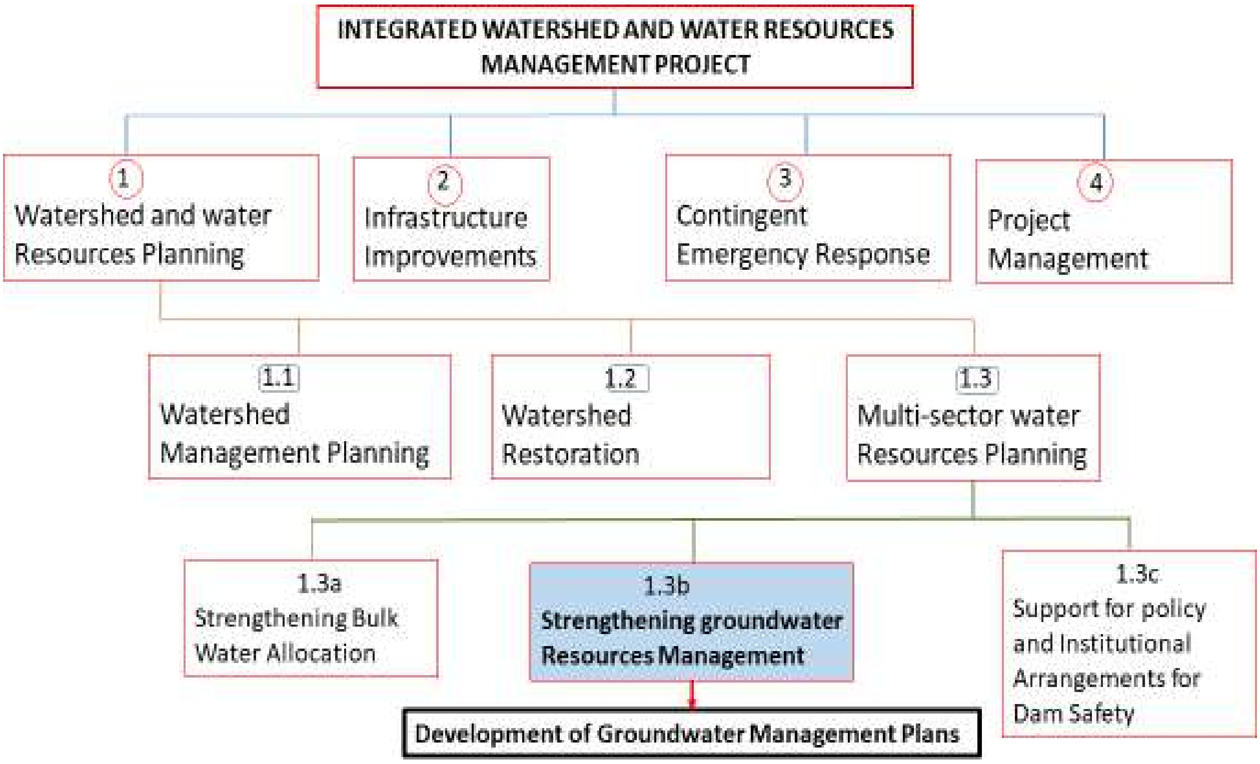


Figure 2.2: Field-level Data Collection Strategy

CHAPTER 3: KEY PROPERTIES AND PROCESSES OF A RIVER BASIN

This chapter presents some concepts that are needed to consider for characterizations of river basins in a common platform.

A river basin, also known as a drainage basin or catchment area, is the area of land where all surface water converges to a single point. Table 2.2 highlights the task description and the data requirement in order to identify the groundwater uses and the pattern of abstraction with respect to the spatial changes across the basin with temporal variations. These spatial changes and temporal variations influence the occurrence of groundwater, resulting in the availability of groundwater for different uses and the pattern of abstraction at the river basin scale. The following section provides a description of key physical properties and hydrologic processes of a river basin that control the availability of water resources.

3.1. Key Physical Properties

The physical properties of a river basin include its size and shape (morphometry), topography, the characteristics of its soil, the nature of the underlying geology, the type and density of vegetation, and the climate within the basin. These attributes, which describe the land and its elements, influence how water moves through the basin, affecting processes like runoff, infiltration, evaporation, and erosion.

3.1.1. Morphometric Properties:

- Drainage Area: The total land area drained by a river and its tributaries.
- Basin Shape: The geometric outline of the drainage basin, which influences the timing of water flow.

3.1.2. Stream Network:

- Drainage pattern: The number of streams, their order (stream hierarchy), and the lengths of channels, all of which form the basin's drainage pattern.
- Stream Density: The total length of stream channels per unit area.

3.1.3. Topographic Properties:

- Elevation and Slope: The elevation of different parts of the basin and the steepness of its surfaces, which control water flow and erosion.
- Landforms: Features such as V-shaped valleys, waterfalls, and plains that result from the river's erosive power over time.

3.1.4. Soil and Geology:

- Soil Characteristics: The texture, depth, and hydraulic properties of the soil, such as permeability and drainage, which affect water infiltration and storage.
- Subsurface Geology: The type of rock and geological formations underlying the basin, which influence groundwater flow and the availability of water resources.

3.1.5. Vegetation:

- Plant Cover: The type, density, and distribution of vegetation, which play a crucial role in intercepting rainfall, influencing soil moisture, and reducing erosion.

3.1.6. Climate:

- Rainfall and Temperature: The amount of precipitation (rain, snow, hail) and the average air temperature, which drive the hydrologic cycle.
- Evaporation and Transpiration: The rates at which water evaporates from the surface and is transpired by plants, returning water vapor to the atmosphere.

3.1.7. Hydro-geochemistry

- Hydrochemistry: Hydrochemistry plays a vital role in the use of groundwater for different purposes. Chemistry refers to the water quality, and the anthropogenic activities cause the quality to deteriorate.

3.2. Key Processes

The key processes (Figure 3.1) in a river basin involve the interconnected hydrological cycle and fluvial geomorphology, including water flow from precipitation and groundwater, sediment transport by erosion (hydraulic action, abrasion, attrition, solution) and deposition, and the resulting shaping of the landscape through meanders, floodplains, and other features.

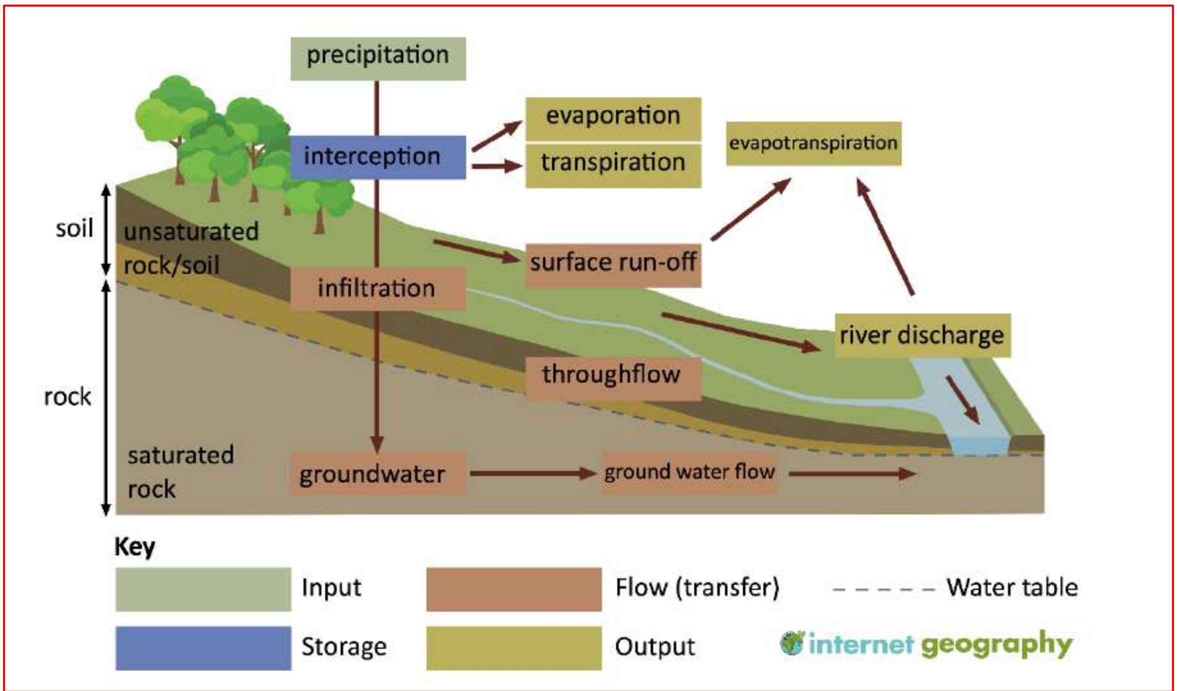


Figure 3.1: Typical Key Processes of a River Basin

3.2.1. Hydrological Cycle Processes

- Precipitation & Runoff: Water from rain and snowmelt flows over the land surface and into streams.
- Infiltration & Groundwater Flow: Some water soaks into the ground, replenishing aquifers and flowing into rivers as groundwater.
- Evapotranspiration: Water returns to the atmosphere from plants and the land's surface, influencing the amount of water available in the basin.

3.2.2. Fluvial Basin's Landforms:

Erosion:

- Hydraulic Action: The force of water alone wearing away rock.
- Abrasion (Corrasion): Rocks and sediment carried by the river scraping against the bed and banks.
- Attrition: Rocks and stones within the river knocking against each other, becoming smaller and rounder.
- Solution: Dissolving of certain types of rock by chemical reactions with the water.

Transportation:

The movement of eroded material (sediment) downstream. This happens through:

- Traction: Larger, heavy rocks rolling along the riverbed.
- Saltation: Smaller pebbles and stones bouncing along the riverbed.
- Suspension: Fine, light material like silt and clay carried by the water.
- Solution: Dissolved minerals carried invisibly within the water.

Deposition

- When the river loses energy, it drops the sediment it is carrying. These form features like floodplains and deltas.

3.2.3. Other Interconnected Processes

- Sediment Flux: The movement and transfer of sediment from hillslopes into rivers and through the river system.
- Biogeochemistry: The cycling of elements like carbon and nitrogen within the basin, affecting water quality and ecosystem health.
- Aquatic Ecosystems: The biodiversity and function of riverine environments, impacted by water flow, sediment, and other factors.

- Geochemistry: The process by which groundwater interacts with the surrounding geological environment and forms different water types.

CHAPTER 4. BASIN CHARACTERIZATION

The main objective of this chapter is to look at each study area and characterize them with respect to water resources availability in terms of the annual precipitation and water usage. The annual groundwater recharge in each study area varies with respect to the climatic zone in which they are located. Nexus between rainfall recharge and abstraction influence the water balance in any hydrologic unit. The main challenge of this report is to identify the pattern of abstraction of groundwater for different uses such as water supply, agriculture, industrial and domestic, etc. and quantify the outflow that will provide one of the basic components in the water balance equation.

The following will be discussed in this chapter:

I. Rainfall distribution across each study area

II. Land cover (LC) and land Use (LU)

III. Groundwater use for different purposes

Rainfall distribution across the basin varies with many factors. Hence, it is better to evaluate at the catchment scale for proper evaluation of water resources. The groundwater quality depends on basically anthropogenic activities such as land use, and also due to geochemical reactions, geogenic processes/actions of groundwater with the geological environment over the time in the course of its flow. This is discussed in a separate chapter as it plays an important role in the water use for different purposes. LC/LU are also principal factors that affect the groundwater recharge/discharge, resulting in changes of groundwater quality and quantity.

The following sections will discuss the above three factors for each study area, which are closely related to the water availability and water use for the following requirements:

I. Water supply

II. Industrial and commercial

III. Irrigation

4.1. Deduru Oya Basin

4.1.1. Meteorology

General

Physiography of the basin can be divided into two broad categories, namely (a) Uplands, and (b) Lowlands. Within these two categories, a few Geomorphic Surfaces (terrains) can be identified on the basis of absolute altitude, slope and other characteristics according to the DEM of the basin (Figure 4.1).

It features a significant land gradient, with a steep slope in the upper reaches originating in the central highlands, gradually becoming flatter as the river flows towards the lowland coastal area, resulting in a distinct difference between the mountainous upstream and the relatively flat downstream terrain within the basin.

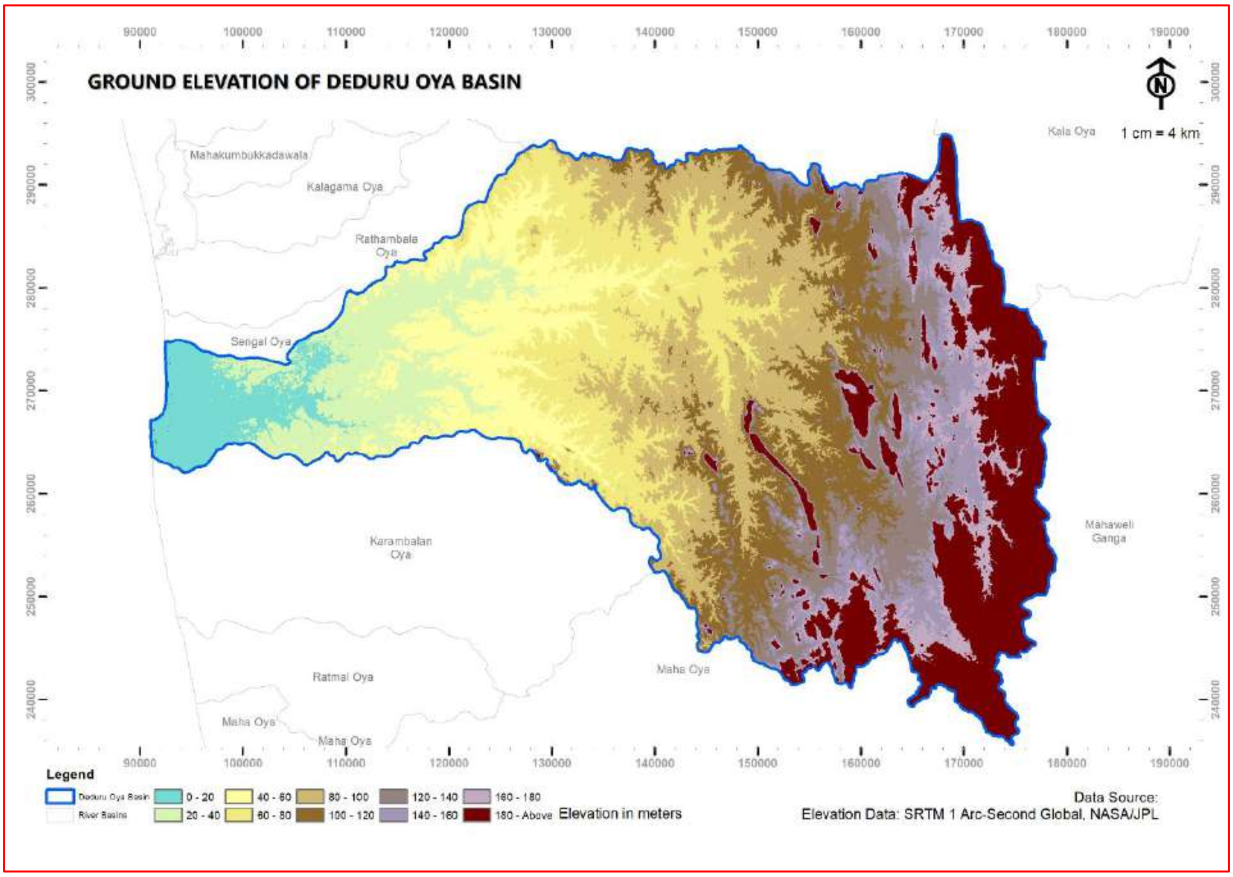


Figure 4.1 : Digital Elevation Model of Deduru Oya basin

A major portion of the basin falls under the intermediate climatic zone, with far upper reaches of the watershed originating in the Wet Zone as shown in Figure 1.4. A significant variation in rainfall over the basin can be expected due to these two zones affecting the water resources in different parts of the basin. The upper watershed area of the basin in the Wet Zone generates runoff, which flows into the lower portion of the basin, which has a low tendency to experience high rainfall events.

4.1.1.1 Rainfall

Rainfall is the only source of water for the Deduru Oya river basin. Water users in this basin benefit from direct rainfall, stream flow consisting of direct runoff, base flow or groundwater discharge, surface water storage in reservoirs, and groundwater storage. The basin primarily receives rainfall during the monsoon season, specifically from September to December, which is considered the North-East monsoon season, with the highest rainfall records.

Annual rainfall varies from 1100 mm to 2600 mm. The rainfall pattern in the basin shows two clear peaks in April/ May and October/November, and the minima are in February and August.

Rainfall Measurements

Figure 4.2 shows the distribution of the rain gauge stations in the basin. Four gauges are located within the boundary, while another two are located just outside the western boundary of the basin. The rainfall data is available in the respective institutions.

As per the geomorphology, the basin shows features attributed to a mixed terrain, such as flat and mountainous land forms. According to the WMO standards, and when considering the terrain features of the basin, the coverage of a single rain gauge station can be adjusted as $400km^2$.

Table 4.1 presents the percentage coverage of the basin by the rain gauges. and the weightage with respect to the standard coverage recommended by the WMO respectively.

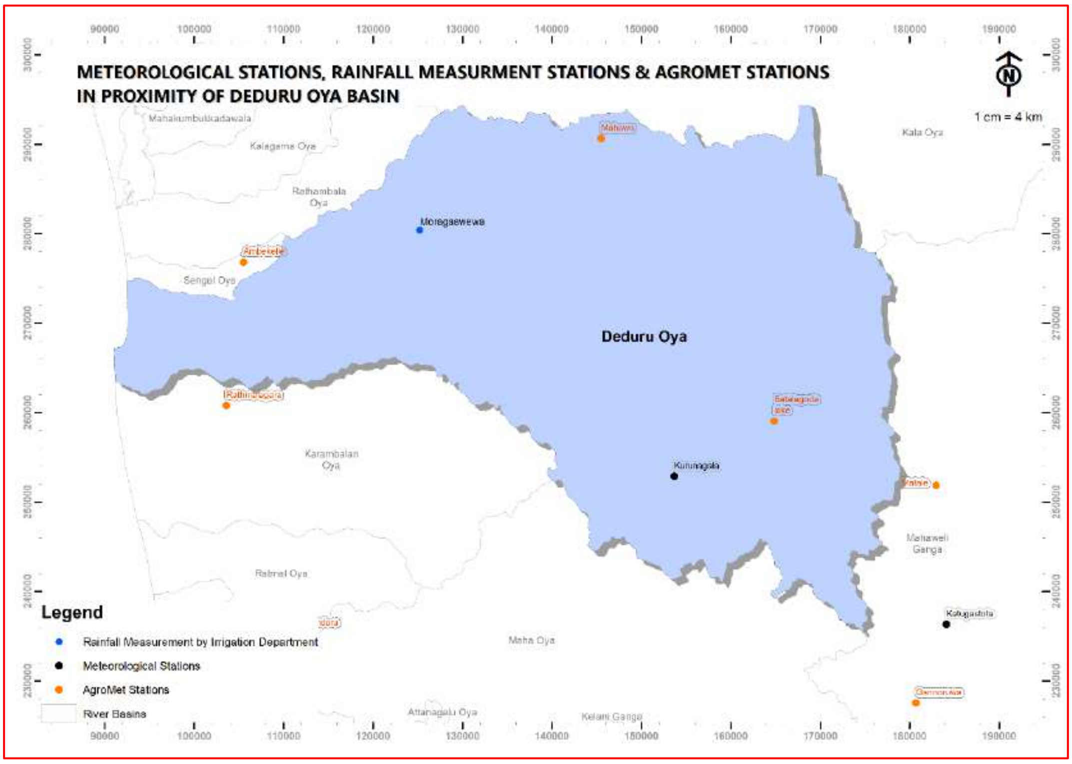


Figure 4.2: Locations of Rain Gauge Stations in Deduru Oya Basin

Table 4.1: Rainfall Gauge Coverage in Deduru Oya Basin

Number of Gauges	Total Coverage (km^2)	Unit Coverage (km^2)	Standard Coverage (km^2) by One Gauge	% of Standard Coverage to the Coverage by the gauges.
6	2623	440	400	100

As there are no trans-basin diversions to the Deduru Oya basin, rainfall is the only source of water. Average monthly rainfall in the basin, presented in Table 4.2 shows temporal variations of rainfall. High rainfall occurs in the basin area from March to April and September to December.

Table 4.2: Average Rainfall in Deduru Oya Basin

Month	Average Rainfall (mm)
January	66
February	65
March	72
April	217
May	159
June	87

Month	Average Rainfall (mm)
July	81
August	56
September	108
October	268
November	283
December	146
Average (Annual)	1,609

The occurrence of rainfall is not uniform throughout the basin (Figure 4.3). The data collected from rain- gauge stations (Table 4.3) in different parts of the basin show that spatial variations of rainfall are very high within the basin.

Table 4.3: Spatial Variation of Rainfall in Deduru Oya Basin

Location	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wariyapola	122	89	72	212	135	112	113	85	127	288	308	236
Chilaw	39	49	94	232	193	69	70	25	92	277	260	125
Batalagoda	70	66	80	211	155	114	89	69	125	277	256	151
Hakwatuna Oya	66	63	19	218	178	36	81	86	107	210	314	175
Magalla	59	58	29	182	118	63	65	17	65	202	252	104
Kurunegala	59	73	124	262	211	160	112	85	156	359	334	132
Nikaweratiya	45	59	83	198	127	55	40	26	84	263	262	102

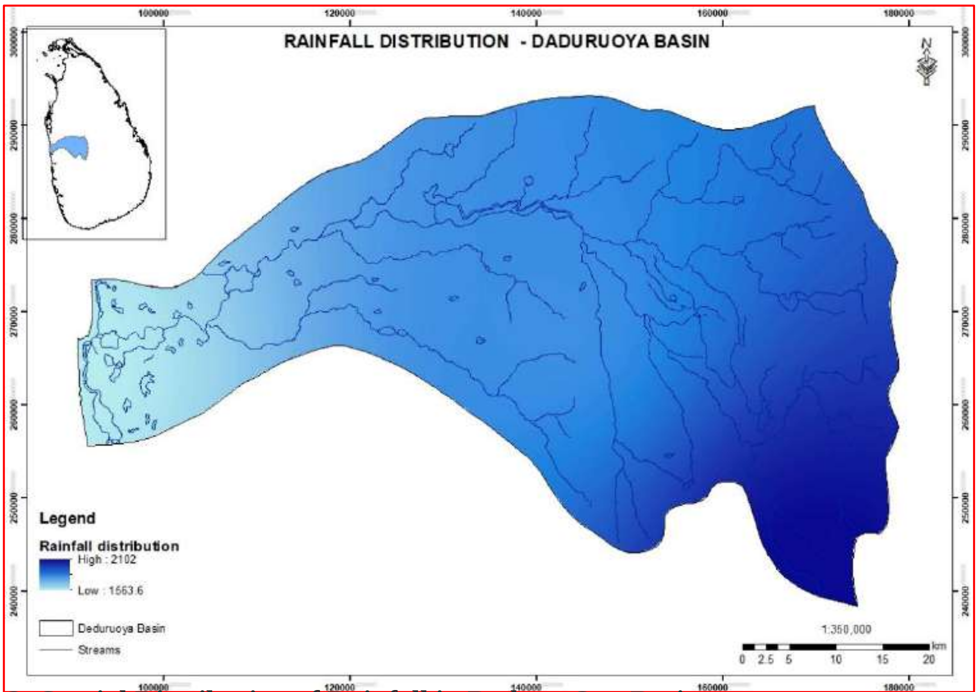


Figure 4.3: Spatial Distribution of Rainfall in Deduru Oya Basin

4.1.2. Land Use Pattern

Type and extent of Land use in the Deduru Oya basin is given in Table 4.4 and the nature of distribution is given in the Figure 4.4. The forest cover in the basin is around 5.14 per cent of the total land area of the basin. The total land use is fairly high, amounting to 94.16% of the land cover, of which most of the lands are utilized for the cultivation of coconut, highland crops, and paddy and settlement purposes. A great extent of land, about 38.47% is utilized for home gardens, and they are watered by groundwater available from the dug wells located in the gardens itself. Ground water usage by different users is described in Section 4.1.3.

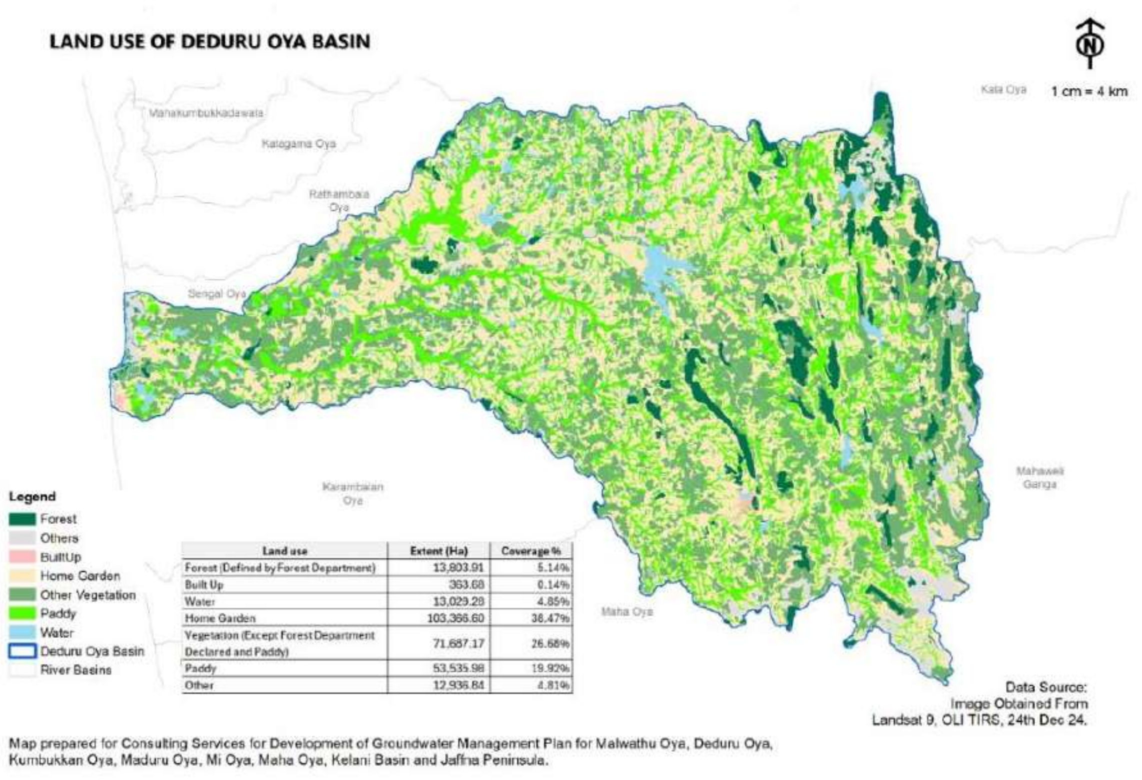


Figure 4.4: Land Use Pattern in Deduru Oya Basin

Table 4.4: Land Use Extents in Deduru Oya Basin

Land use	Extent (Ha)	Coverage %
Forest (Defined by Forest Department)	13,803.91	5.14%
Built Up	363.68	0.14%
Water	13,029.28	4.85%
Home Garden	103,366.60	38.47%
Vegetation (Except Forest Department Declared and Paddy)	71,687.17	26.68%
Paddy	53,535.98	19.92%
Other	12,936.84	4.81%

4.1.3. Utilization of Groundwater Resources

User Groups of Groundwater

Groundwater user identification and assessment of community experiences with groundwater stress were conducted in the Deduru Oya basin, which originates in the Kandy and Matale districts and flows through both the wet and intermediate climatic zones. Despite the variation in hydrological and climatic conditions across the basin, groundwater remains a critical and often primary water source for communities in these areas.

Groundwater users in the Deduru Oya basin range from individual households to national-level institutions (Table 4.5). The key groundwater user groups in the area are identified as follows:

(i) **Households** utilizing individual domestic wells, including shallow wells, shallow hand pump wells, and deep hand pump wells;
(ii) **Water consumer groups** accessing hand pump wells primarily for drinking purposes;
(iii) **Community Based Organizations (CBOs)** operating small-scale water supply systems drawing from both shallow and deep groundwater sources;
(iv) **National Water Supply and Drainage Board (NWSDB)**, which utilizes groundwater as a supplementary source in areas experiencing high demand or limited surface water availability;
(v) **Small-scale farmers** relying on groundwater to irrigate small plots cultivating vegetables, grains, coconuts, and fruits;
(vi) **Large-scale agricultural operators** using groundwater for the cultivation of both short-term and long-term cash crops.

According to the available district profiles prepared based on the household data collected through GN and other data sources, the groundwater users in Deduru Oya basin have been identified and are indicated in the table below:

Table 4.5: Groundwater User Groups in Deduru Oya Basin

	Groundwater Users	No.
1	Households with privately owned wells	128,026
2	Water consumer groups formed around hand-pump tube wells	8,576
3	Community Based Organization (CBO) that manages & operates RWS systems	254
4	Users of NWSDB-managed urban and small-town water supply schemes	4
5	Small-, medium-, and large-scale agricultural landowners utilizing agro-wells	2,573

4.1.3.1. Mode, Purpose, and Quantity of Groundwater Extraction

Groundwater serves as a vital source of fulfilling domestic water needs, including the drinking water supply in rural Sri Lanka. While paddy cultivation is primarily sustained by surface or irrigated water systems, shallow groundwater is extensively utilized for highland agricultural practices by farming communities in minor tank settlements in the dry zone areas.

The details on the methods of groundwater extraction for various purposes highlight the extent of groundwater usage across Deduru Oya basin, underscoring its critical role in sustaining rural livelihoods and agriculture. A considerable proportion of the population within the basin depends on groundwater for drinking, domestic use, and highland agriculture.

Domestic shallow-wells

Shallow wells play a vital role in the domestic water supply within Deduru Oya basin, having 128,026 shallow wells, although the inhabitants are provided with adequate water from four urban and 254 rural water supply (RWS) schemes (Table 4.6).

Table 4.6: Distribution of Dug Wells in Deduru Oya Basin

DS Area	No. of Dug Wells	DS Area	No. of Dug Wells
Bamunukotuwa	9,279	Mawathagama	12,353
Bingiriya	13,310	Palagala	n/a
Chilaw	3,623	Pallama	850
Ganewatta	8,459	Panduwasnuwara East	4,496
Kobaigane	8,092	Panduwasnuwara West	n/a
Kotavehera	1,530	Polgahawela	4,308
Kurunegala	17,033	Polpitigama	
Madampe		Rasnayakapura	1,647
Mallawapitiya	11,774	Wariyapola	12,704
Maspotha	9,564	Weerambugedara	8,930
Total	**82,664**	**Total**	**45,288**
Grand total			**127,952**

Since there are no records of water extraction from the domestic shallow wells, the quantity of water extracted has to be estimated based on the per-person water consumption, which is typically 65 lpcpd for all domestic purposes: drinking, cooking, bathing and washing. Accordingly, the total quantity of water extracted from shallow private wells for domestic use in the study area is 37,896m³ per day (Table 4.7).

Table 4.7: Quantity of Abstraction of Groundwater for Domestic Use in Deduru Oya Basin

River Basin	No. of Shallow wells	Population	Extraction Qty. (litres/day)	Extraction Qty. (m^3/per day)
Deduru oya	128,026	473,696	37,895,696	37,896

Rural Water Supply Schemes

There are currently 254 rural water supply (RWS) systems that use groundwater sources (shallow and deep wells) in operation within the Deduru Oya basin, which serve 54,959 households. It is evident that a significant number of these systems have completed the design horizon and are now considered aged RWS systems that need rehabilitation to overcome various operational challenges. As usual, many systems lack the necessary fittings and components required for effective operation and monitoring of groundwater extractions, and are unaware whether groundwater sources are being exhausted or stressed. Notably, a considerable proportion of the systems do not have bulk meters to measure water pumping activities, and where meters are present, they are often either malfunctioning or non-operational. Despite these issues, pump operators generally possess a rough understanding of the volume of water required to meet the demand of the population and typically manage to maintain delivery within acceptable limits. However, this situation prevents a reliable assessment of the exact quantity of water being pumped from groundwater sources by the RWS systems, and limits the use of design data for safe pumping levels determined during the system's initial planning and design phase. The available data revealed that the RWS systems in the Deduru Oya basin extract around 24,402 m^3 per day.

The summary of the groundwater extracted by the Community Based Organizations for the operation of the Rural Water Supply Systems (RWSs) in the study area are presented in Table 4.8 and Figure 4.5 below.

Table 4.8: Quantity of Abstraction of Groundwater for RWS Schemes in Deduru Oya Basin

River Basin	No of RWS Schemes	HH Covered	Extraction Qty. (Litres/day)	Extraction Qty. (m^3/per day)
Deduru Oya	254	54,959	24,401,796	24,402

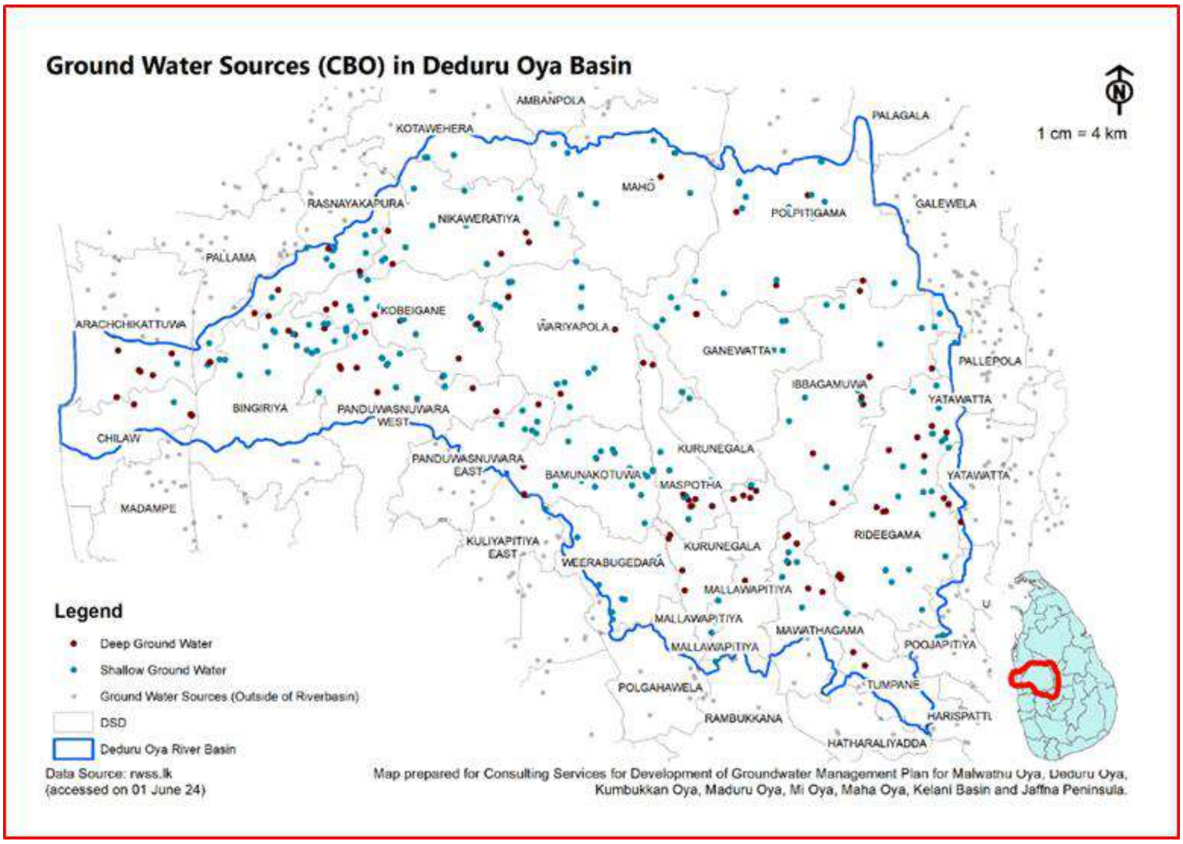


Figure 4.5: Distribution of RWS Schemes Operated by CBOs in Deduru Oya Basin

Urban Water Supply Schemes

Four (4) urban water supply schemes use groundwater in the Deduru Oya Basin (Table 4.9). As per the data obtained from the NWSDB, these schemes extract around 9,575m^3 of groundwater per day. This is a significant amount, as these systems are located in Intermediate Zone where the groundwater stress is notable.

Table 4.9: Quantity of Abstraction of Groundwater for Urban Schemes in Deduru Oya Basin

River Basin	No of Urban schemes Using GW	Extraction Qty. (m^3/per day)
Deduru Oya	4	9,575

Hand Pump Wells

According to village profiles compiled by the Divisional Secretariats within the study river basin, a total of 8,576 hand pump tube wells are currently serving a population of 31,731 individuals (Table 4.10 and Figure 4.6). For over three decades, tube wells were widely relied upon as a primary source of drinking water. However, the prevalence of chronic kidney disease (CKD) in Dry Zone areas has led to a significant decline in the use of groundwater extracted from deep tube wells for drinking purposes. As a result, many communities have abandoned tube wells for potable water, shifting to alternative sources.

In regions where water scarcity is particularly severe, some households continue to rely on tube wells for drinking water, despite growing health concerns. In general, the water extracted from these tube wells is now predominantly utilized for non-potable purposes such as bathing, washing, and other daily activities.

For the purpose of assessing water extraction, a consumption rate of 45 lpcpd was adopted.

Table 4.10: Quantity of Abstraction of Groundwater from Tube Well Hand Pumps in Deduru Oya Basin

River basin	No. of Tube Wells with Hand Pumps	Families	Population	Extraction Qty. (litres/day)	Extraction Qty (m^3/per day)
Deduru oya	8,576	42,880	31,731	1,427,904	1,428

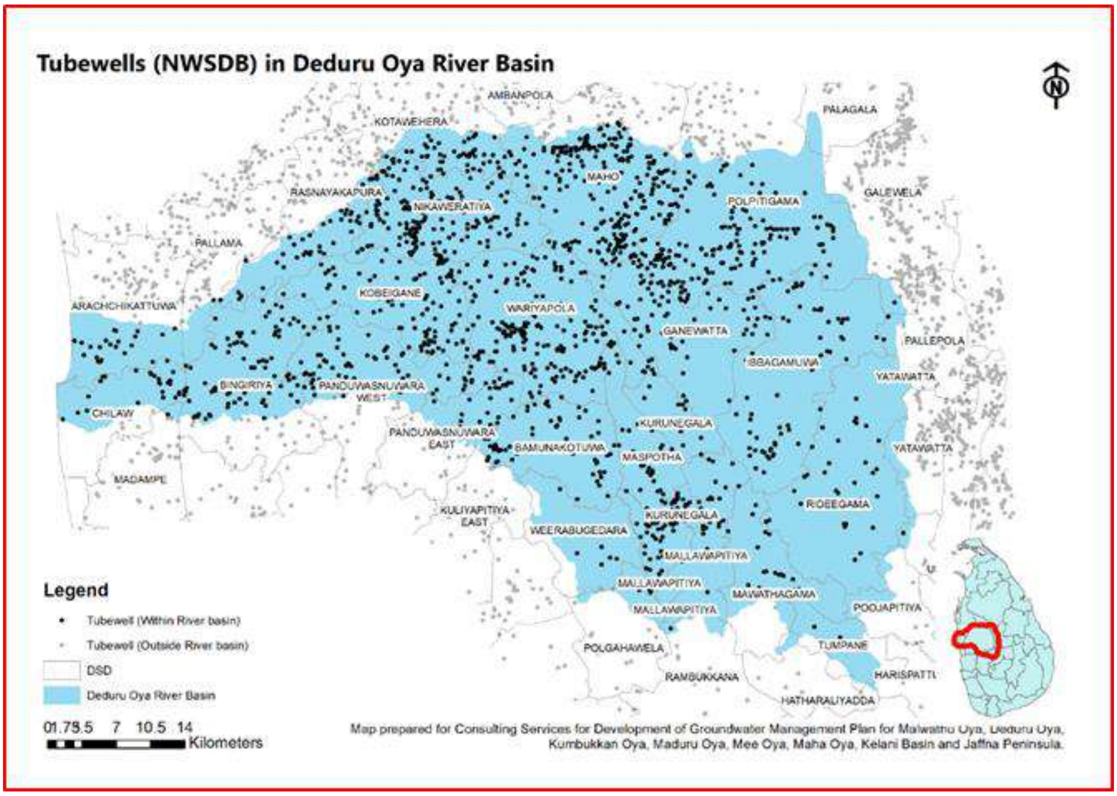


Figure 4.6: Distribution of Tube Wells with Hand Pumps in Deduru Oya Basin

Argo Wells

In the Deduru Oya basin, approximately 2,573 agro-wells are used to irrigate variety of crops (Table 4.11). These wells support cultivation during the dry season and unexpected dry spells. One of the prominent crops, pineapple, is often intercropped with large coconut plantations in the Kurunegala District, which lies within the Deduru Oya basin. In this region, agro-well water is typically used only during prolonged dry periods.

Table 4.11: Details of Agro Wells in Deduru Oya Basin

DS Division	No of Agro Wells	DS Division	No of Agro Wells
Bamunukotuwa	25	Mawathagama	9
Bingiriya	102	Palagala	
Chilaw		Pallama	
Ganewatta	221	Panduwasnuwara East	118
Kobaigane	288	Panduwasnuwara West	
Kotavehera	300	Polgahawela	20
Kurunegala	44	Polpitigama	
Madampe		Rasnayakapura	1,024
Mallawapitiya	8	Wariyapola	242
Maspotha		Weerambugedara	
		Total	**2,401**

Agro-wells also supply water to coconut plantations during the dry season, as well as to small-scale farms that grow vegetables, grains, and cash crops such as guava and maize. Discussions with local communities revealed that nearly all households cultivating more than 3 to 5 acres possess their own agro-wells—typically shallow—and larger landowners often have multiple wells on their properties.

However, the exact volume of groundwater extracted per day remains unknown, and water usage varies throughout the year. Many wells are only actively used during the dry season, as sufficient water is usually available during the monsoon period.

Medium-scale vegetable farmers who participated in the discussions reported using approximately 2,000 litres of water per vegetable plot per day during the dry season, occasionally doubling that amount depending on the crop. During the rainy season, however, agro-well usage significantly drops, with average usage estimated at 1,000 litres per day or less.

Based on the information gathered, it is estimated that approximately 2,573 m³ of groundwater is extracted daily from the 2,573 agro-wells in the Deduru Oya basin (Table 4.12).

Table 4.12: Quantity of Abstraction of Groundwater from Agro Wells in Deduru Oya Basin

River Basin	No. of Agro Wells	Ave. Extraction (litres/day)	Extraction Qty. (litres/day)	Extraction Qty. (m^3/per day)
Deduru Oya	2,573	1000	2,573,000	2,573

4.1.3.2. Outcomes of the Discussion with Groundwater User Groups

A series of field observations and stakeholder consultations were conducted with groundwater users in the study area. Villages were selected based on the presence of rural water supply (RWS) systems and the assumed availability of agro-wells, large agricultural landholdings, and tube wells. The key outcomes of these discussions are summarized in the table4.13 below.

Table 4.13: Summary of Discussion Outcomes in Deduru Oya Basin

Village / DS Division	Key Findings of the Discussion
Deduru Oya Basin	
Pothuwagonna Ganewatta	• RWS system started in 2008. The water source, the 50-meter-deep production borehole (tube well) with a capacity of pumping 30,000 litres of water per day. Yield has declined after 2013. It runs dry between August and October (the dry season) each year. • New shallow wells have been constructed at the lower periphery of the Deduru Oya reservoir. • A total of 22 agro-wells (with a 20x20 feet diameter) are operated by households on their cultivation plots and home gardens. Approximately 2,000 litres of water are extracted daily from each well • A brick maker uses a shallow well to obtain water for production • It appears that moderate water stress prevails in the area.
Ambalngodella Nikaweratiya	• The RWS (Rural Water Supply) system was initiated in 2008 with the construction of a 100-foot-deep tube well situated approximately 10 meters from the bank of the Deduru Oya. However, the well was subsequently abandoned due to concerns related to both the quantity and quality of the water, including elevated levels of iron and manganese, as well as a slight odour. • Currently, water is being sourced from a 20-foot shallow well located within the river itself. • In addition, five brick makers in the area extract water either directly from the Pahala Galpitiyagama minor tank channel or from nearby wells constructed for this purpose • There are no agro wells in his village
Serukele Anamaduwa/ Pallama	• The Rural Water Supply (RWS) system began in 1999 with the installation of three deep wells: a 72-meter-deep tube well installed by the Water Resources Board (WRB) for the Gam-Udawa function, and a 175-foot-deep borehole and a 200-foot-deep borehole installed by the Community Water Supply and Sanitation Project (CWSSP). At present, the latter two tube wells are abandoned—one due to a lack of water and the other due to a pump failure. • To meet the increasing water demand in the area, two shallow wells (20x20 feet in diameter) were constructed by the community organization to extract 132m^3 per day. • The exact amount of groundwater being extracted cannot be accurately assessed, as water from a tube well pumped directly into the distribution

Village / DS Division	Key Findings of the Discussion
	network, while one shallow well pumps water into a 22m³ capacity elevated tank six times per day. • Water quality is not accepted by the people due to hard taste • There are seven farmland plots covering more than 25 acres each. These farms have several agro-wells and deep tube wells. Some have also constructed small on-site tanks to retain rainwater within their properties. • According to local residents, there are approximately 25 hand-pump tube wells within the Grama Niladhari Division (GND), which are used for all purposes except drinking. • The area experiences significant water stress during the dry season.
Puliyankulama, Pallama	• The Rural Water Supply (RWS) system was initiated in 2014 and later improved by the Department of National Community Water Supply (DNCWS) in 2019. The system pumps an average of 60 m³ of water per day and currently serves 175 households. • As the area is relatively remote, most residents own sizable land plots ranging from 3 to 5 acres. Coconut is the predominant permanent crop cultivated on these lands, while vegetables, maize, cowpea, green gram, and other short-term cash crops are grown as supplementary income sources. • According to local residents, there are approximately 20 agro-wells within these larger landholdings that cultivate short-term cash crops; however, people have no idea of the volume of groundwater extraction. • The President of the RWS Society reported that around 2,000 litres of water are pumped twice daily during the dry season. However, during prolonged dry spells, this amount cannot be consistently extracted due to reduced groundwater availability. It is reported that the yield assessed during the design phase has declined over time. • Water stress typically occurs in this area between August and October each year

4.2. Kelani River Basin

4.2.1. Meteorology

General

The Kelani River originates from the Western face of the central highlands located in the Horton Plains National Park and Peak Wilderness Sanctuary. It drains approximately 2,292 square kilometres of land area (Survey Department, 2007). It is the second largest river basin and the fourth longest river in Sri Lanka. The topography of the basin includes three peneplains, namely, the first peneplain (lower and mostly flat), the second peneplain (middle, starting around 100 meters of elevation and extending to about 300 meters) and the third peneplain (upper consisting of complex mountain chains, massifs and basins with different degrees of erosion).

The Kelani River Basin landforms vary significantly and includes 11 landforms, namely, Mountain, Hill and Ridge, Ridge and Valley, Hill and Valley, Mantled Plain (gently undulating to rolling plains), Rock Knob Plain (rough and broken relief of extensive tracts), Erosional Remnant (isolated, steeply rising bedrock controlled hills and ridges), Flood Plain, Coastal Plain, Sand Dune and Beach (Cooray, 1984).

Figure 4.7 illustrates the Digital Elevation Model (DEM) with different elevations from upstream to the lowest reach.

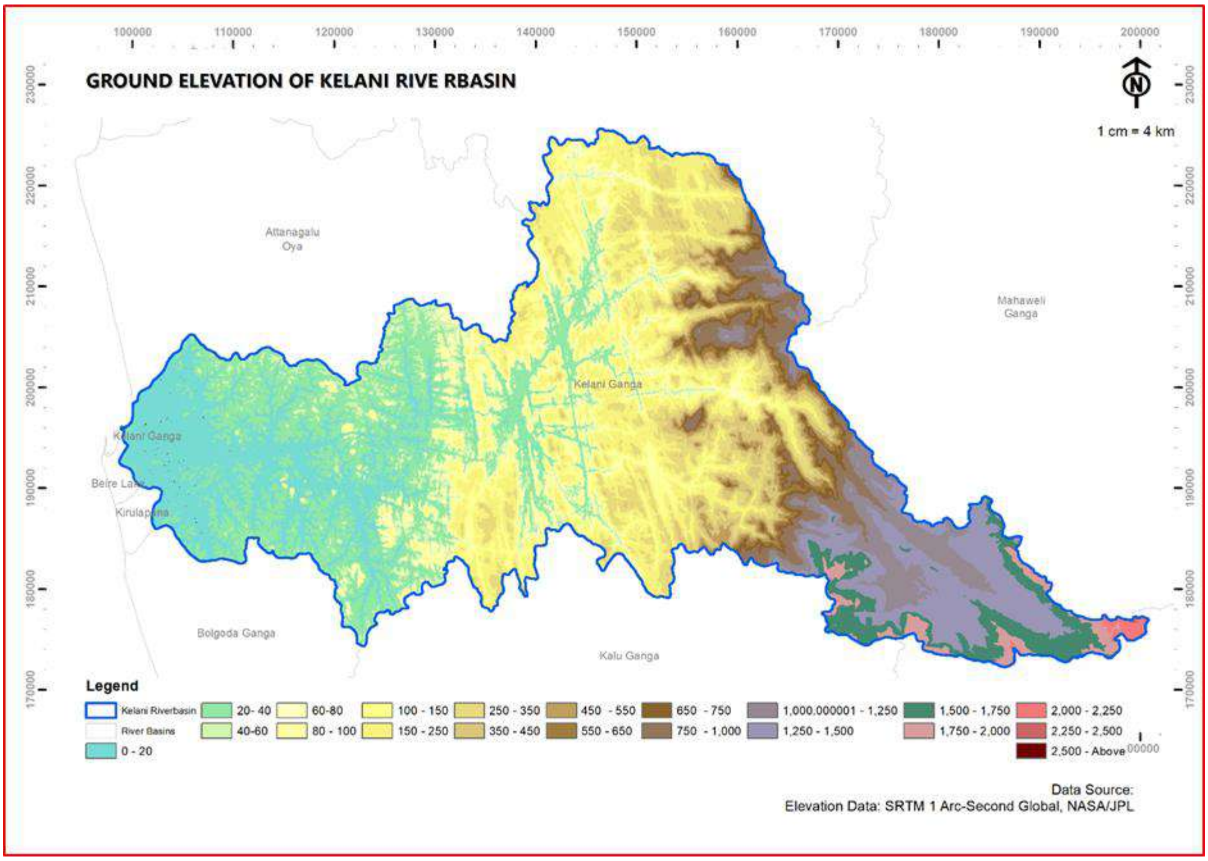


Figure 4.7: Digital Elevation Model of Kelani River Basin

The river basin receives rain throughout the year, but from May to June and from October to December, it receives heavy rainfall. The watersheds in the middle of the Kelani River Basin receive the highest rainfall. The Basin usually is not a severely drought-prone basin, as the basin is in the wet climatic zone and the catchment of Kelani Basin originates from the Peak Wilderness area of the Central Massif, which is rich in vegetation cover and rainfall. The months with the lowest rainfall are February and March, during which time there could be occasional drought impacts.

4.2.1.1 Rainfall

The amount of rainfall experienced in the different parts of the basin is given in Table 4.14 and Figure 4.8. The rainfall in the basin varies from 2,500 mm to 4,000 mm, with an average mean annual rainfall of about 3,500 millimeters. The basin receives a good amount of annual rainfall, and it can be assumed that there is sufficient water for groundwater recharge. This will be assessed during the water balance computation.

Table 4.14: Variation of the Amount of Rainfall Across the Kelani River Basin

Rain Gauge Station	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	2020/2021	2021/2022	Long term annual average (mm)
Norwood	3116	1845	2429	2492	2018	3427	2689	3026	2823	2806	2559
Kitulgala	5158	2893	2976	4908	3784	4951	4131	4505	5690	5194	4181
Glencourse	4814	3272	4012	3864	3479	4036	4110	4170	5087	4028	3984
Hanwella	4779	3209	3912	3363	3381	2308	1883	3512	4906	3229	3445
Deraniyagala	6373	4277	4799	5238	4774	6035	4673	4725	5003	4713	4931
Holombuwa	4270	2900	4850	2967	1943	2682	2841	3151	4164	3633	3272
Colombo	2159	1807	3015	2551	2292	2396	2926	2532	2539	2255	2437

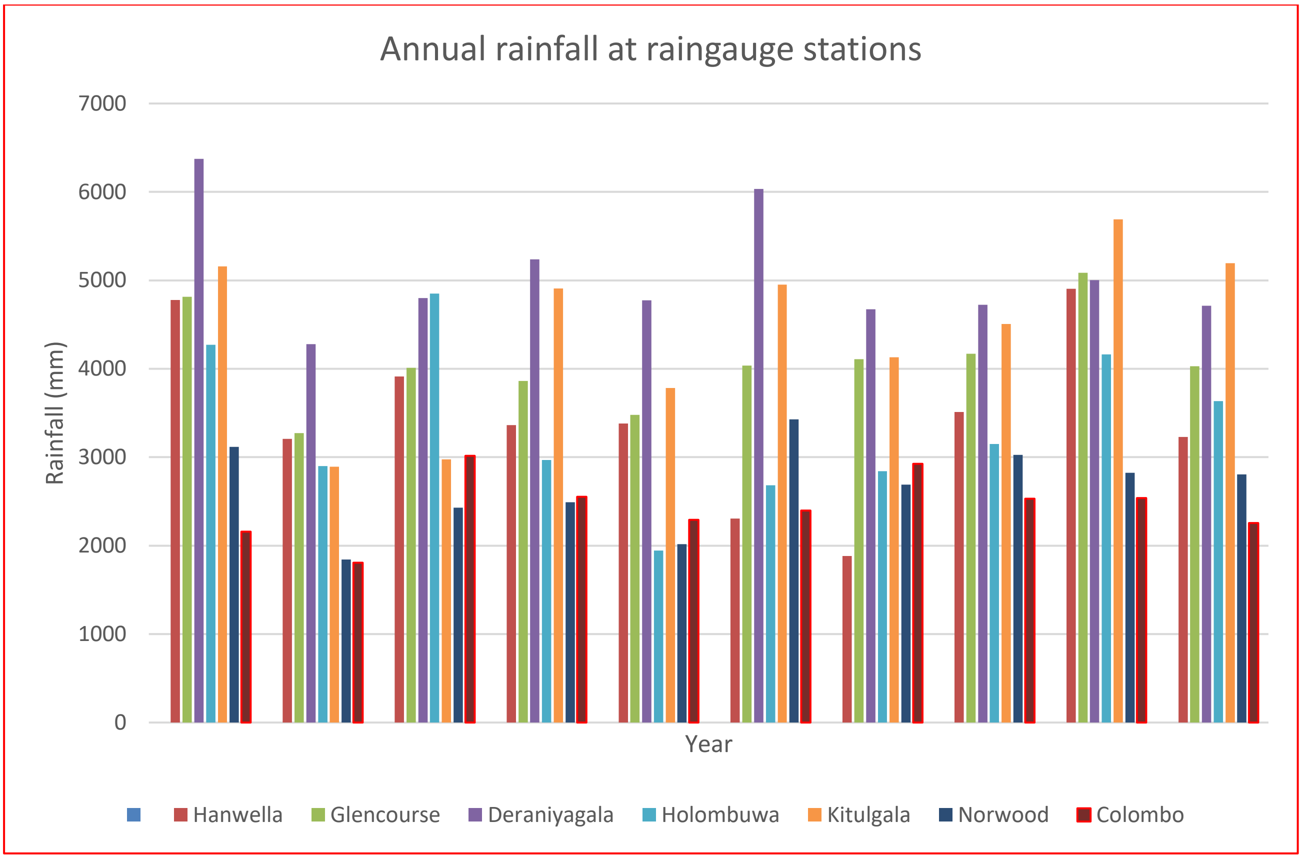


Figure 4.8: Annual Rainfall Measured at Rain Stations in the Kelani Basin

<u>Rainfall Measurements</u>

Five rain gauges are located within the basin, of which four belong to the Department of Irrigation, while the other one is controlled by the Department of Meteorology (Figure 4.9).

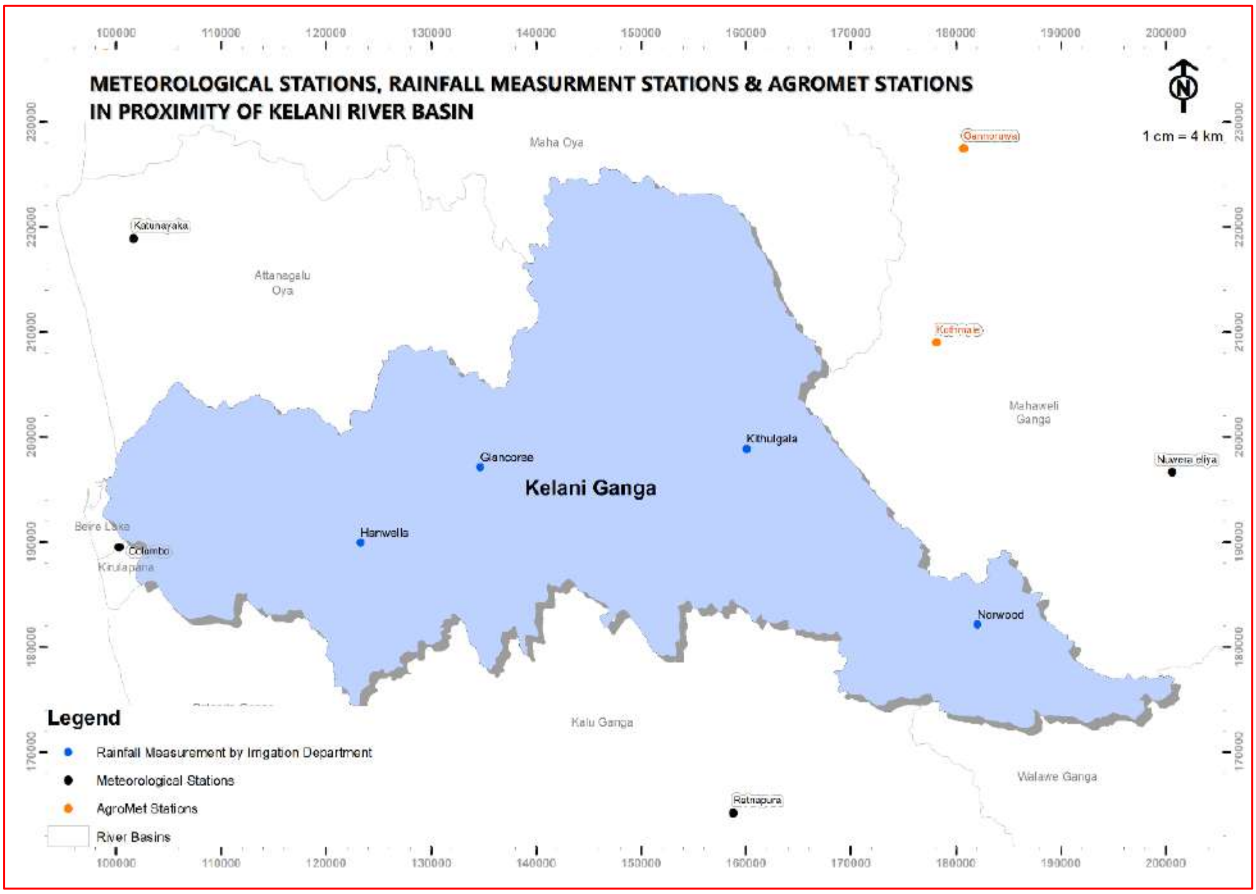


Figure 4.9: Locations of Rain Gauge Stations in Kelani River Basin

Table 4.15: Rain Gauge Coverage in Kelani River Basin

Number of Gauges	Total Coverage (km^2)	Coverage of Land by One Gauge (km^2)	Standard Coverage by One Gauge (km^2)	% of Standard Coverage to the Coverage by the Gauges
5	2292	458	300	65

Figure 4.10 provides an insight into the distribution of rainfall across the basin in each physiographical unit during the year. Lower reaches experience more rainfall than the middle reaches of the basin.

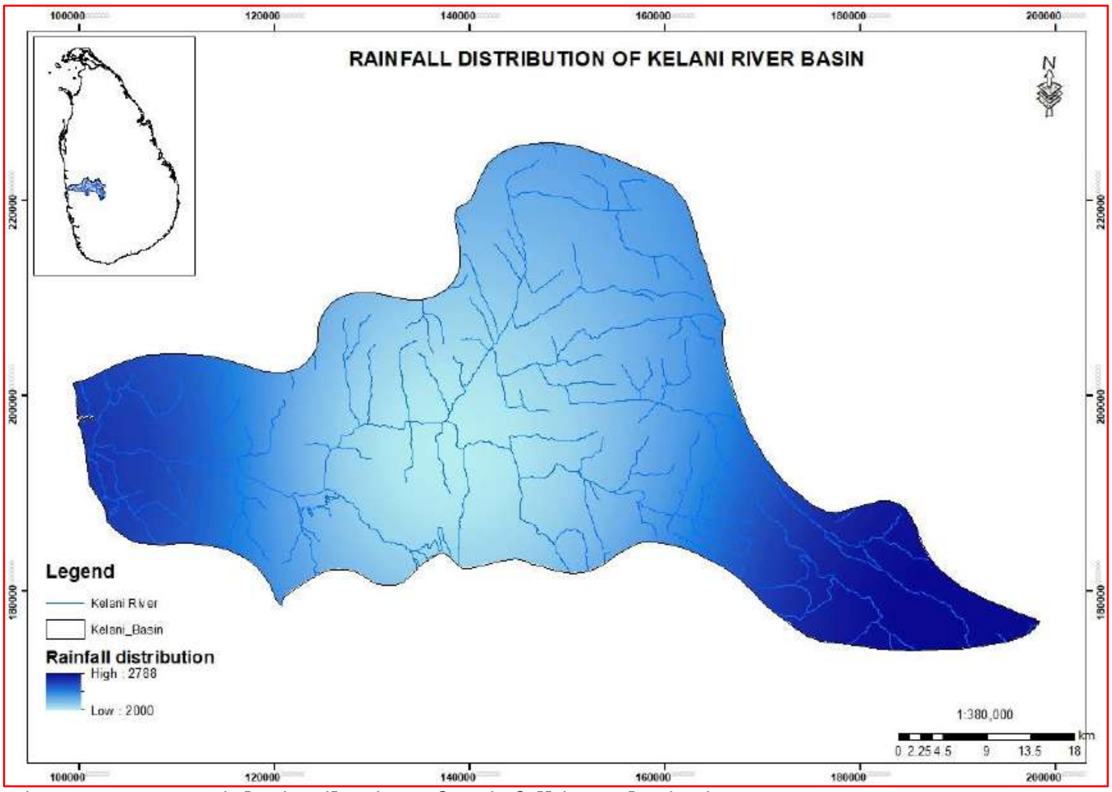


Figure 4.10: Spatial Distribution of Rainfall in Kelani River

4.2.2. Land Use pattern

Out of the total area of the Kelani River Basin, 21.25 per cent is covered with settlements and built-up area, while 52.04 per cent is covered with vegetation. Only 13.9 per cent of the total land extent is covered by forest defined by the Forest Department. A relatively higher percentage of the Montane and Sub-Montane forests is located in the Eastern part of the basin. A large extent of paddy lands, which represent 12.21 per cent of the total area, is found in the medium and lower reaches of the basin. The land use distribution of Kelani River Basin is given in Figure 4.11 and Table 4.16 below.

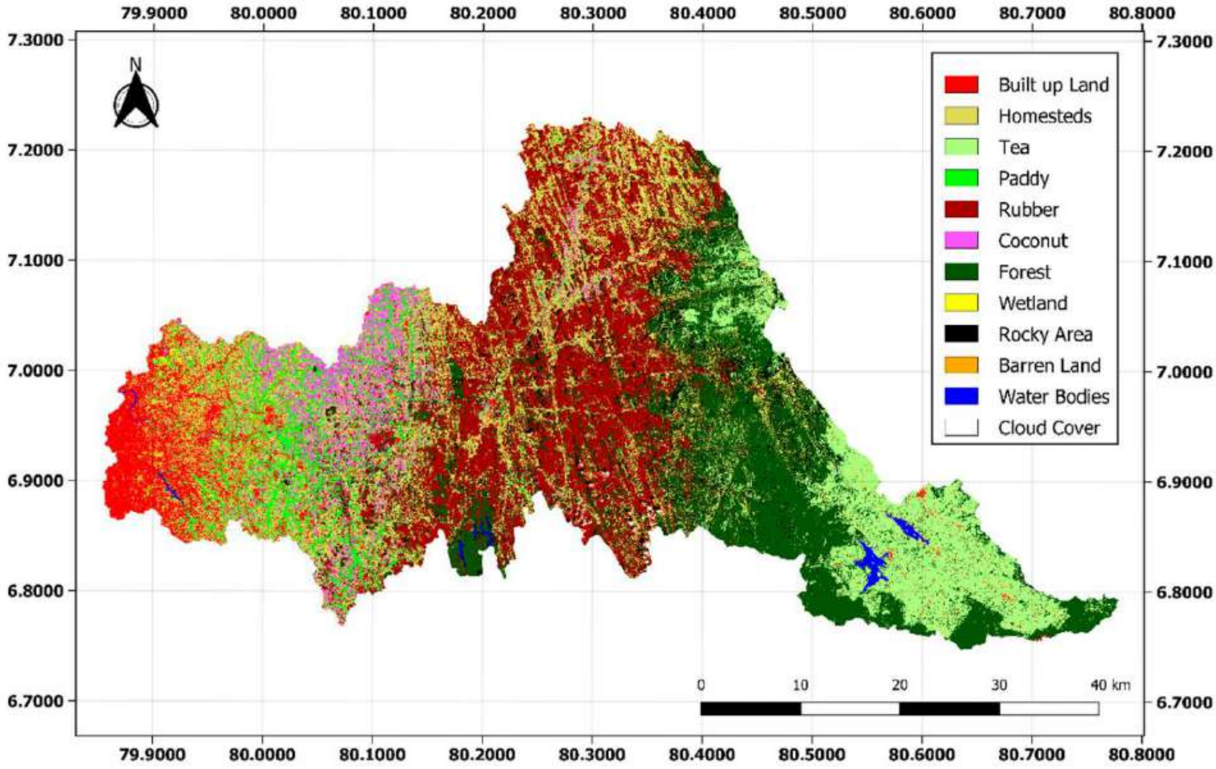


Figure 4.11: Land Use Pattern of Kelani River Basin

Table 4.16 : Land Use Distribution in Kelani River Basin

Land use	Extent	Coverage %
Built up Area / Setllements	49,303.18	21.25%
Paddy Land	28,325.07	12.21%
Forest (Defined by Forest Department)	32,257.38	13.90%
Vegetation (Except Forest Department Declared and Paddy)	120,750.29	52.04%
Water	1,378.46	0.59%

4.2.3. User Groups of Groundwater in Kelani River Basin

Groundwater user identification and assessment of community experiences with groundwater stress were carried out in the Kelani River basin. Located in Sri Lanka's wet zone, the Kelani River basin is generally abundant in both surface and groundwater resources. Although several large urban water supply schemes—primarily reliant on surface water—serve most areas in the Colombo and Gampaha districts, a significant number of people in remote and rural areas within these districts still depend on groundwater to meet their daily water needs.

Furthermore, in districts such as Ratnapura, Kegalle, and Nuwara Eliya, groundwater remains the only reliable source of water for many communities, due to the region's challenging topography and hydrological constraints, which limit the feasibility of piped water supply systems.

Groundwater users in the Kelani River basin range from individual households to large-scale national institutions. The key groundwater user groups in the area are identified as follows:

(i) **Households** utilizing individual domestic wells, including shallow wells, shallow hand pump wells, and deep hand pump wells;
(ii) **Water consumer groups** accessing hand pump wells primarily for drinking purposes;
(iii) **Community Based Organizations (CBOs)** operating small-scale water supply systems drawing from both shallow and deep groundwater sources;
(iv) **National Water Supply and Drainage Board (NWSDB)**, which utilizes groundwater as a supplementary source in areas experiencing high demand or limited surface water availability;
(v) **Small-scale farmers** relying on groundwater to irrigate small plots cultivating vegetables, grains, coconuts, and fruits;
(vi) **Large-scale agricultural operators** using groundwater for the cultivation of both short-term and long-term cash crops.

Table 4.17 below provides the details of groundwater users and the purpose of extraction in the four study areas.

Table 4.17: Groundwater User Groups in the Kelani River Basin

	Groundwater Users	Number
1	Households with privately owned wells	64,870
2	Water consumer groups formed around hand-pump tube wells	2,549
3	Community Based Organization (CBO) that manages & operates RWS systems	235
4	Users of NWSDB-managed urban and small-town water supply schemes	1
5	Small-, medium-, and large-scale agricultural landowners utilizing agro-wells	0

4.2.3.1. Mode, Purpose, and Quantity of Groundwater Extraction

Groundwater serves as a vital source of drinking water and supports a range of domestic needs across rural regions of Sri Lanka. Within the Kelani River basin, this role remains significant, particularly in remote and hilly areas where access to piped water is limited.

The Kelani River, the fourth longest river in Sri Lanka at 145 km, flows through the wet zone and densely populated urban areas near its lower reaches. As a result, groundwater use in these urban zones is moderate due to the availability of surface water supply schemes. However, in more remote parts of the basin, groundwater use is substantial. An estimated 60,000 domestic wells and 235 rural water supply (RWS) systems operating on groundwater currently serve these communities.

While data on agro-well usage within the basin is not reported, overall observations indicate that a considerable proportion of the population continues to rely on groundwater for drinking and other essential domestic purposes. The following section provides a detailed overview of groundwater usage.

Domestic Dug Wells

Shallow wells play a vital role in the domestic water supply within the Kelani River basins, especially areas that fall under Kegalle, Nuwar-eliya and Rathnapura districts. There are 60,248 sallow wells in

Kelani River basin providing water to 222,918 inhabitants for all domestic needs (Table 4.18).

Of the total, only 19,641 shallow dug wells are found in Colombo and Gampaha districts within the areas fall within the Kelani River basin, while the balance is in Kegalla (36,109) and Ratnapura (4,678) districts.

Since there are no records of water extraction from the domestic shallow wells, the quantity of water extracted must be estimated based on a typical per-person consumption rate, which is 65 lpcd. for all purposes: drinking, cooking, bathing, and washing. Accordingly, the assessed total quantity of water extracted from private dug wells in the study area is 17,833m³ per day.

Table 4.18: Details of Domestic Wells in Kelani River Basin

River basins	No. of wells	Population	Extraction Qty. (litres/day)	Extraction Qty. (m^3/day)
Kelani River	60,248	222,918	17,833,408	17,833

Rural Water Supply Schemes

There are currently 235 rural water supply (RWS) systems that use groundwater sources (shallow and deep) in operation within the Kelani River basin, which serves 73,895 households (Figure 4.12).

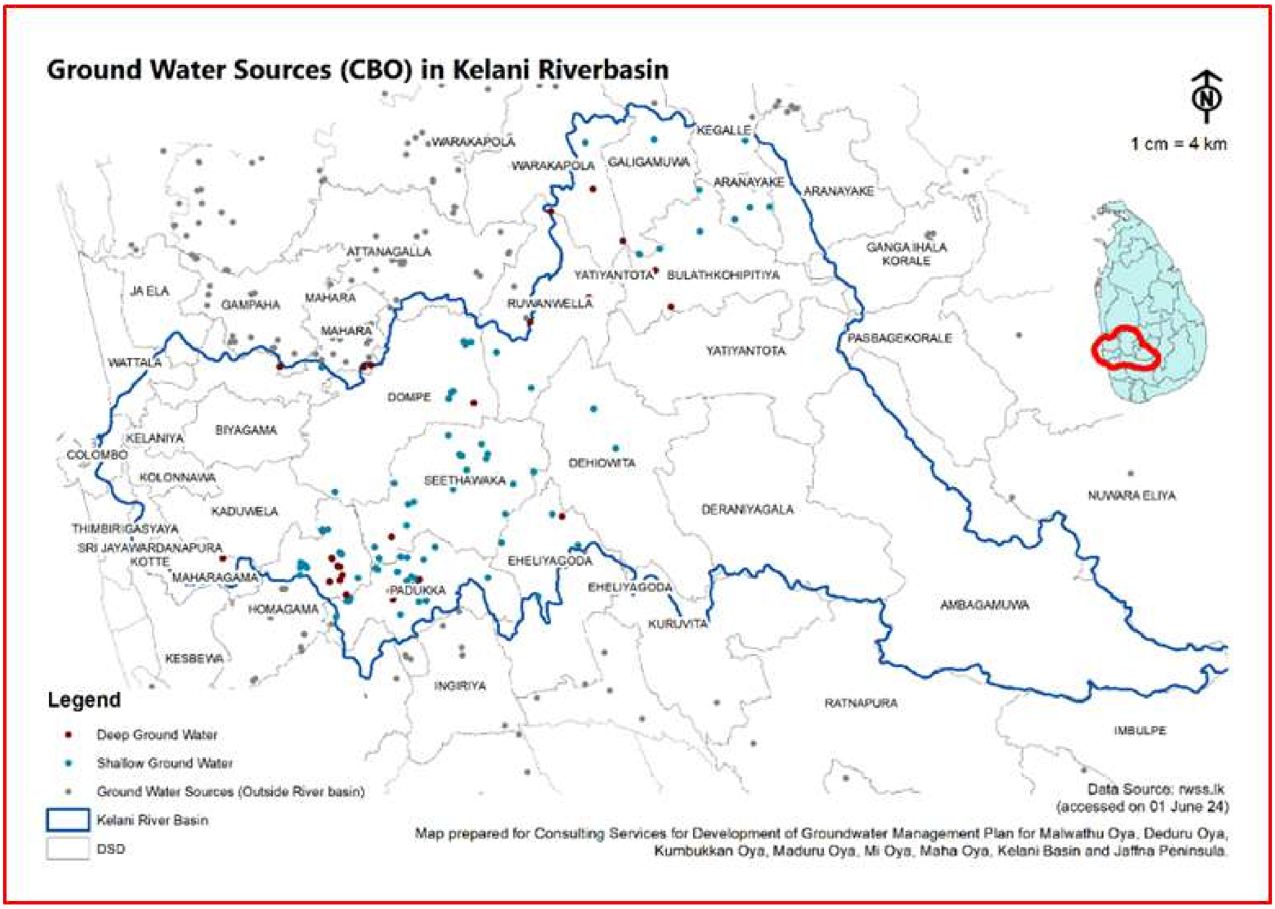


Figure 4.12: Locations of Rural Water Supply Schemes Operated by CBOs in Kelani River Basin

It is informed that some of these systems are aging and facing various operational challenges, including frequent technical malfunctions and quality issues etc. Many systems lack the necessary fittings and components required for effective operation and monitoring of groundwater extractions. Notably, a considerable proportion of the systems do not have bulk meters to measure water pumping activities, and where meters are present, they are often either malfunctioning or non-operational. Despite these issues, pump operators generally possess a rough understanding of the volume of water required to meet the demand of the population and typically manage to maintain delivery within acceptable limits. However, this practice prevents a reliable assessment of the exact quantity of water being pumped from groundwater sources by the RWS systems, and limits the use of design data for safe pumping levels determined during the system's initial planning and design phase.

The details of the groundwater extracted by the community organizations for the operation of 235 Rural Water Supply Systems (RWSS) in the Kelani River basin are provided in the table below.

Table 4.19: Quantity of Abstraction of Groundwater for RWS Schemes in Kelani River Basin

River Basin	No of RWS scheme	HH covered	Extraction Qty. (Litres/day)	Extraction Qty. (m^3/per day)
Kelan River	235	73,895	32,809,380	32,809

Urban Water Supply Schemes

The Nuwara Eliya Water Supply Scheme is the only urban water supply system within the Kelani River basin that utilizes both surface water and groundwater. Due to the limited availability of surface water, the scheme relies on groundwater to supplement the supply and meet the demands of the urban population. Approximately 6,500 m³ of groundwater is extracted daily for this integrated system, ensuring a more reliable and continuous water supply for the area.

Table 4.20: Details of Urban Water Supply Schemes in Kelany River Basin

River Basin	No of Urban schemes Use GW	Extraction Qty. (m^3/per day)
Kelan River	1	6,500

Hand Pump Wells

According to village profiles compiled by the Divisional Secretariats within the Kelani River basin, a total of 2,549 hand pump tube wells currently serve a population of 47,157 across 12,745 households (Table 4.21 & Figure 4.13). Although there are no reported cases of chronic kidney disease (CKD) linked to groundwater use in the area, most residents now primarily use water from these tube wells for non-potable purposes such as bathing, washing, and other domestic activities. Groundwater continues to play a key role in supporting daily household needs, even as its use for drinking has declined.

For the purpose of assessing water extraction, a consumption rate of 25 lpcpd was adopted.

The estimated water extraction from the tube wells in the Kelani River Basin is around 1.18m³ per day (Table 4.21).

Table 4.21: Quantity of Abstraction of Groundwater from Tube Well Hand Pumps in Kelani River Basin

River basins	No. of tube wells	Families	Population	Qty. extract (ltrs.)	M^3/per day
Kelani River	2,549	12,745	47,157	1,178,913	1,179

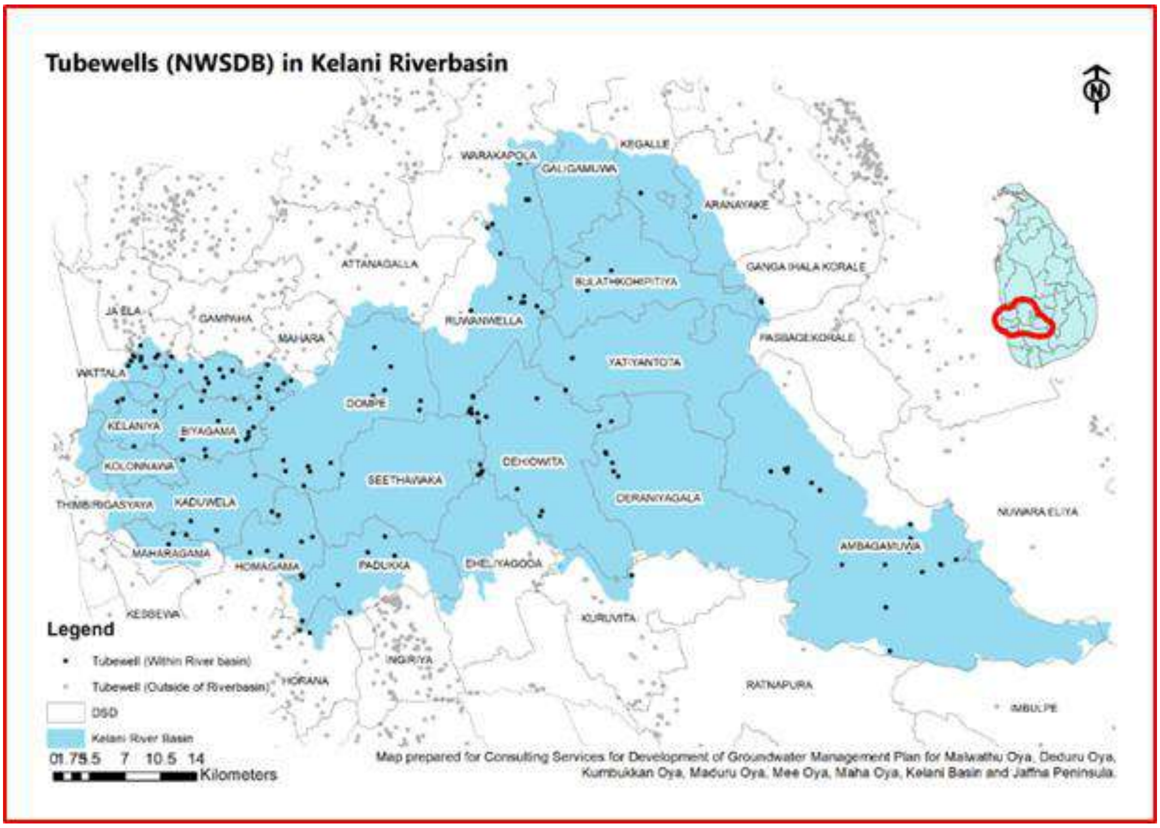


Figure 4.13: Distribution of hand pumps in Kelani River Basin

4.2.3.2. Outcomes of the Discussion with Groundwater User Groups

A series of field observations and stakeholder consultations were conducted with groundwater users in the study area. Villages were selected based on the presence of rural water supply (RWS) systems and the assumed availability of agro-wells, large agricultural landholdings, and tube wells. The key outcomes of these discussions are summarized in Table 4.22 below.

Table 4.22: Summary of Discussion Outcomes in Kelani River Basins

Village / DS Division	Key Findings of the Discussion
Kelani River Basin	
Dompe Udugama	• The Rural Water Supply (RWS) system was established in 2008 to serve 65 households and currently provides water to 132 households. Water quality in this source is at acceptable level. • There is no significant water stress in the area, and the production capacity is sufficient to meet the current demand. The area consists of large landholdings, with coconut being the predominant crop. Many of these lands have been leased out for pineapple cultivation as an under crop. • Water availability is generally adequate across the region, with the exception of certain hilly areas where minor water stress may occur.

Village / DS Division	Key Findings of the Discussion
Warakapola Dedigama	• The Small-Town Water Supply (WS) system in Dedigama was established with a deep tube well located near Dedigama town to serve 560 households. • This deep well dried up after a few years of operation. Currently, the system relies on a shallow well-constructed on the bank of the Gurugoda Oya. The quality and quantity issues of the water supply system existed previously have been resolved with the use of the new source. • Water is extracted from the Gurugoda Oya at a rate of approximately 120 m^3 per day during the wet season and 80 m^3 per day during the dry season, resulting in an intermittent supply to consumers during the dry season. • Water stress occurs during the dry season, particularly because Dedigama is situated in a minor hilly area near the upper reaches of the Gurugoda Oya, where river flow is relatively low.
Galgamuwa Kotiyakumbura	• The Small-Town Water Supply (WS) system of Kotiyakumbura was initiated with one deep tube well and two shallow wells constructed along the bank of the Gurugoda Oya. The system currently provides water to 1,350 households. • At present, the deep tube well has been abandoned, and the system relies solely on the two shallow wells, which together produce a combined yield of approximately 140 m^3 per day. • There is no water stress in the system, as the flow of the Gurugoda Oya remains stable throughout the year with no significant seasonal fluctuations.

4.3. Malwathu Oya Basin

4.3.1. Meteorology

General

Malwathu Oya (called Aruvi Aru at the lower reaches) has a total length of 162 km and is the second-longest river in Sri Lanka. The catchment area of the river is 3,291 km^2. It originates at Ritigala and Inamaluwa Hills (766 m and 383 m above MSL, respectively) in the North Central Province and flows to the sea at Arrippu in Mannar district.

The Ritigala mountain range, which comprises four main peaks (the highest of which is over 900 m (3,000 ft) high), in the upper reaches of the river, serves as the main catchment. Except for the headwater area, the Malwathu Oya catchment is rather flat or slightly rolling with some isolated hills (Figure 4.14). The major part has an elevation of 150m or less. The catchment is full of small and large tanks for the irrigation of paddy lands. Apart from paddy fields, the catchment area is covered with shrubs, some forests, and non-irrigated plots.

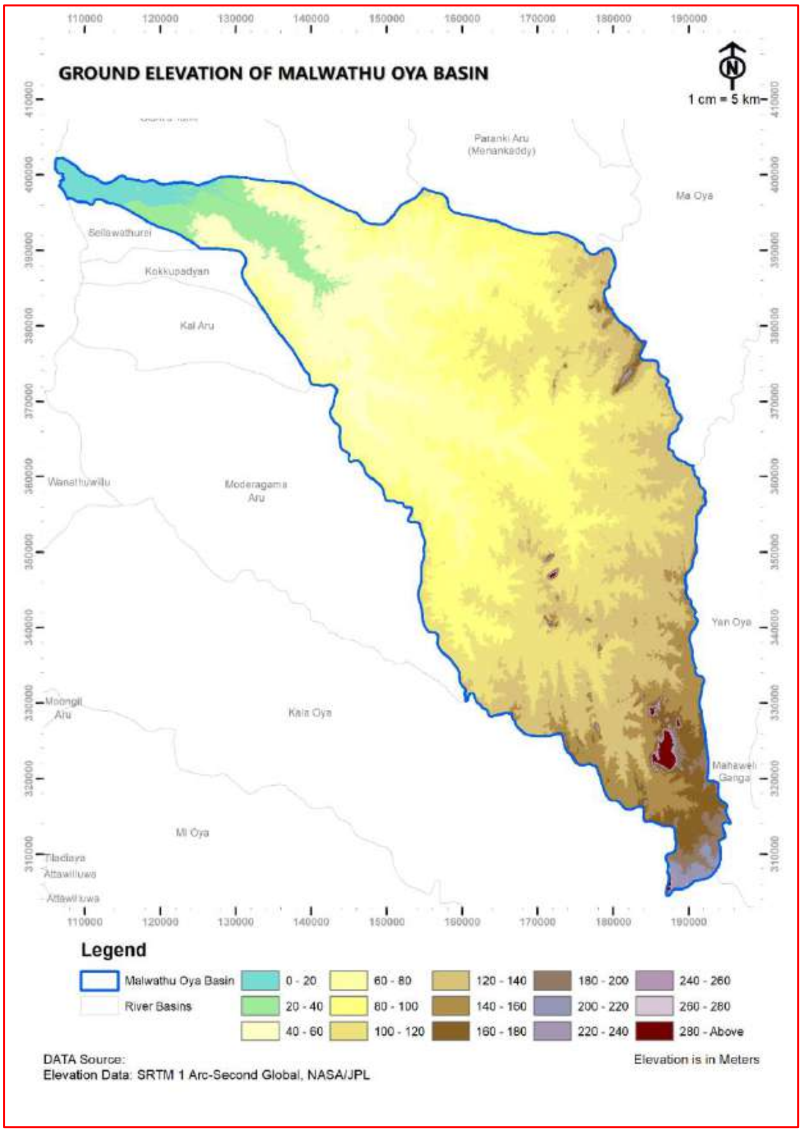


Figure 4.14: Digital Elevation Model of Malwathu Oya Basin

The basin falls within the dry zone in Sri Lanka, primarily receiving rainfall during the northeast monsoon season, which typically occurs from December to March, with a secondary rainy period during the "second inter-monsoon" in October and November. The rest of the year is generally dry. Therefore, a significant variation in rainfall over the basin can be expected due to the position of the basin.

4.3.1.1. Rainfall

The basin is situated entirely in the Dry Zone of the country. The average annual rainfall of the catchment is around 1,350 mm and the average discharge to the sea has been estimated as 260 MCM per annum (Irrigation Department).

Rainfall Measurements

Figure 4.15 provides the distribution of the rain gauge stations in the basin. Two gauges are located within the boundary, while another two are located just outside the far South-Western and the Northern boundaries of the basin. Further to these, WRB recently established five rain gauge stations close to some of the groundwater monitoring wells. The rainfall data is available in the respective institutions.

As per the geomorphology, the basin shows features attributed to a mixed terrain, such as flat and mountainous land forms. According to the WMO standards, and when considering the terrain features of the basin, the coverage of a single rain gauge station can be adjudged as 400km^2.

Table 4.23 presents the percentage coverage of the basin against the standard coverage recommended by the WMO. Figure 4.16 illustrates the rainfall distribution measured by the rain gauges.

Table 4.23: Rainfall Gauge Coverage in Malwathu Oya Basin

Number of gauges	Total coverage (km^2)	Unit coverage (km^2)	Standard coverage (km^2) by one gauge	% coverage against standard coverage
4	3291	1097	400	48

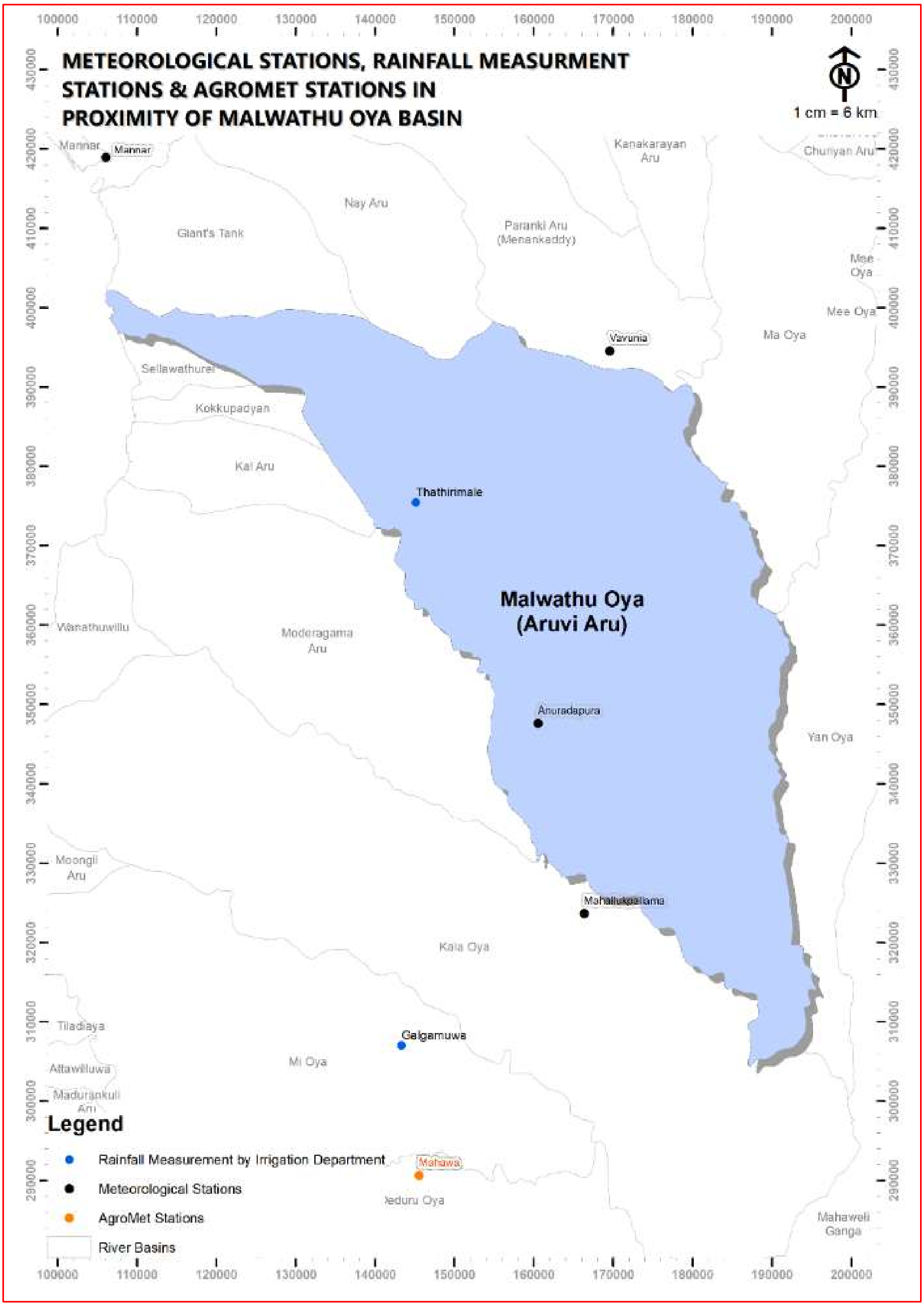


Figure 4.15: Locations of Rain Gauge Stations

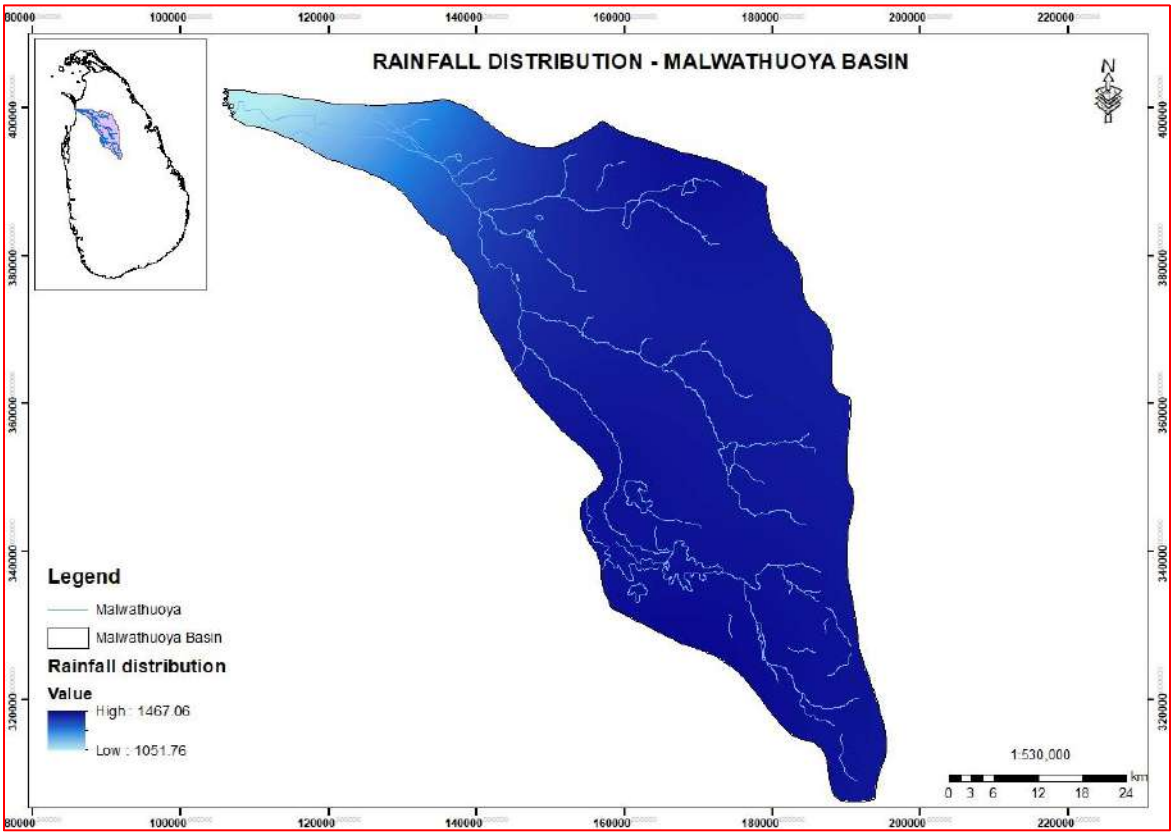


Figure 4.16 : Spatial Distribution of Rainfall in Malwathu Oya Basin

4.3.2. Land use pattern

Malwathu Oya river basin is the second-largest river basin in Sri Lanka, consisting of diverse forest ecosystems, archaeological sites, and geographical features. It spreads over the North Central and Northern Provinces, and it is one of the most widely used water sources for irrigation and water supply. The land use pattern in the Malwathu Oya basin is primarily dominated by agriculture, with paddy cultivation as the dominant crop, largely supported by a system of ancient irrigation tanks known as "tank cascades" which utilize water from the river basin. This includes extensive areas of rice cultivation, alongside some areas of chena cultivation (shifting cultivation) and grazing lands, with limited forested areas in the upper reaches of the basin. The land use pattern is illustrated in Figure 4.17 and the types and percentages are given in Table 4.24. Natural forest occupies the majority of the land cover to a percentage of 33.77 of the total land area while the paddy comes to the 2nd highest of the total land use. The other important area of land use is allocated for built up category which seems to be a fairly small compared to the total land use. Home gardens represent 14.19 of the total land area indicating that groundwater is used for watering these gardens.

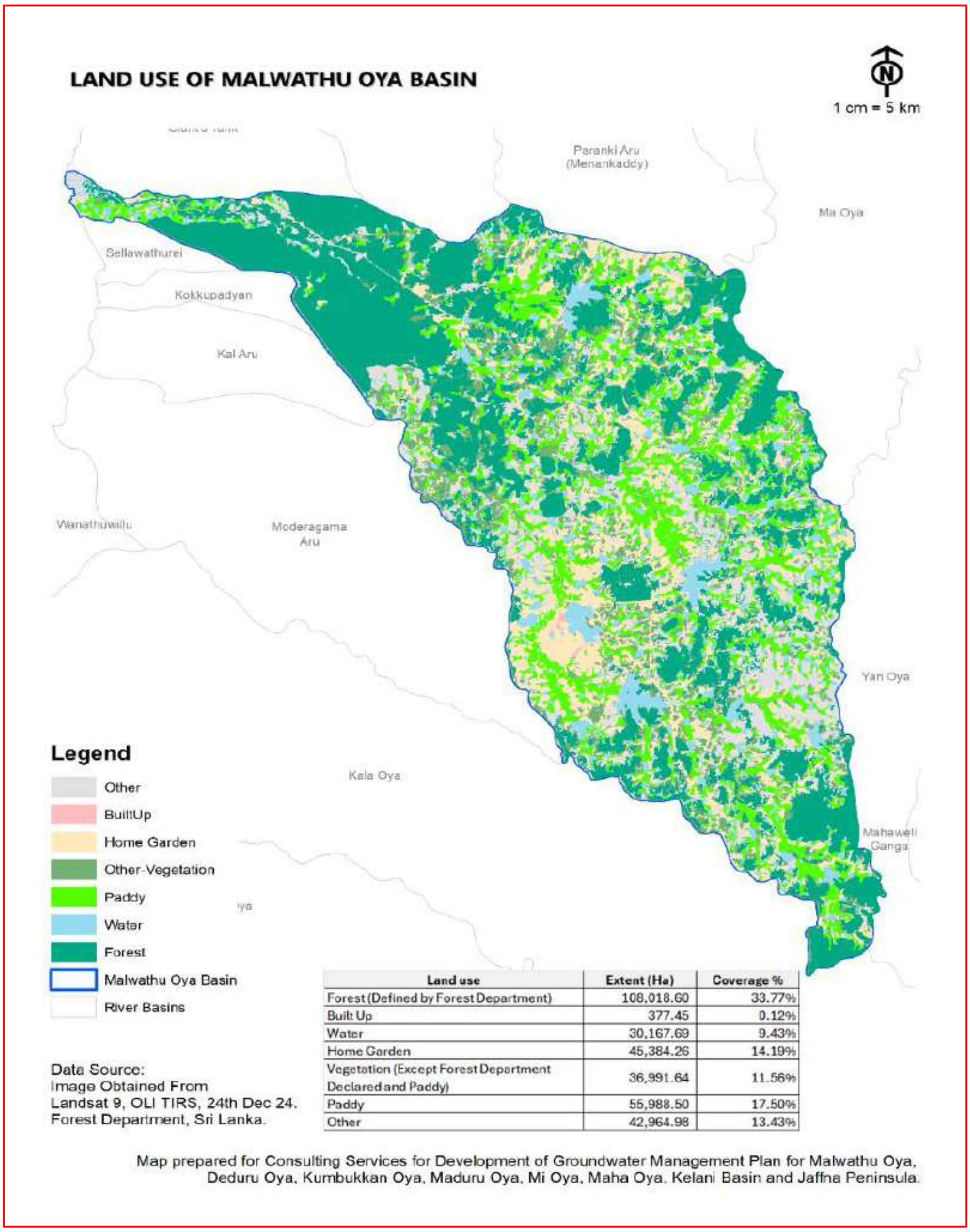


Figure 4.17 : Land Use in Pattern Malwathu Oya Basin

Table 4.24: Land Use Distribution in Malwathu Oya Basin

Land use	Extent (Ha)	Coverage %
Forest (Defined by Forest Department)	108,018.60	33.77%
Built Up	377.45	0.12%
Water	30,167.69	9.43%
Home Garden	45,384.26	14.19%
Vegetation (Except Forest Department Declared and Paddy)	36,991.64	11.56%
Paddy	55,988.50	17.50%
Other	42,964.98	13.43%

4.3.3. User Groups of Groundwater in Malwathu Oya Basin

Groundwater user identification and assessment of community experiences with groundwater stress were conducted in the Malwathu Oya basin. Despite the semi-arid and dry climatic conditions, groundwater remains a critical and, in many cases, the primary source of water for populations in the Malwathu Oya Basin.

Groundwater users in the Malwathu Oya basin represent a broad spectrum, from individual households to national-level institutions. The key groundwater user groups in the area are identified as follows:

(i) **Households** utilizing individual domestic wells, including shallow wells, shallow hand pump wells, and deep hand pump wells
(ii) **Water consumer groups** accessing hand pump wells primarily for drinking purposes,
(iii) **Community-Based Organizations (CBOs)** operating small-scale water supply systems drawing from both shallow and deep groundwater sources.
(iv) **National Water Supply and Drainage Board (NWSDB)**, which utilizes groundwater as a supplementary source in areas experiencing high demand or limited surface water availability,
(v) **Small-scale Farmers** relying on groundwater to irrigate small plots cultivating vegetables, grains, coconuts, and fruits,
(vi) **Large-scale agricultural operators** using groundwater for the cultivation of both short-term and long-term cash crops.

According to the available district profiles prepared based on the household data collected through GN and other data sources, the groundwater user in the Malwathu Oya basin have been identified and are indicated in the Table 4.25 below:

Table 4.25: Groundwater User Groups in Malwathu Oya Basin

User Groups	Number of Users
Households with privately owned wells	11,917
Water consumer groups formed around hand-pump tube wells	3,629
Community Based Organization (CBO) that manages & operates RWS systems	117
Users of NWSDB-managed urban and small-town water supply schemes	7
Small-, medium-, and large-scale agricultural landowners utilizing agro-wells	18,082

4.3.3.1. Mode, Purpose, and Quantity of Groundwater Extraction

Groundwater serves as a vital source of drinking water and supports various domestic needs across rural regions of Sri Lanka. While paddy cultivation is primarily sustained by surface or irrigated water systems, shallow groundwater is extensively utilized for highland agricultural practices by farming communities in minor tank settlements.

The details on the methods of groundwater extraction for various purposes highlight the extent of groundwater usage across the Malwathu Oya basin, underscoring its critical role in sustaining rural livelihoods and agriculture.

A considerable proportion of the population within the basin depends on groundwater for a range of activities, including drinking, domestic use, and highland agriculture.

Shallow-wells for Domestic Water Requirements
Shallow wells play a vital role in the domestic water supply within the Malwathu Oya basin, which contains a total of 11,917 shallow wells (Table 4.26).

Table 4.26: Distribution of Dug Wells in Malwathu Oya Basin

DS Division	No of Dug Wells	DS Division	No of Dug Wells
Ipologama	259	Thirappane	3,117
Medawachchiya	3672	Palugaswewa	717
Galenbidunuwewa	3163	Kebithigollewa	118
Rambawa	1864	Kekirawa	1,015
Nuwaragampaltha Central	1835	Thalawa	177
Nuwaragampaltha East	922	Vengalcheddikulam	4,330
Nachchaduwa	545	Vauniyawa South	1,703
Mihinthale	n/a	Madu	283
Khatagasdigiliya	678	Nanandan	740
Total			**11,917**

Apart from the Anuradhapura Group Town Water Supply Scheme—which uses surface water from the Mahaweli River and serves only urban and semi-urban areas—there are no major piped water supply schemes in the basin.

Since there are no records of water extraction from domestic shallow wells, the quantity extracted must be estimated based on per capita consumption, which is 65 litres per person per day (lpcpd) for all purposes, including bathing, washing, and drinking. Accordingly, the total estimated daily extraction from private shallow wells in the Malwathu Oya basin is 3,527 m³ (see Table 4.27 below).

Table 4.27: Quantity of Abstraction of Groundwater for Domestic Use in Deduru Oya Basin

River Basin	No. of Shallow Wells	Population	Extraction Qty. (litres/day)	Extraction Qty. (m^3/per day)
Malwathu oya	11,917	44,093	3,527,432	3,527

Rural Water Supply Schemes
There are 117 rural water supply (RWS) systems that use groundwater sources (shallow and deep wells) in operation within the Malwathu Oya basin, which serves around 40,000 in 10,755 households (Figure 4.18).

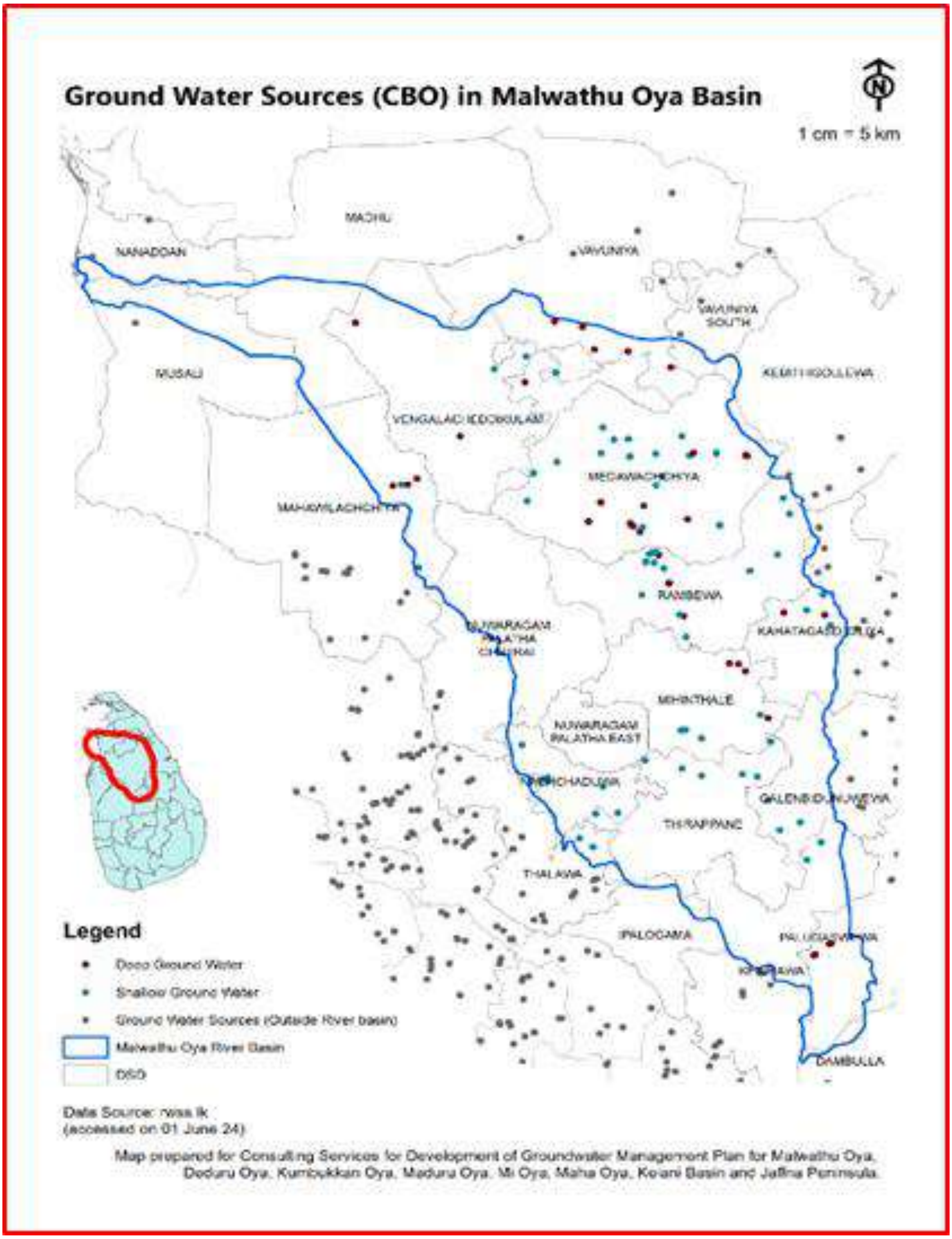


Figure 4.18: Distribution of RWS Schemes in Malwathu Oya

However, several systems are aging and facing various operational challenges, including frequent technical malfunctions and water stress in the groundwater sources, etc. Many systems lack the necessary fittings and components required for effective operation and monitoring of groundwater extractions. Notably, a considerable proportion of the systems do not have bulk meters to measure water pumping activities, and where meters are present, they are often either malfunctioning or non-operational. Despite these issues, pump operators generally possess a rough understanding of the volume of water required to meet the demand of the population and typically manage to maintain delivery within acceptable limits. However, this situation prevents a reliable assessment of the exact quantity of water being pumped from groundwater sources by the RWS systems, and limits the use of design data for safe pumping levels determined during the system's initial planning and design phase. However, based on the acceptable norm in per capita consumption of RWS, which is 120- lpcpd, it is estimated that around 4,775m^3 per day is extracted from these systems.

The details of the groundwater extracted by the community organizations for the operation of the Rural Water Supply Systems (RWSS) in the study area are provided in Table 4.28. below.

Table 4.28: Quantity of Abstraction of Groundwater for RWS Schemes in Malwathu Oya Basin

River Basin	No of RWS scheme	HH covered	Extraction Qty. (Litres/day)	Extraction Qty. (m3/per day)
Malwathu Oya	117	10,755	4,775,220	4,775

Urban Water Supply Schemes

Along Malwathu Oya basin there are seven (7) urban water supply schemes that use groundwater. From these, Mihinatale WS scheme extract a substantial amount of water, which is around 1,564m^3 per day. All the seven urban WS systems extract around 5,632m^3 of groundwater per day, which is substantial, as these systems are in dry zone areas where these is groundwater stress is notable.

Table 4.29: Quantity of Abstraction of Groundwater for Urban Schemes Schemes in Malwathu Oya Basin

River Basin	No of Urban schemes Use GW	Qty. extract (M^3/per day)
Malwathu Oya	7	5,632

Hand Pump Wells

According to village profiles compiled by the Divisional Secretariats within Malwathu Oya basin, a total of 3,629 handpump tube wells are currently serving 18,145 households and 67,131 individuals (Table 4.30 & Figure 4.19)

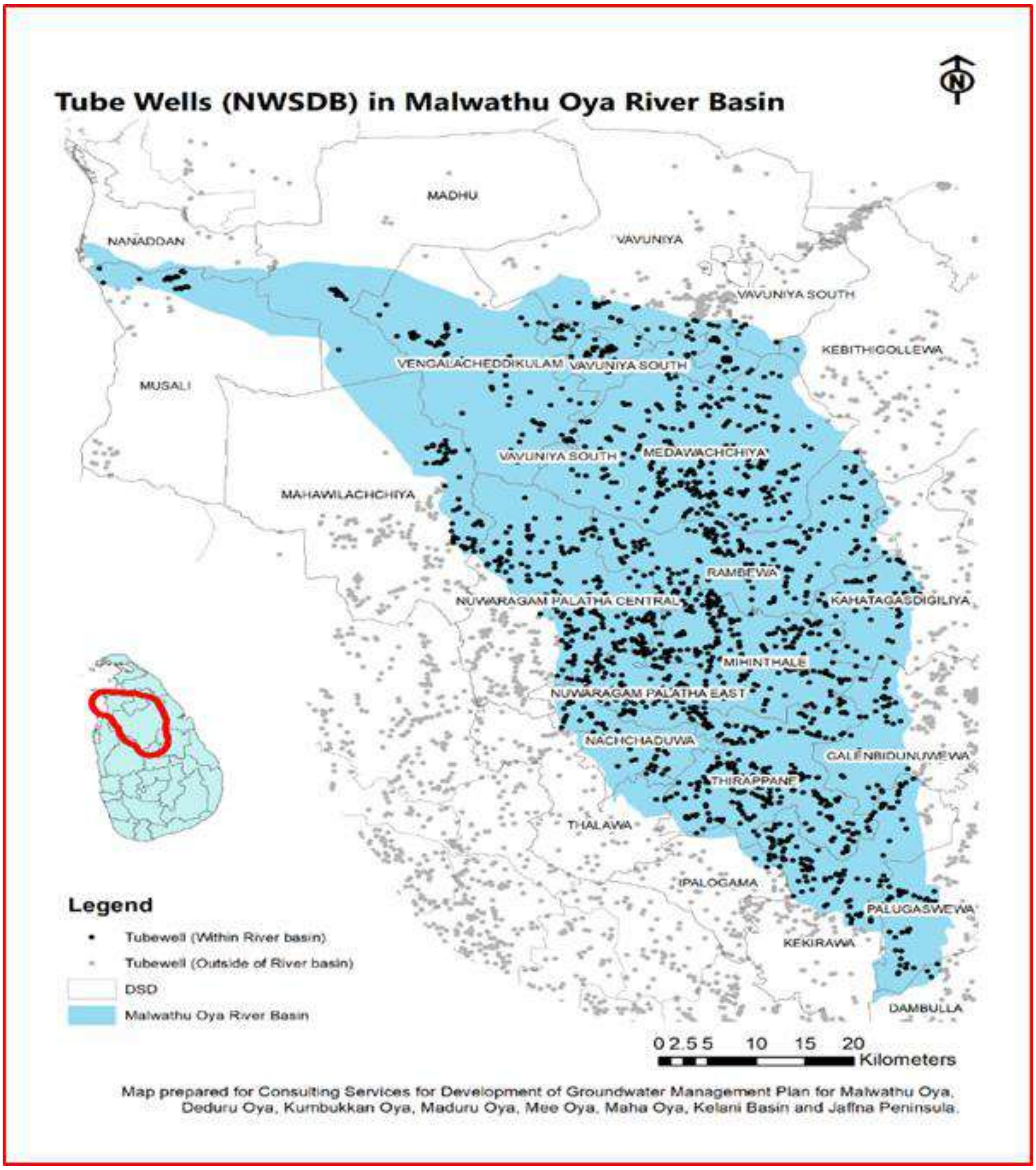


Figure 4.19: Distribution of Hand Pumps in Malwathu Oya Basin

For over three decades, tube wells were widely relied upon as a primary source of drinking water. However, the prevalence of chronic kidney disease (CKD) in dry zone areas has led to a significant decline in the use of groundwater for drinking purposes. As a result, many communities have abandoned tube wells for potable water, shifting to alternative sources.

In community clusters in the region where water scarcity is particularly severe, some poor households continue to rely on tube wells for drinking water, despite growing health concerns. In general, the water extracted from these tube wells is now predominantly utilized for non-potable purposes such as bathing, washing, and other daily activities.

The estimated water extraction from the tube wells in the Malwathu Oya Basin is around 1.68m³ per day (Table 4.30).

Table 4.30: Quantity of Abstraction of Groundwater from Tube Well Hand Pumps in Malwathu Oya Basin

River basins	No. of Tube Wells with Hand Pumps	Families	Population	Extraction Qty. (litres/day)	Extraction Qty (m^3/per day)
Malwathu oya	3,629	18,145	67,137	1,678,413	1,678

Argo wells

In Malwathu Oya basin, 18,082 agro-wells are used to irrigate a variety of crops.(Table 4.31).

Table 4.31: Details of Agro Wells in Malwathu Oya Basins

DS Division	No of Agro Wells	DS Division	No of Agro Wells
Ipologama	259	Mihinthale	n/a
Medawachchiya	3,672	Khatagasdigiliya	678
Galenbidunuwewa	3,163	Thirappane	3,117
Rambawa	1,864	Palugaswewa	717
Nuwaragampaltha Centeral	1,835	Kebithigollewa	118
Nuwaragampaltha East	922	Kekiraw	1,015
Nachchaduwa	545	Thalawa	177
Total			**18,082**

These wells provide water to home gardens with trees such as coconut and orange, as well as to small-scale farms cultivating vegetables, grains, and cash crops, including guava, maize, and gherkin. Medium and large-scale farms—some exceeding 50 hectares—also rely on these wells, particularly for crops like orange, mango, and guava.

Discussions with local communities revealed that nearly all households cultivating more than 3 to 5 acres have their own agro-wells (typically shallow wells), while larger landowners have installed multiple wells within their properties. However, the exact volume of groundwater extracted per day is unknown, and water usage is not consistent year-round. Many wells are only actively used during the dry season, as ample water is available during the monsoon months.

Medium-scale vegetable farmers who participated in discussions reported using approximately 2,000 litres of water per vegetable plot per day during the dry season, occasionally applying this amount twice daily, depending on the crop type. However, they do not use water from agro-wells during the rainy season, and accordingly, the average usage may be 1,000 litres of water per day or less throughout the year.

Based on the information gathered, it is estimated that around 1,808,000m^3 million litres of groundwater are extracted daily from these 18,082 agro-wells.

4.3.3.2. Outcomes of the Discussion with Groundwater User Groups

A series of field observations and stakeholder consultations were conducted with groundwater users in the study area. Villages were selected based on the presence of rural water supply (RWS) systems and the assumed availability of agro-wells, large agricultural landholdings, and tube wells. The key outcomes of these discussions are summarized in the table below.

Table 4.32: Summary of discussion outcomes

Village / DS Division	Key Findings of the Discussion
Malwathu Oya Basin	
Sembukuliya Kekirawa	• The RWS system operates using two tube wells: one installed in 2008 at the time the scheme was commissioned, and another that was previously abandoned by the Pradeshiya Sabha (PS) after the Kekirawa town area was incorporated into the National Water Supply and Drainage Board (NWSDB) scheme. • The system supplies an average of 60 m^3 of water per day, serving approximately 410 households. Water from both wells is inadequate to supply household needs (washing, cooking, sanitation and bathing etc.) of the people. Also, the water quality is not at an acceptable level, and people obtain water from other sources for drinking. • The village contains around 160 land plots, each with a minimum of 3 acres of highland, although some plots have been subdivided. • There are nearly 100 agro-wells located in the highland where cash crops are grown. • Significant groundwater stress has been reported in the area, although the release of Mahaweli water through irrigation canals that traverse the area and supply nearby paddy fields.
Seeppukulama Mihinthale	• RWS system supplies water to 506 households from two deep groundwater sources of 70 meters in depth. The daily extraction of water in these two wells are around 80m^3. • There are 20 lands with 5-6 acres and others are smaller plots. • There were 5 handpump tube wells and currently only 1 well is in operation status with quality water. Others were abandoned due to lack of water and due to quality issues. According to the community, the water in both wells has a strong mineral taste. • Water stress occurs in the area during the dry season; however, it does not appear to affect the water table of the two deep boreholes.
Ikirigollewa Rambewa	• The Rural Water Supply (RWS) scheme was launched in 2010, initially serving 100 households. At present, the number of beneficiary households has increased to 800, with an additional 5 connections pending. • The scheme is supported by three water sources: one shallow well and two deep tube wells. The shallow well, located near the Bogaswewa tank, supplies approximately 40 m^3 of water per day. The two deep wells are designed to provide a combined yield of 160m^3 per day. However, the supply capacity from all sources declines significantly during the dry

Village / DS Division	Key Findings of the Discussion
	season, leading to increased stress on the already intermittent water supply, exacerbated by the growing population. • The water quality of these wells is at an unacceptable level due to their strong mineral taste typical of hard water. • Severe water stress prevails in the area during dry periods, further affecting the small, rain-fed Bogaswewa tank. • Additionally, there are approximately 50 agro-wells in the area; however, they are insufficient to meet the water demands for crop cultivation during extended dry spells.
Helambagaswewa Medawachchiya	• The Rural Water Supply Scheme (RWSS) was initiated in 2003 to serve 100 households. Currently, 261 households are receiving water through the system. • Initially, two deep tube wells were used as the primary water sources; however, both have since dried up, with the community unaware of the exact cause. At present, the RWSS is connected to a deep borehole—200 feet in depth—owned by the Pradeshiya Sabha (PS). The current water source has a capacity of approximately 50 m^3 per day, which is insufficient to meet the community's needs. • Water has a hard taste, and people are reluctant to accept. • In the area, there are four large agricultural lands, each around 25 acres in size, primarily cultivating guava and other fruits. These farms have their own water sources for irrigation, likely agro-wells. • Additionally, within the village, there are four agro-wells used by small-scale farmers for cultivating cash crops. Out of the four hand-pump tube wells previously available, only two remain in use. • The area experiences high levels of water stress, particularly during dry periods
Dunudambu Wewa Nochchiyagama	• The Rural Water Supply (RWS) system was established in 2008 to serve 145 households. Currently, it supplies water to 261 households, with an additional 10 service connections pending. • The system's water source is a shallow well with a production capacity of approximately 40 m^3 per day. However, during the dry months of July, August, and September, the yield significantly declines, resulting in water stress. Currently, water is supplied to households for only about 3 hours per day. • Water has a hard taste according to people in the area. • Within the village, there are an estimated 30–35 agro-wells and approximately 200 private shallow wells. Additionally, one brickmaker in the area uses water from a dedicated well constructed near his kiln.

4.4. Jaffna Peninsula

4.4.1. Meteorology

General

The Jaffna Peninsula lies in the northernmost part of Sri Lanka. It is separated from the mainland by two external lagoons, namely the Elephant Pass lagoon and the Jaffna lagoon. The Peninsula is narrow and elongated. The topography of the peninsula is flat with a maximum elevation of about10 m above MSL (Figure 4.17).

The land area is about of 1,000 km^2 and it has a coastline of 160 km.

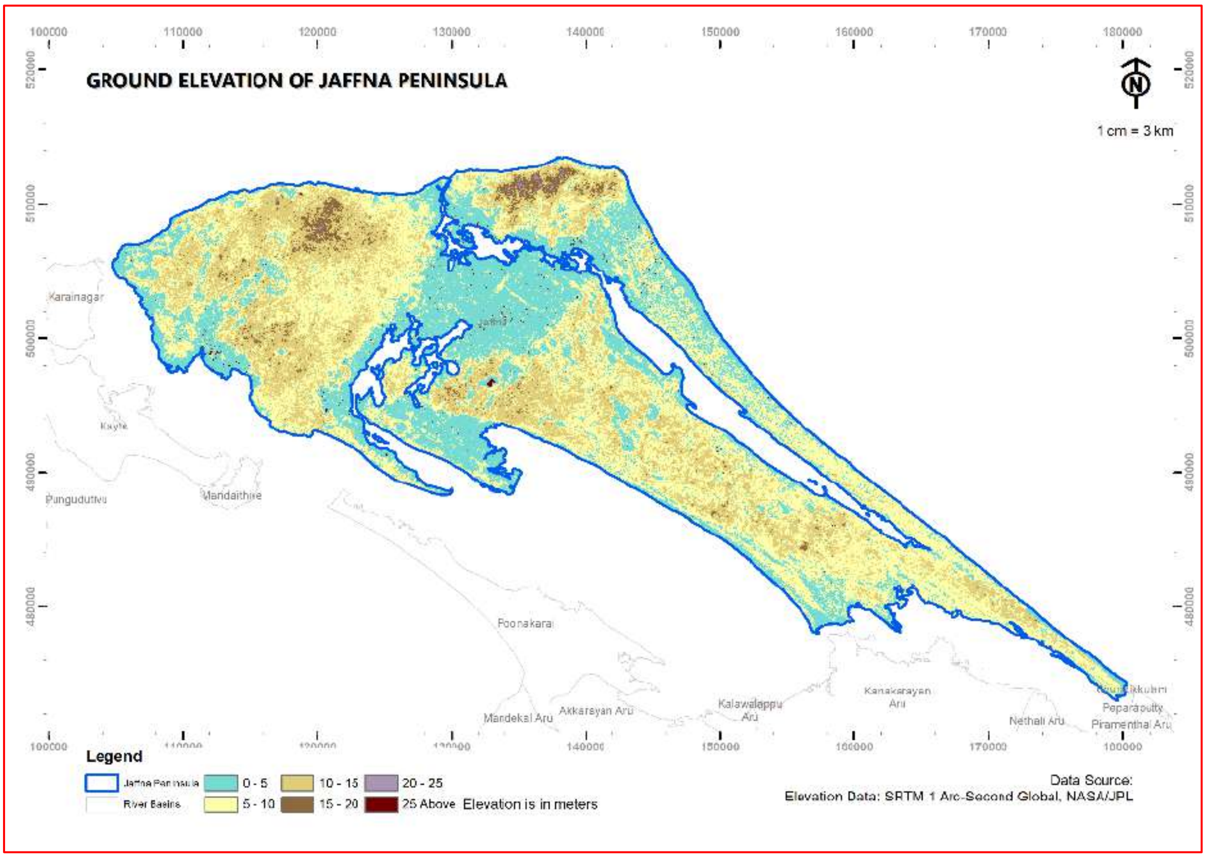


Figure 4.20 : Digital Elevation Model of Jaffna Peninsula

The Peninsula entirely falls within the dry climatic zone. The annual average pan evaporation is around 1,230 mm/year and slightly higher than the annual precipitation.

4.4.1.1. Rainfall

The precipitation of the Jaffna peninsula averages approximately 1,200 mm/year. The precipitation is concentrated during the NE monsoon that falls in October – December. (Figure 4.21).

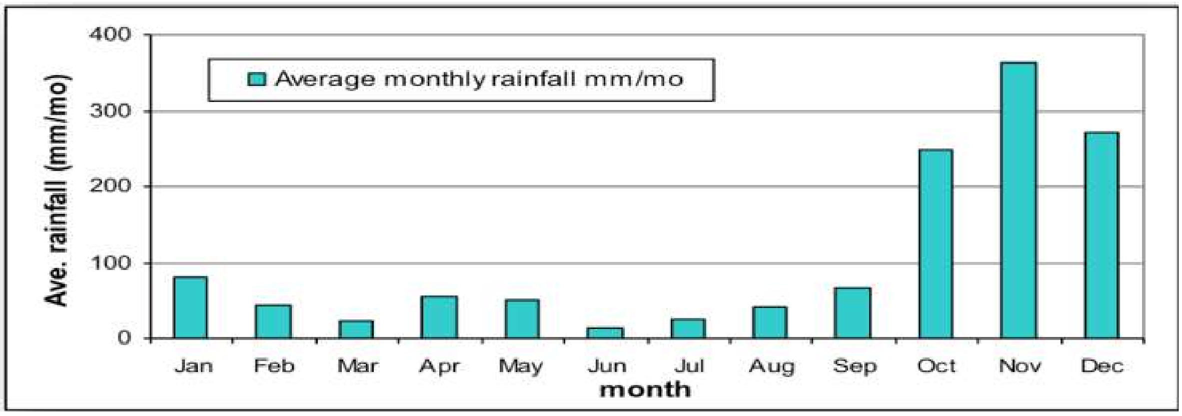


Figure 4.21 : Average monthly rainfall in Jaffna Peninsula

Rainfall Measurements

Figure 4.19 presents the distribution of the rain gauge stations in the basin. One gauge is located within the basin. The rainfall data is available in the respective institution.

As per the geomorphology, the basin shows features attributed to a flat terrain. According to the WMO standards and also when considering the terrain features of the basin, the coverage of a single rain gauge station can be considered as 600km^2/ per gauge.

Table 4.33 presents the percentage coverage of a basin against the standard coverage recommended by the WMO.

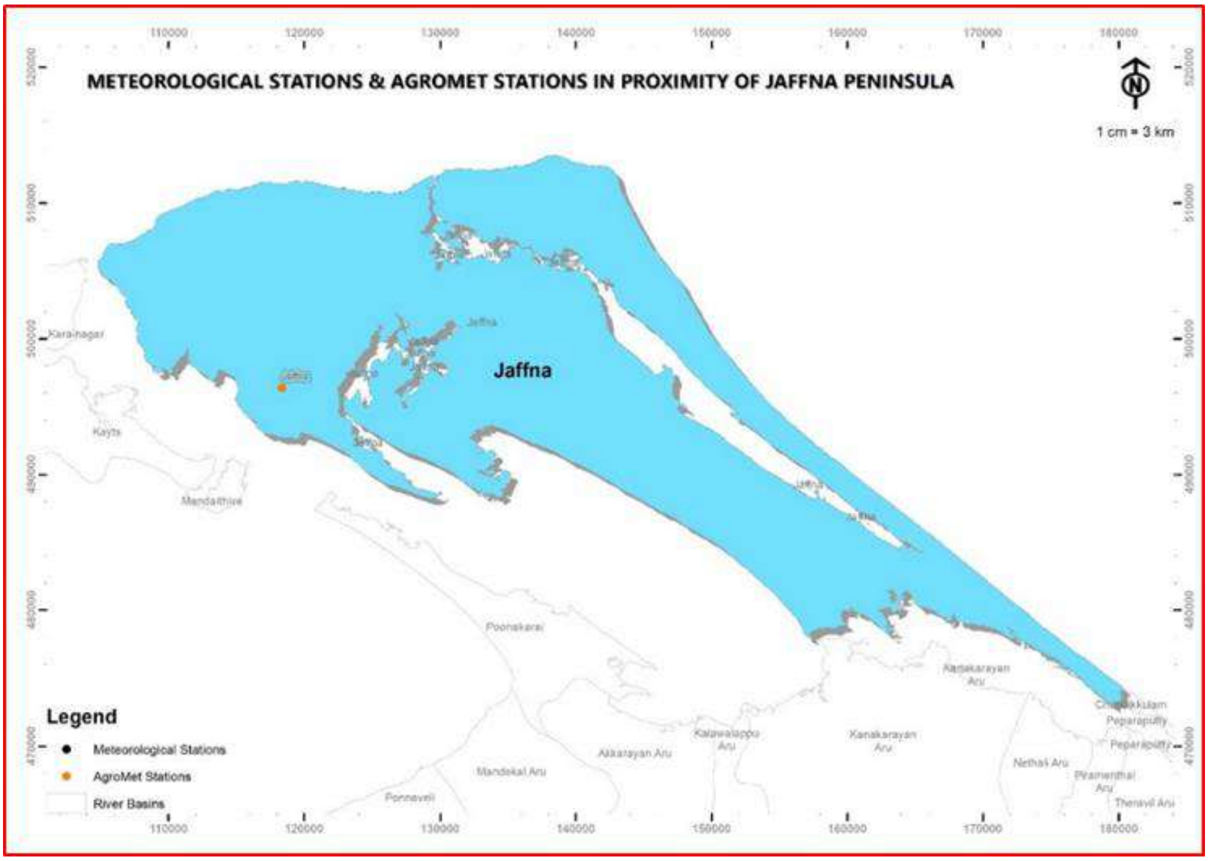


Figure 4.22: Locations of Rain Gauge Stations in Jaffna Peninsula

Table 4.33: Rainfall Gauge Coverage in Jaffna Peninsula

Number of Gauges	Total Coverage (km^2)	Unit Coverage (km^2)	Standard Coverage (km^2) by One Gauge	% Coverage Against Standard Coverage
1	1000	758	600	60

Rainfall Analysis

Rainfall data collected at long term vs for the hydrologic year of 2021/2022 is given in the Table 4.34 and Figure 4.23 with a segregation of North East and South West monsoon seasons. North East monsoon covers the major amount of total annual rainfall indicating that 75% of total rainfall occurs during this period. This is very important fact in the assessment of aquifer stress due to the poor/or recharge during the rest of the hydrological year.

Table 4.34: Long Term and Short Term Rainfall Data in Jaffna Peninsula

Rainfall data range	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	NEM Total	SWM Total	Annual Total
2021/2022 (Recent)	0	752	147	181	102	19	185	10	5	73	95	3	1,201	372	1,573
Long term average from 1971/1972	214	450	250	84	29	40	68	66	17	28	59	64	1,066	302	1,368

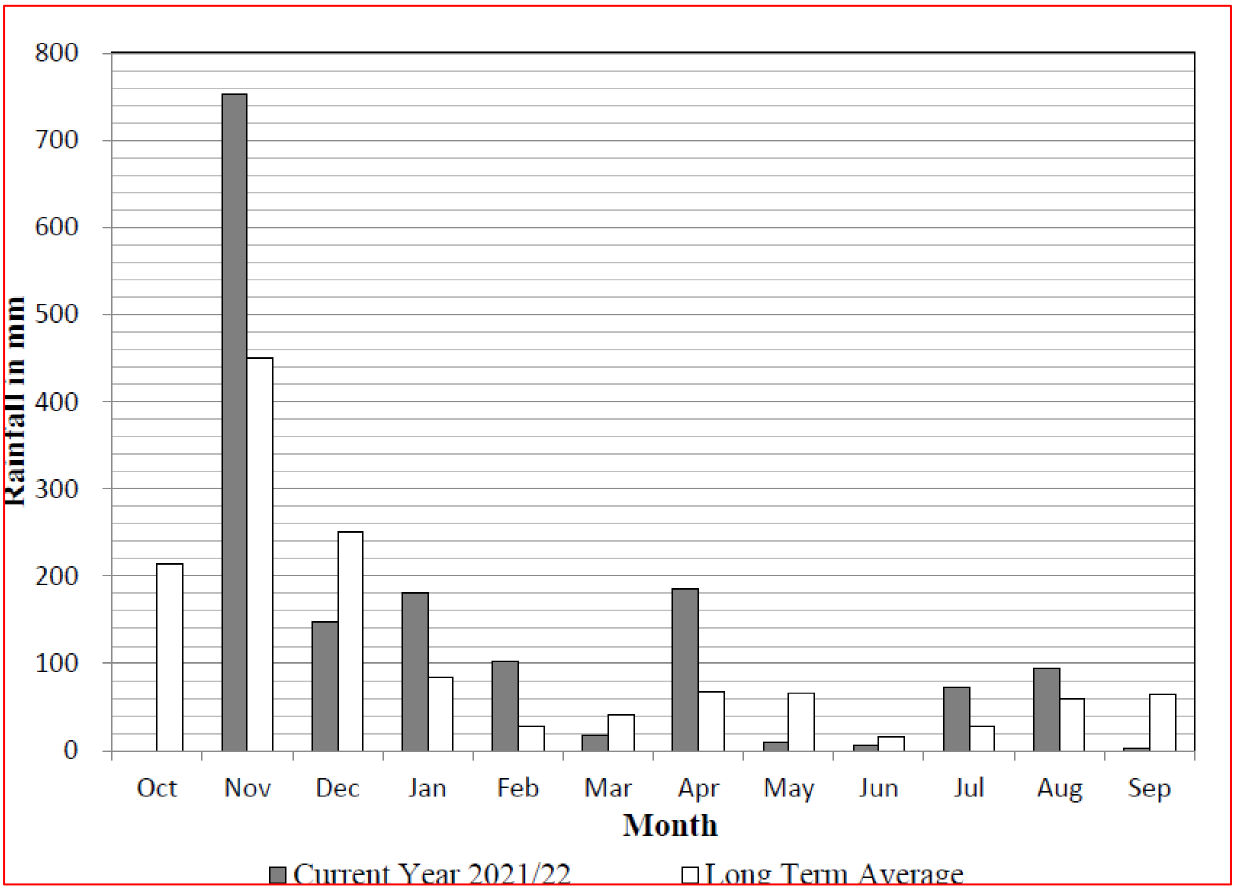


Figure 4.23: Rainfall long-term Annual and Current in Jaffna Peninsula

4.4.2. Land Use Pattern

The land use pattern is illustrated in the Figure 4.24 and the types and percentages are given in the Table 4.35. Home gardens occupies the majority of the land cover to a percentage of 30.79 of the total land area indicating the use of groundwater in large amounts at domestic level. The paddy cultivation is also remarkably high with its percentage reaching to 13.33 of the total land use but it has no impact to the groundwater as it is basically confined to the S-E monsoon season. The Jaffna District is predominantly an agricultural area with crops such as red onions, chillies, potatoes, tobacco, vegetables, bananas and grapes being cultivated for commercial purposes. Other crops such as paddy, pulse, coconut cultivation at subsistence level, and palmyrah products are also a source of income.

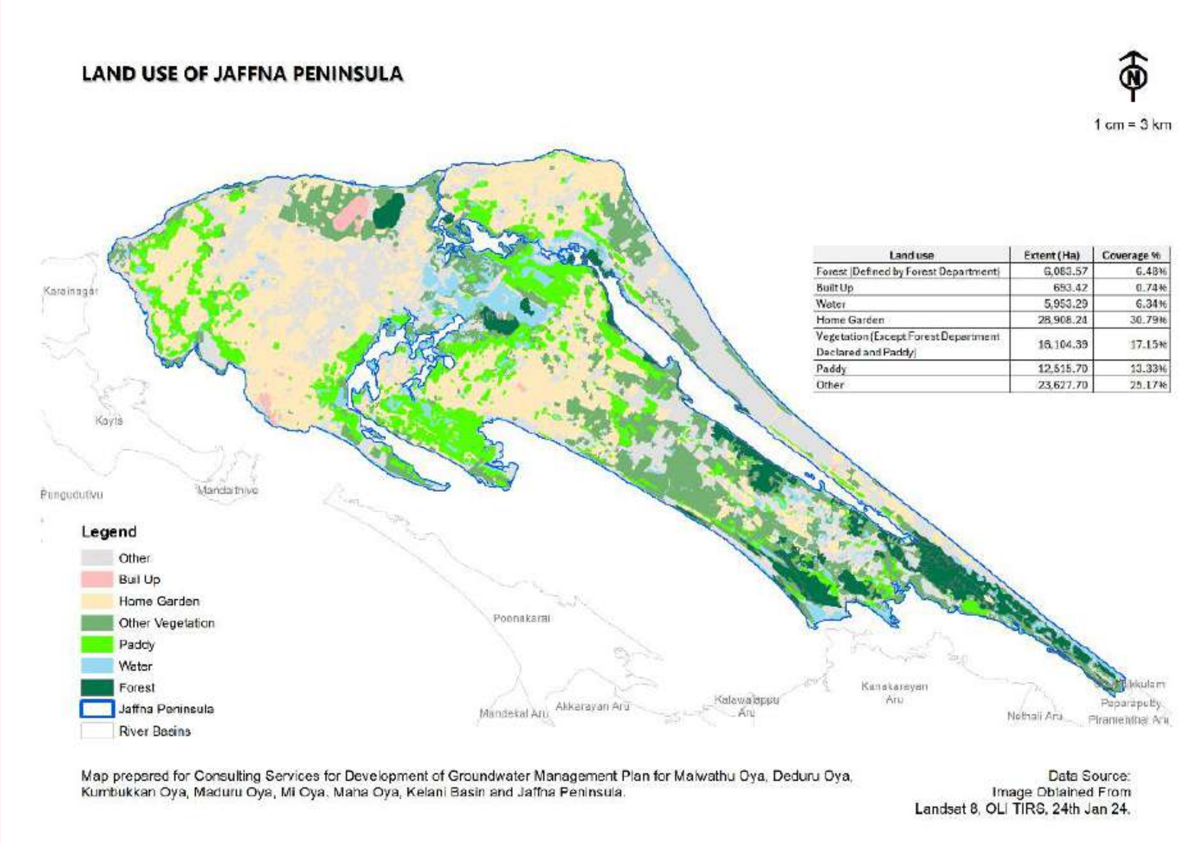


Figure 4.24: Land use Pattern in the Jaffna peninsula

Table 4.35: Land Use Extents in Jaffna Peninsula

Land use	Extent (Ha)	Coverage %
Forest (Defined by Forest Department)	6,083.57	6.48%
Built Up	693.42	0.74%
Water	5,953.29	6.34%
Home Garden	28,908.24	30.79%
Vegetation (Except Forest Department Declared and Paddy)	16,104.39	17.15%
Paddy	12,515.70	13.33%
Other	23,627.70	25.17%

4.4.3. **Utilization of Groundwater Resources**

4.4.3.1. User Groups of Groundwater in the Jaffna Peninsula

Groundwater user identification was carried out across the Jaffna Peninsula, a geographically distinct region marked by the absence of significant surface water resources. Despite certain quality concerns, groundwater remains abundant in the peninsula and continues to serve as the primary and essential water source for the majority of households.

Groundwater users in Jaffna represent a broad spectrum, from individual households to national-level institutions. The key groundwater user groups in the area are identified as follows:

(i) **Households** utilizing individual domestic wells, including shallow dug wells and shallow hand pump wells,
(ii) **Water consumer groups** accessing hand pump wells primarily for drinking purposes,
(iii) **Community-Based Organizations (CBOs)** operating small-scale water supply systems drawing from groundwater sources.
(iv) **National Water Supply and Drainage Board (NWSDB)**, which utilizes groundwater for the provision of water supply,
(v) **Small-scale farmers** relying on groundwater to irrigate small plots cultivating vegetables, grains, coconuts, and fruits,
(vi) **Large-scale agricultural operators** using groundwater for the cultivation of both short-term and long-term cash crops.

According to the available district profiles prepared based on the household data collected through GN and other data sources, the groundwater users in the peninsula have been identified and are indicated in Table 4.36 below:

Table 4.36: Groundwater User Groups in Jaffna Peninsula

	Groundwater Users	No
1	Households with privately owned wells	86,531
2	Water consumer groups formed around hand-pump tube wells	26,099
3	Community Based Organization (CBO) that manages & operates RWS systems	18
4	Users of NWSDB-managed urban and small-town water supply schemes	15
5	Small-, medium-, and large-scale agricultural landowners utilizing agro-wells	23,584

4.4.3.2. Mode, Purpose, and Quantity of Groundwater Extraction

Groundwater serves as a vital source of drinking water and supports various domestic needs across rural regions of Sri Lanka. In Jaffna peninsula, where there are no surface water sources, shallow well water is extensively utilized for all agricultural practices by farming communities.

The details on the methods of groundwater extraction for various purposes highlight the extent of groundwater usage across the Jaffna peninsula, underscoring its critical role in sustaining rural livelihoods and agriculture.

A considerable proportion of the population within the basin depends on groundwater for a range of activities, including drinking, domestic use, and highland agriculture.

Domestic shallow-wells

Shallow wells play a vital role in the domestic water supply within the Jaffna Peninsula, with approximately 86,531 wells currently in use, serving an estimated population of 129,178 people (Table 4.37).

Table 4.37: Distribution of Dug Wells in Jaffna Peninsula

	Divisional Secratariat Area	No. of Dug Wells
Jaffna	Chankanai (Walikamam West)	6,880
	Jaffna	6,596

	Divisional Secratariat Area	No. of Dug Wells
Jaffna	Nallur	13,644
	Thenmarachchi	13,956
	Vadamaradchchi East	3,623
	Vadamaradchchi South West	4,002
	Vadamaradchchi North	6,337
	Valikamam East- Kopay	99
	Valikamam North thellipalai	4,264
	Valikamam South West	109
	Valikamam South	7,379
Kilinochchi	Pachchilapalli	
Total		**66,889**

Aside from a few small-scale water supply schemes serving some towns, there was, until recently, no major piped water supply system in place.

The operation of a large reverse osmosis (RO) plant, which purifies seawater to supply the urban population, may have reduced the dependence on groundwater in the Jaffna town area. However, residents in remote parts of the peninsula continue to rely heavily on shallow wells to meet their daily water needs.

The average quantity of water extracted from shallow wells in the peninsula is estimated at 65 litres per person per day (lpcpd), covering all domestic uses including bathing, washing, and drinking. Based on this estimate, the total daily water extraction from shallow private wells in the study area is approximately 10,334 cubic metres, and potentially more (Table 4.38).

Table 4.38: Quantity of Abstraction of Groundwater for Domestic Use in Jaffna Peninsula

	No. of wells	Population	Qty. extract (litrs)	M^3/per day
Jaffna Peninsular	86,531	129,178	10,334,240	10,334

Rural Water Supply Schemes

There are 18 small-scale Rural Water Supply (RWS) projects currently in operation within the Jaffna Peninsula (Figure 4.25).

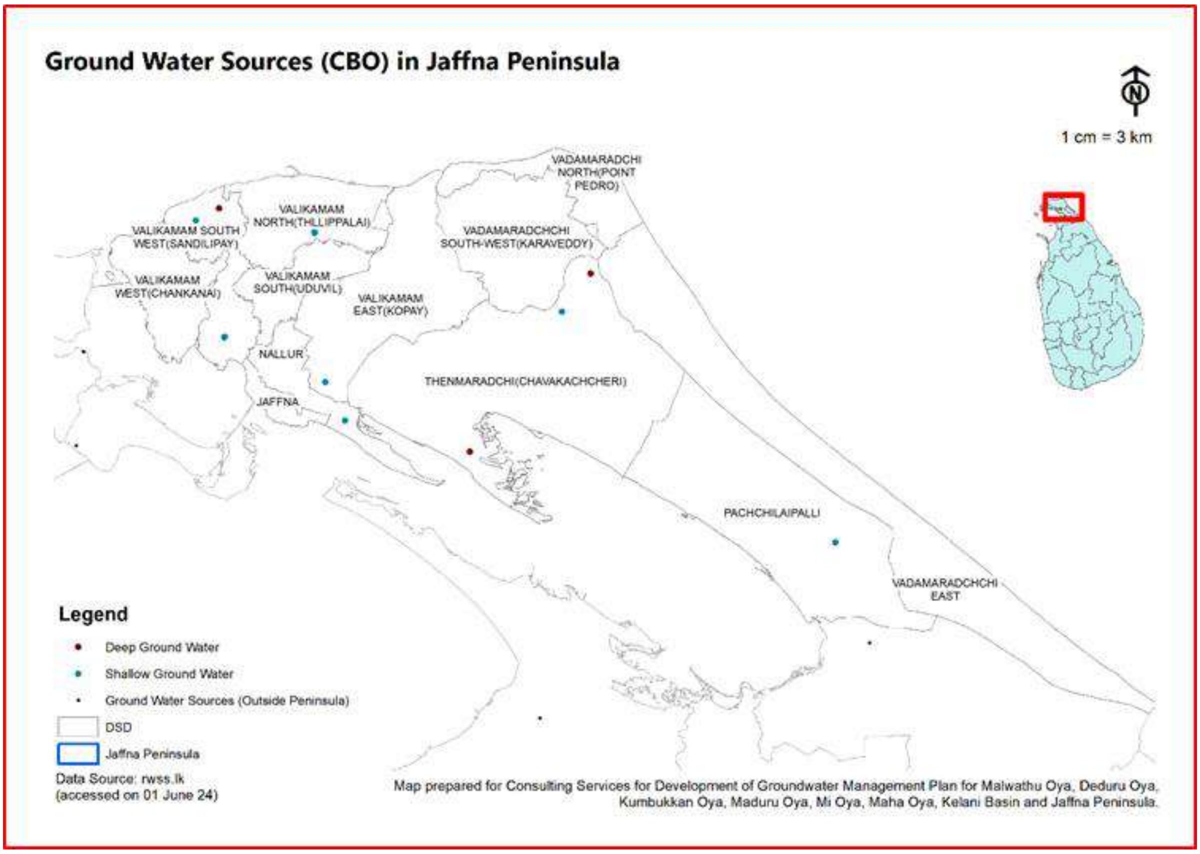


Figure 4.25: Distribution of RWS Schemes Operated by CBOs in Jaffna Peninsula

Water Supply Schemes Operated by CBOs

Water Supply Schemes Operated by CBOs in Jaffna peninsula (18 schemes) draw water from shallow wells with depths ranging from 7 to 10 meters and diameters of approximately 6 meters. Collectively, they extract only 527 cubic metres of water per day—a volume that is negligible compared to groundwater extraction from shallow dug wells and agro-wells. Due to limitations in the availability of good-quality groundwater at the source, all of these rural water supply systems operate at low service levels, typically providing water through common collection points.

The details of the groundwater extracted by the community organizations for the operation of the Rural Water Supply Systems (RWSS) in the peninsula are provided in the table 4.39 below.

Table 4.39: Water use by RWS schemes in Jaffna Peninsula

River Basin	No of RWS scheme	HH covered	Qty. extract (Litres)	M^3/per day
Jaffna Peninsula	18	1,187	527,028	527

Urban Water Supply Schemes

Currently, there are 15 small water supply systems managed by the National Water Supply and Drainage Board (NWSDB) operating within the Jaffna Peninsula, all of which utilize groundwater sources. These systems serve approximately 1,187 households. The total volume of potable groundwater extracted by these systems is around 2,110 cubic meters per day, which is relatively negligible compared to overall water use in the region (Table 4.40).

Table 4.40: Quantity of Abstraction of Groundwater for Urban Schemes Schemes in Jaffna Peninsula

	No of Urban schemes Using GW	Extraction Qty. (m3/per day)
Jaffna Peninsula	15	2110

Hand Pump Wells

According to statistical data from the District Secretariat, a total of 26,099 hand pump tube wells are currently in use across the Jaffna Peninsula, serving approximately 138,576 individuals (Figure 4.26).

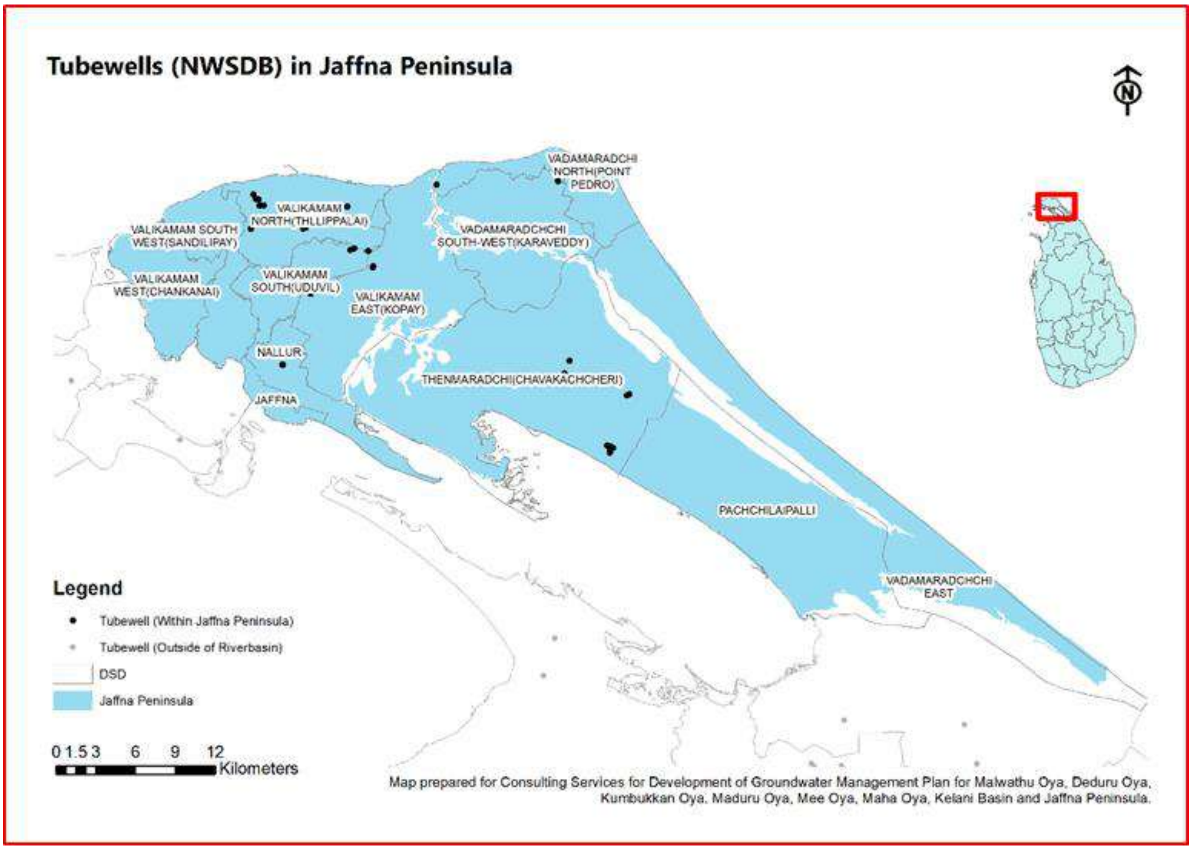


Figure4.26: Distribution of Tube Wells with Hand Pumps in Jaffna Peninsula, completed by NWSDB

Tube wells remain a key source of water for drinking and other daily needs for many residents, despite ongoing concerns regarding water quality and potential contamination. Groundwater continues to be the primary source of freshwater in the region. However, in recent years, some communities have begun to abandon tube wells for potable water, opting instead for alternative water sources.

The estimated water extraction from the tube wells in the peninsula is around 3.46m³ per day (Table 4.41).

Table 4.41: Quantity of Abstraction of Groundwater from Tube Well Hand Pumps in Jaffna Peninsula

	No. of tube wells with and Pumps	Families	Population	Extraction Qty. (litres/day)	Extraction Qty. (m^3/day)
Jaffna Peninsula	26,099	37,453	138,576	3,464,403	3,464

Argo wells

In addition to small-scale farmers, the Jaffna Peninsula is home to individual landowners who manage larger agricultural holdings. The region has a substantial amount of land dedicated to agriculture, particularly for cultivating cash crops such as onions, potatoes, tobacco, chili, and bananas. Water for these agricultural activities is primarily sourced from agro-wells installed on these lands.

It is reported that approximately 23,600 agro-wells are in use across the peninsula, supporting the irrigation for a variety of crops, including home gardens with fruit trees, coconut palms, and other supplementary crops. Discussions with knowledgeable Jaffna residents revealed that nearly all farmlands—regardless of size—are equipped with agro-wells, with some large landowners having multiple wells within their properties.

While the exact volume of groundwater extracted daily is unknown and varies seasonally, it is generally accepted that water usage peaks during the dry season, as monsoon rains reduce the need for irrigation. For medium and small farms, which are typically situated on sandy soils, an estimated 2,000 litres of water are used per day during the dry period. However, when averaged across the year—accounting for non-use during the rainy season—daily usage is estimated at around 1,000 litres per well.

Based on this information, it is estimated that approximately a quantity of 23,584 cubic metres of groundwater is extracted daily from the 23,584 agro-wells in operation across the peninsula (Table 4.42).

Table 4.42: Quantity of Abstraction of Groundwater from Agro Wells in Jaffna Peninsula

River Basins	No. of Agro Wells	Ave. Extraction (litres/day)	Extraction Qty. (litres/day)	Extraction Qty. (m3/per day)
Jaffna Peninsular	23,584	1000	23,584,000	23,584

4.4.4. Summary of Groundwater Abstraction of each study area

Table 4.43 presents an approximate number of all water supply points (wells) of different categories.

Table 4.43: Total Groundwater Abstraction of each study area

Study area	Type of abstraction(m3/d)					Total abstraction (m3/d)	Total annual abstraction(Mm3)
	Domestic	RWS	Urban	Hand pumps	Agro wells		
Deduru Oya basin	37896	24402	9575	1428	2573	75874	28
Malwathu Oya Basin	3527	4775	5632	1678	1808	17417	7
Kelani river Basin	17833	32809	6500	1179	0	58321	22
Jaffna Peninsula	10334	527	2110	3464	23584	42791	15

CHAPTER 5: ASSESSMENT OF POTENTIAL ZONES FOR GROUNDWATER RECHARGE

5.1 Preparation of Groundwater Recharge Potential Maps

Each study area was assessed to identify the zones with high potential to consider for artificial recharge programs as a part of demand management to meet the current and future requirements.

5.1.1. Methodology

The methodology adopted for classifying potential zones is described below, considering Deduru Oya basin as an example. The same procedure will be applied for the rest of the study areas.

Remote sensing and the geographical information system (GIS/RS) were used to integrate the following six contributing factors (Figure 5.1):

a. Soil types
b. Land cover/land use
c. Lineaments
d. Rainfall
e. Drainage, and
f. Slope

The weights of factors contributing to the groundwater recharge mentioned above were derived using satellite imageries, Soil & geology maps, land use and hydrological databases in different formats. The ranks given in the legend of the resultant map of the groundwater recharge potential zone demonstrate the recharge capability across the basin.

The methodology flow chart given below provides an insight into the concise process of the preparation of potential groundwater recharge zones.

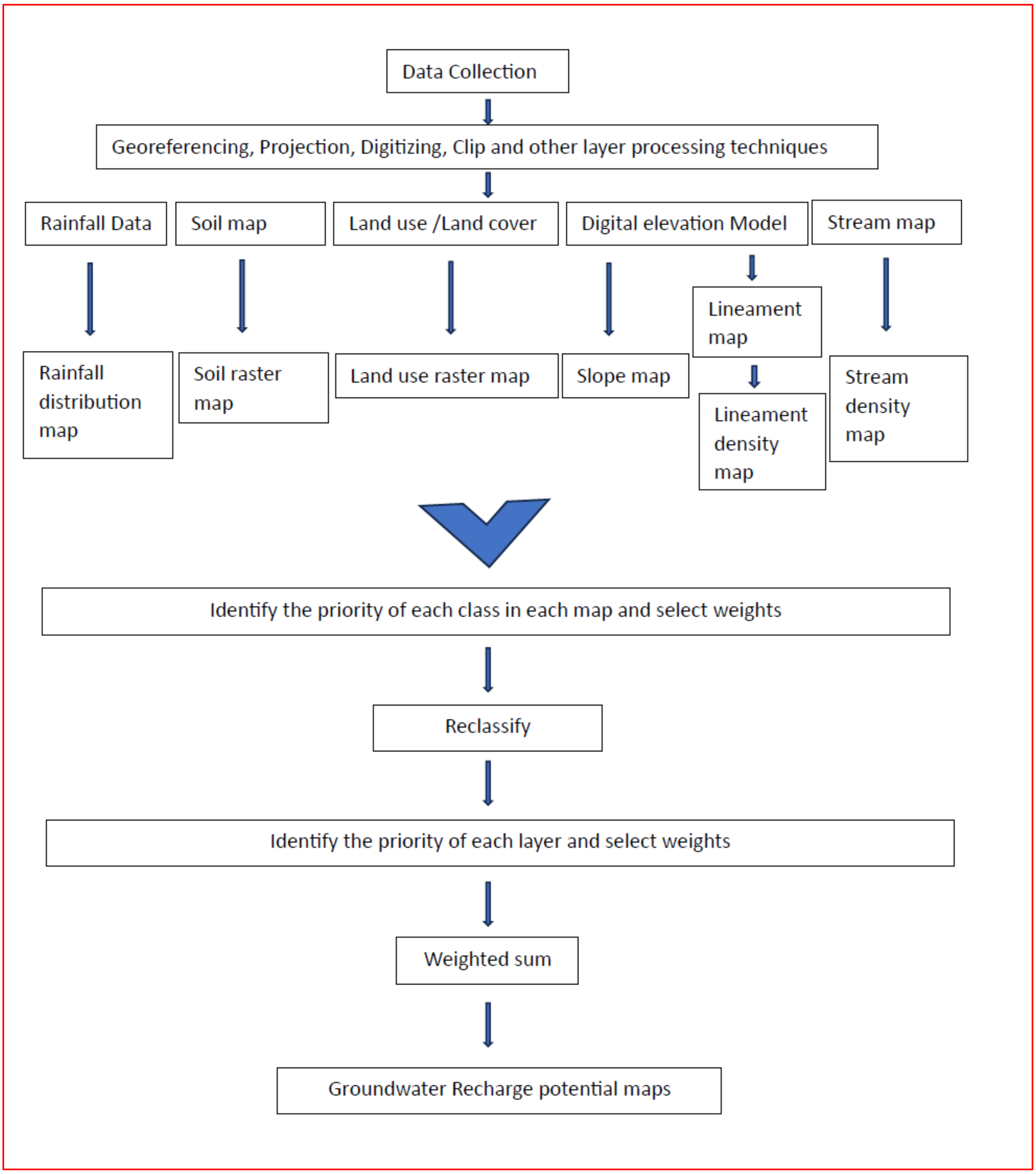


Figure 5.1: Flow Chart for Preparation of Recharge Potential Maps

The following sections will provide the methodology adopted to identify recharge potential zones for each study area.

5.1.1.1. Data collection

After identification of necessary data to prepare groundwater recharge potential map, the data was collected in different formats.

Ex:

i. Average rainfall of the basin in different places (Excel)
ii. Soil map of the basins (JPEG)
iii. Digital Elevation Model (Satellite images)
iv. Land use (Satellite images)
v. Stream network of the basin (Shape files)

5.1.1.2. Layer processing

The above data were processed to convert them into operational formats in ArcGIS.

I. Rainfall Distribution

Average rainfall data were interpolated to prepare the rainfall distribution map of the basin (Figure 5.2). The inverse distance weighted method was used to interpolate data and the raster map was prepared with 100*100-pixel size.

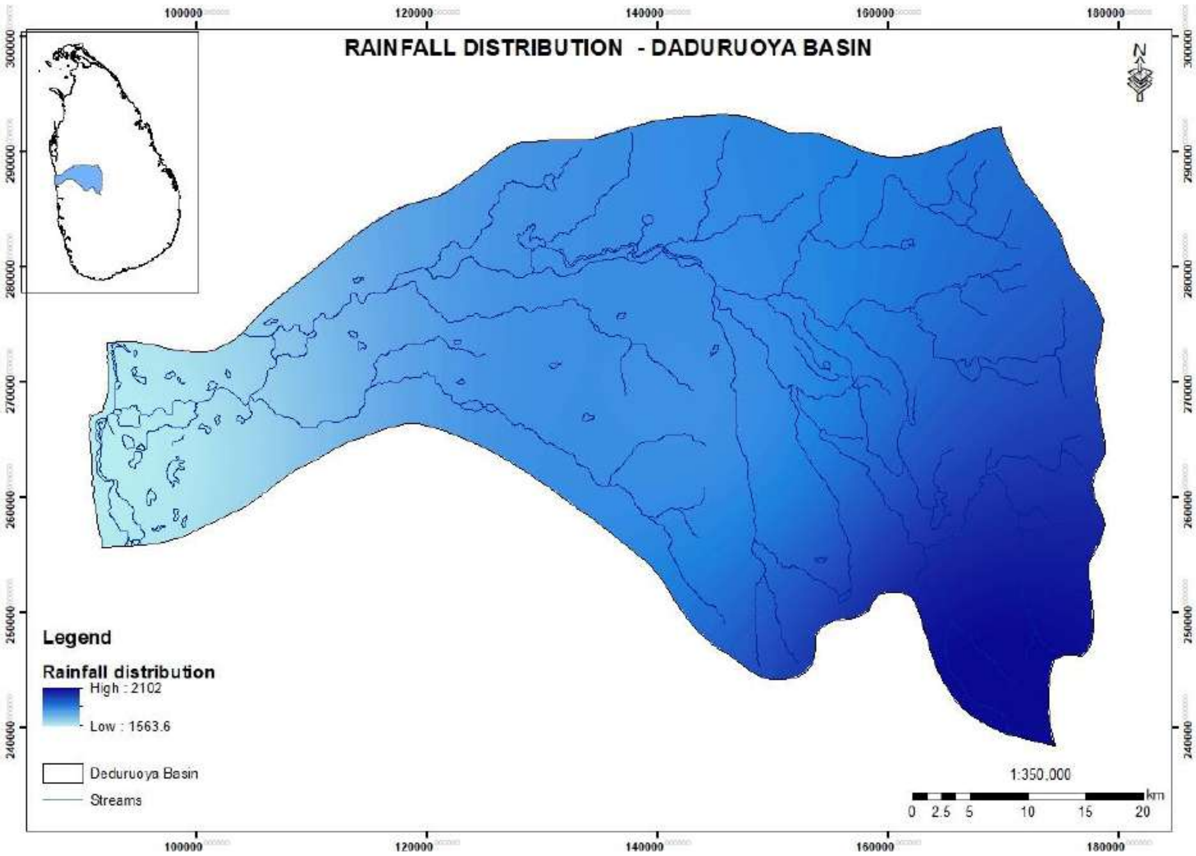


Figure 5.2: Rainfall distribution of Daduru Oya Basin

II. Soil Map

Soil maps of the relevant basins were prepared by using the document on Soil Classification of Sri Lanka by Dr. F. R. Moormann F.A.O., Soil Classification Consultant and Dr. C. R. Panabokke, Head, Land Use Division, Department of Agriculture, Ceylon. (Figure 5.3)

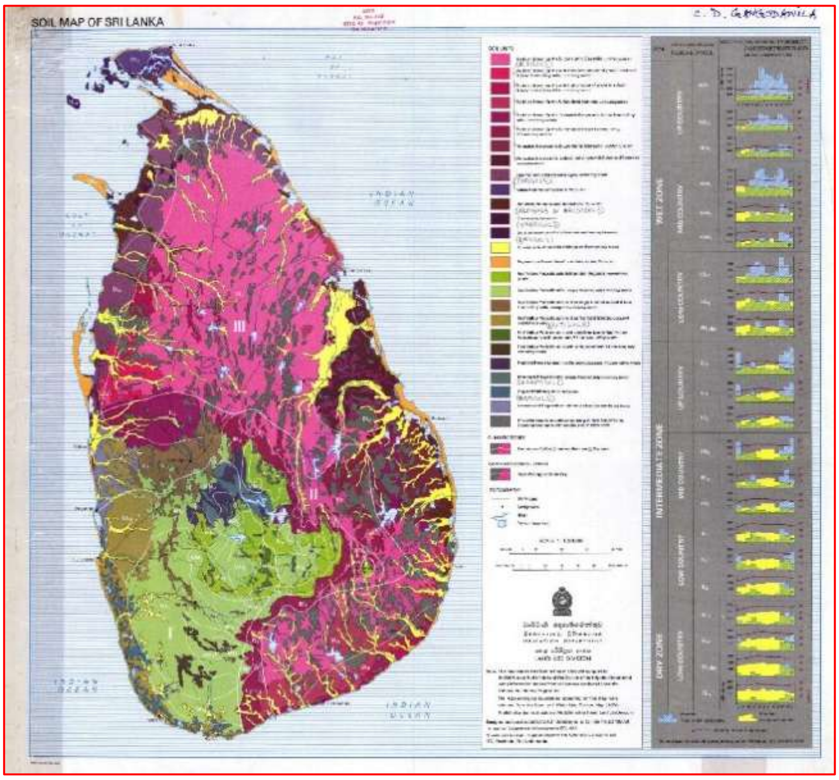


Figure 5.3: Soil Types of Sri Lanka

The soil map was georeferenced and clipped for each basin. By digitizing, a soil map for each basin was prepared in shapefile format (Figure 5.4). Then, the soil types were classified according to their groundwater retention properties, and the map was rasterized to a 100x100 pixel size (Figure 5.5).

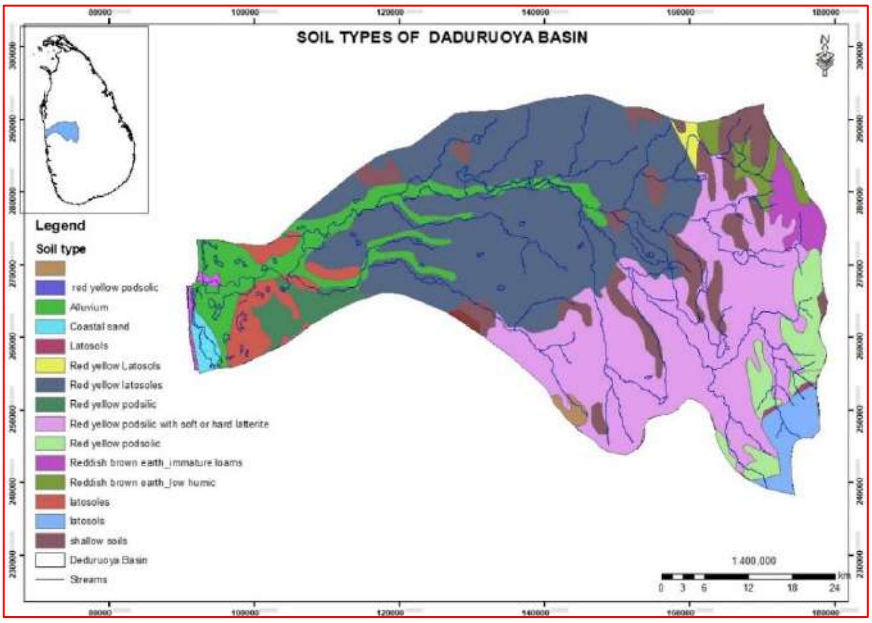


Figure 5.4: Soil Types of Deduru Oya Basin

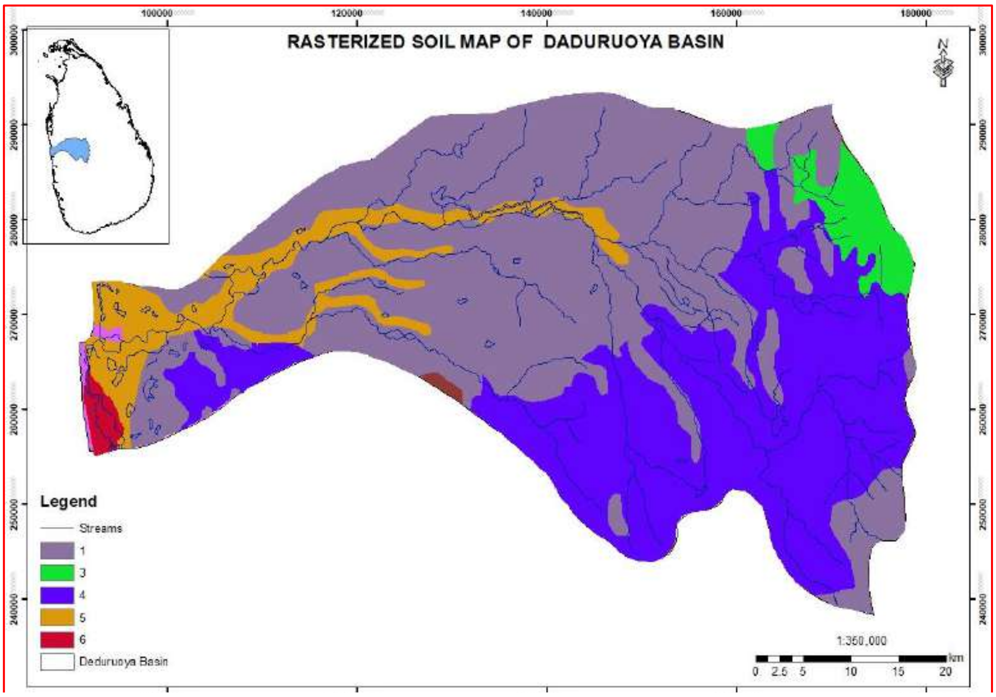


Figure 5.5: Rasterized Soil Map of Dedurupya Basin

Land use

Satellite images of land cover were downloaded from WaPour portal (Figure 5.6).

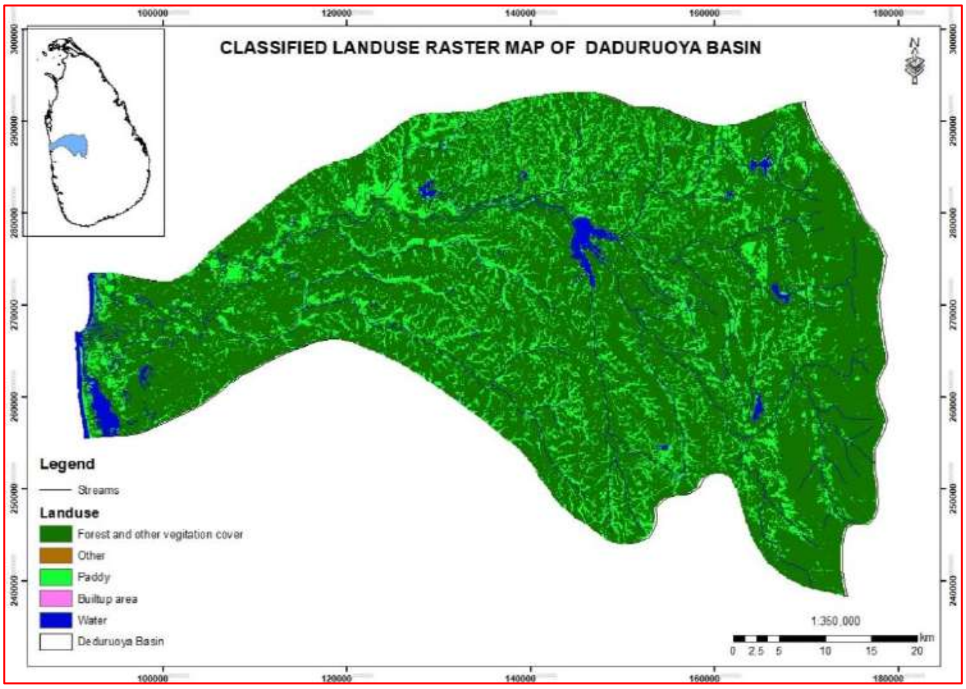


Figure 5.6: Classified Land Use Map of Deduru Oya Basin

III. Digital Elevation Model (DEM)

Aster DEM was downloaded and some corrections were done such as fill sink, project and clipped. (Figure 5.7)

.

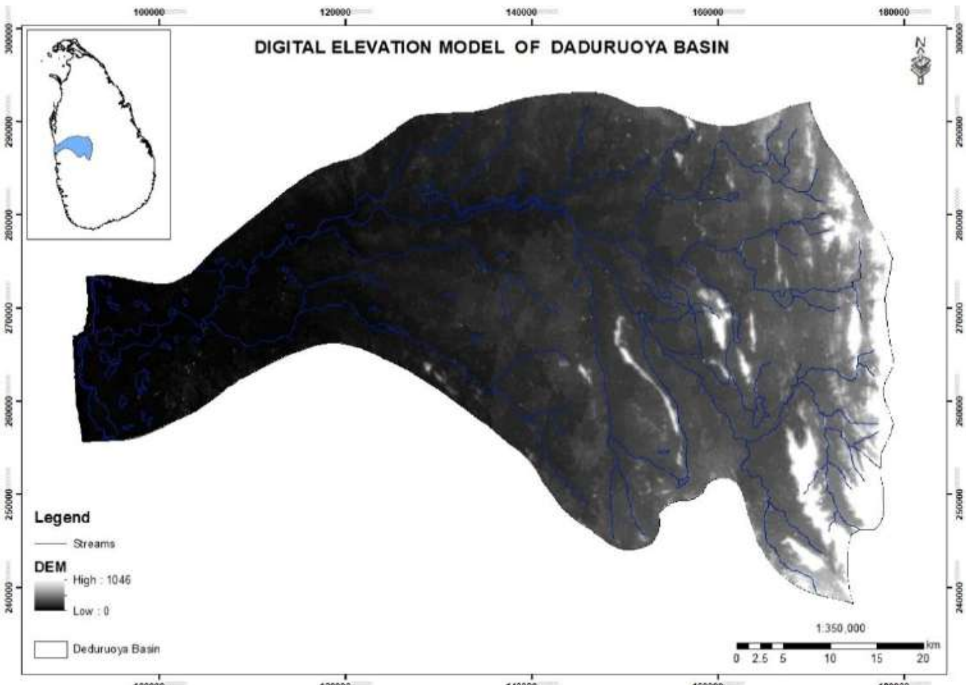


Figure 5.7: Digital Elevation Model (DEM)

This DEM was used to prepare the slope map of the basin (Figure 5.8)

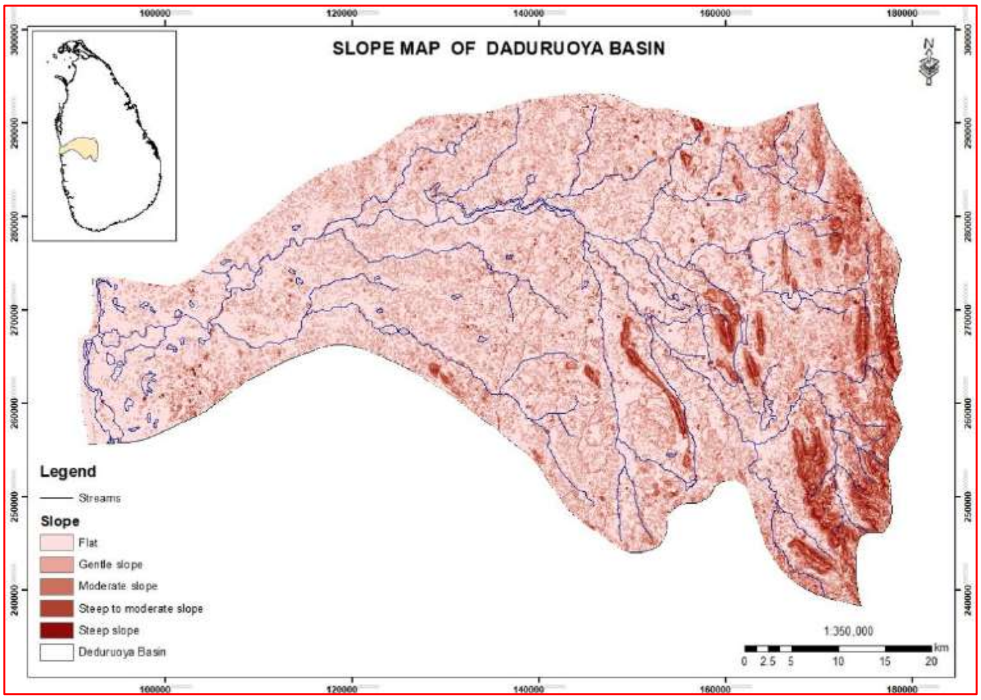


Figure 5.8: Slope Map of Deduru Oya Basin

DEM was used to prepare the relief maps and identify the most prominent lineaments of the basin. Lineaments were digitized and prepared for the lineament map of the basin. Other than the DEM, Geology map also was used to prepare the lineament map of the basin.

Lineament map used to prepare the lineament density map in raster format with 100*100-pixel size.(Figure 5.9).

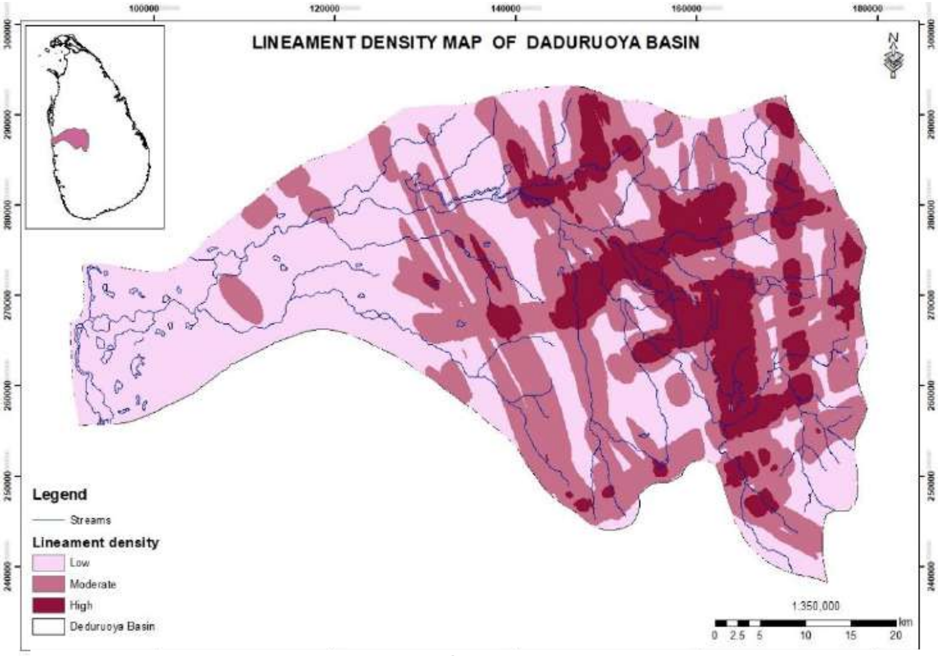


Figure 5.9 Lineament Density map of Deduru Oya Basin

Stream Map

Stream map used to prepare the stream density map in raster format (Figure 5.10)

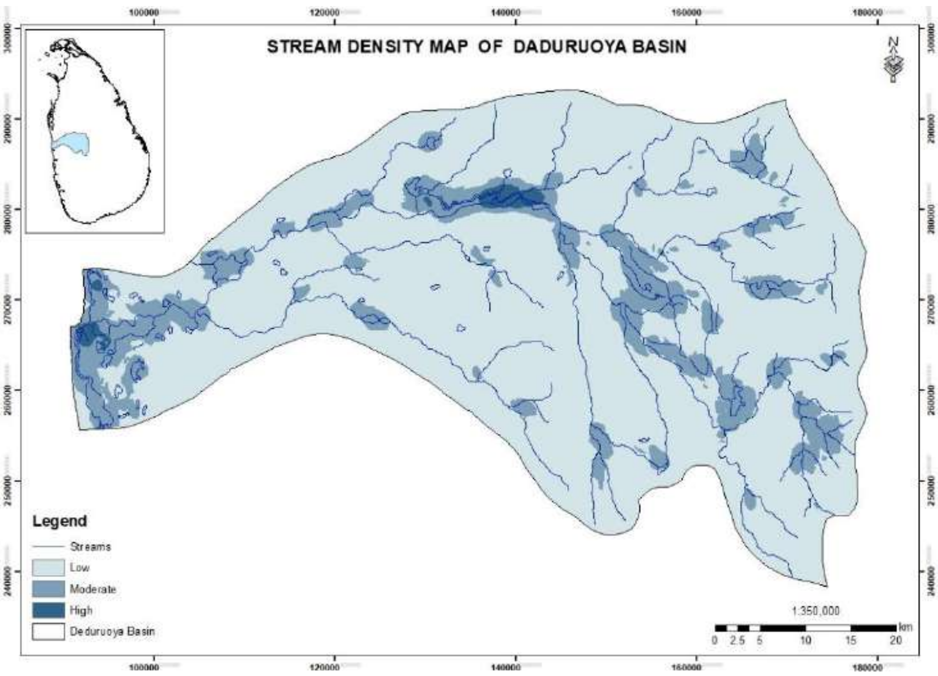


Figure 5.10: Drainage Density Map of Deduru Oya Basin

Reclassification

After preparation of these layers all were reclassified with assigning weights according to the effectiveness of groundwater recharge by each class (Table 5.1 & Figure 5.11).

Table 5. 1: Classes and Weights used for Reclassification Process

No	Major Class	Sub classes Category	Weight
1	**Rainfall**	High	3
		Moderate	2
		Low	1
2	**Linearment density**	High	3
		Moderate	2
		Low	1
3	**Slope**	Flat	5
		agentle	4
		Moderate	3
		Moderate to steep	2
		Steep	1
4	**Drainage density**	High	3
		Moderate	2
		Low	1
5	**Landuse**	Forest and other cultivations	5
		Other	3
		Paddy	2
		Builtup areas	1
		Water bodies	4
6	**Soil type**	Alluvium	5
		Red-yellow Podsolic	4
		Reddish-brown earth, Loams, solodized solonets	3
		Bog and half bog	2
		Shallow soil	1

Reclassified maps

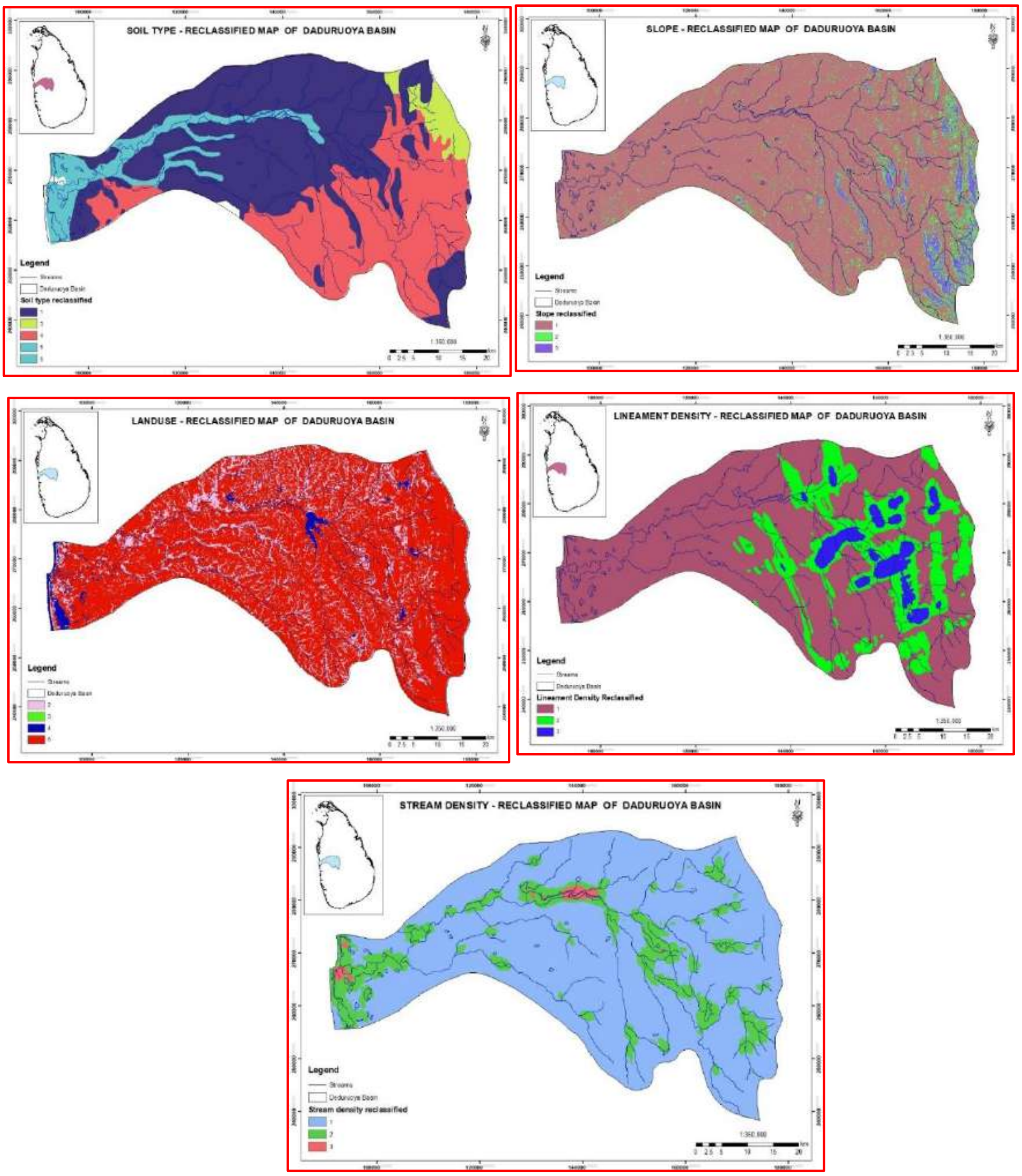


Figure 5.11: Reclassified layers

<u>Weighted Sum</u>

Finally, each layer was given a weight according to the effectiveness of the GWR potential and used weighted sum method to prepare the groundwater recharge potential map (Table 5.2)

Table 5.2: Given Weights for Each Influencing Factor

No.	Influencing factors	Weight
1	Rainfall	8
2	Lineament density	7
3	Slope	25
4	Drainage density	10
5	Land use	30
6	Soil type	20

Groundwater Recharge Potential Map- Deduru Oya

The final recharge potential map is illustrated in Figure 5.12 which provides the identified most suitable zones for artificial recharge programs. This is a preliminary identification by a logical sequence that indicates some potential domains. Further field/ground assessment is vital to determine suitable aquafer/s and their physical and hydraulic properties, such as aquifer thickness and characteristics, to accommodate source water for MAR programs.

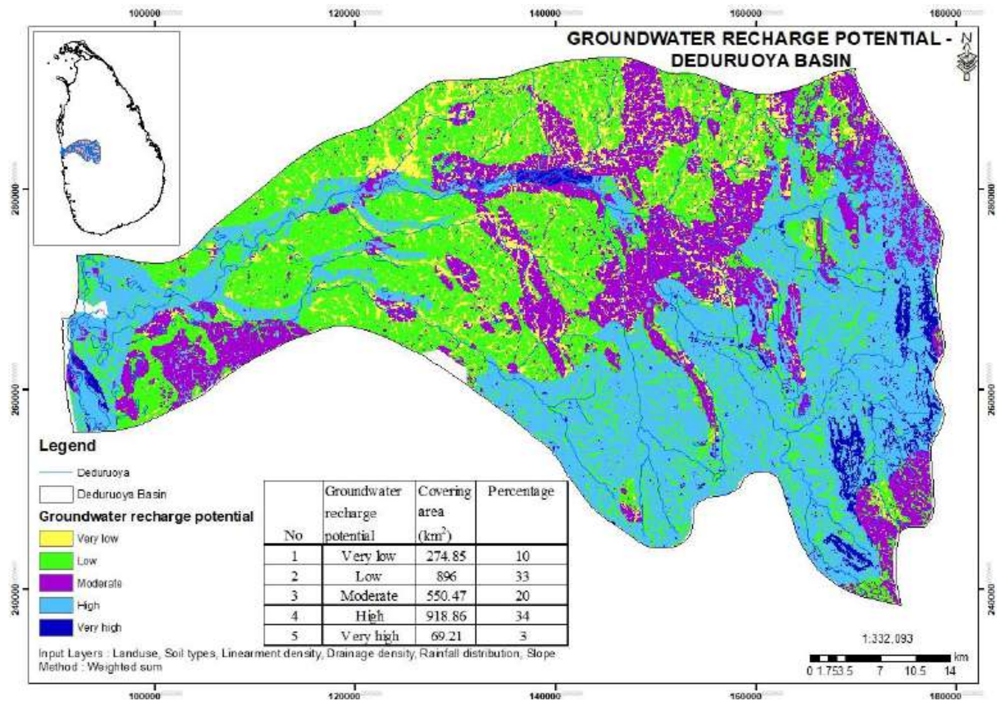
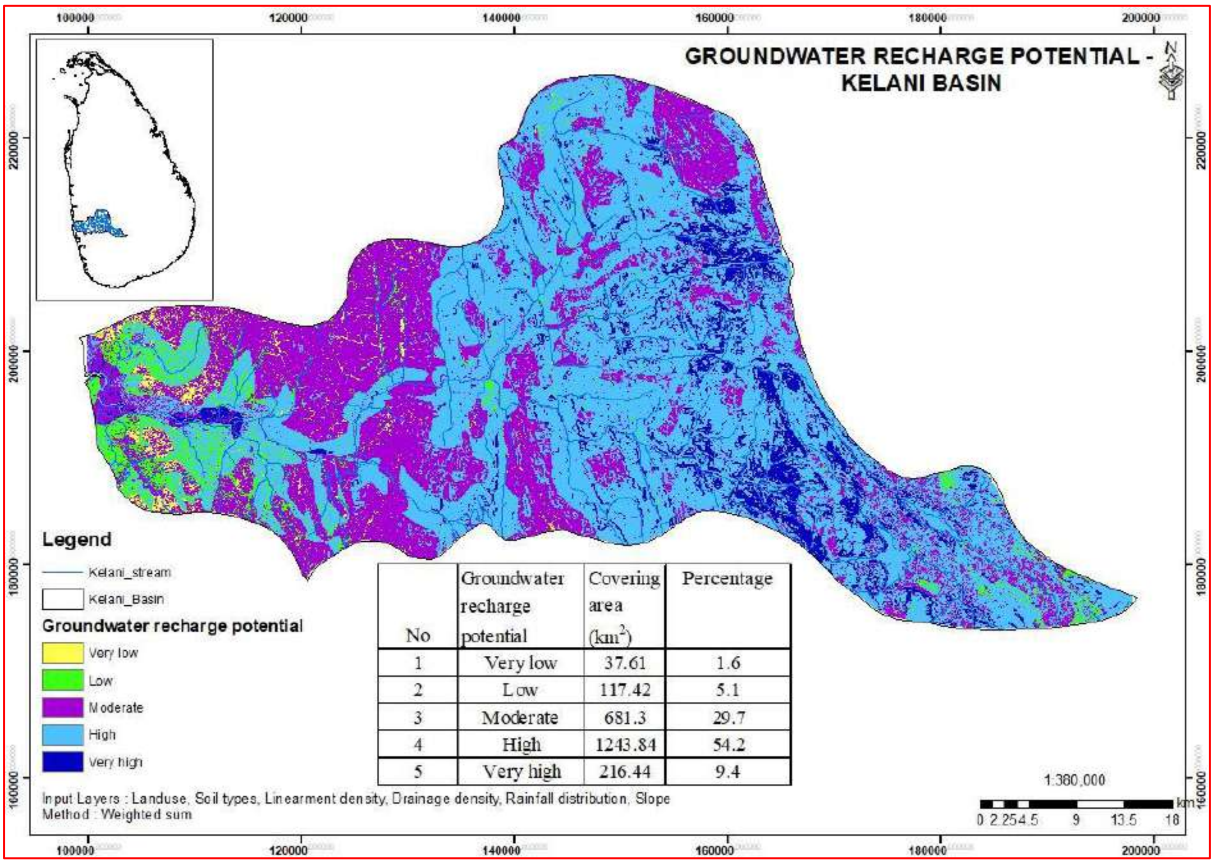


Figure 5.12: Groundwater Recharge Potential Map of Deduru Oya Basin

5.2 Groundwater Recharge Potential Map - Kelani River Basin

The recharge potential map, +prepared on the same basis and procedure described above, for the Kelani River basin is illustrated in Figure 5.13, which provides the identified most suitable zones for artificial recharge programs.



No	Groundwater recharge potential	Covering area (km^2)	Percentage
1	Very low	37.61	1.6
2	Low	117.42	5.1
3	Moderate	681.3	29.7
4	High	1243.84	54.2
5	Very high	216.44	9.4

Figure 5.13: Groundwater Recharge Potential Map of Kelani River Basin

5.3 Groundwater Recharge Potential Map- Malwathu Oya Basin

The recharge potential map, prepared similarly for the Malwathu Oya basin, is illustrated in Figure 5.14, which provides the identified most suitable zones for artificial recharge programs.

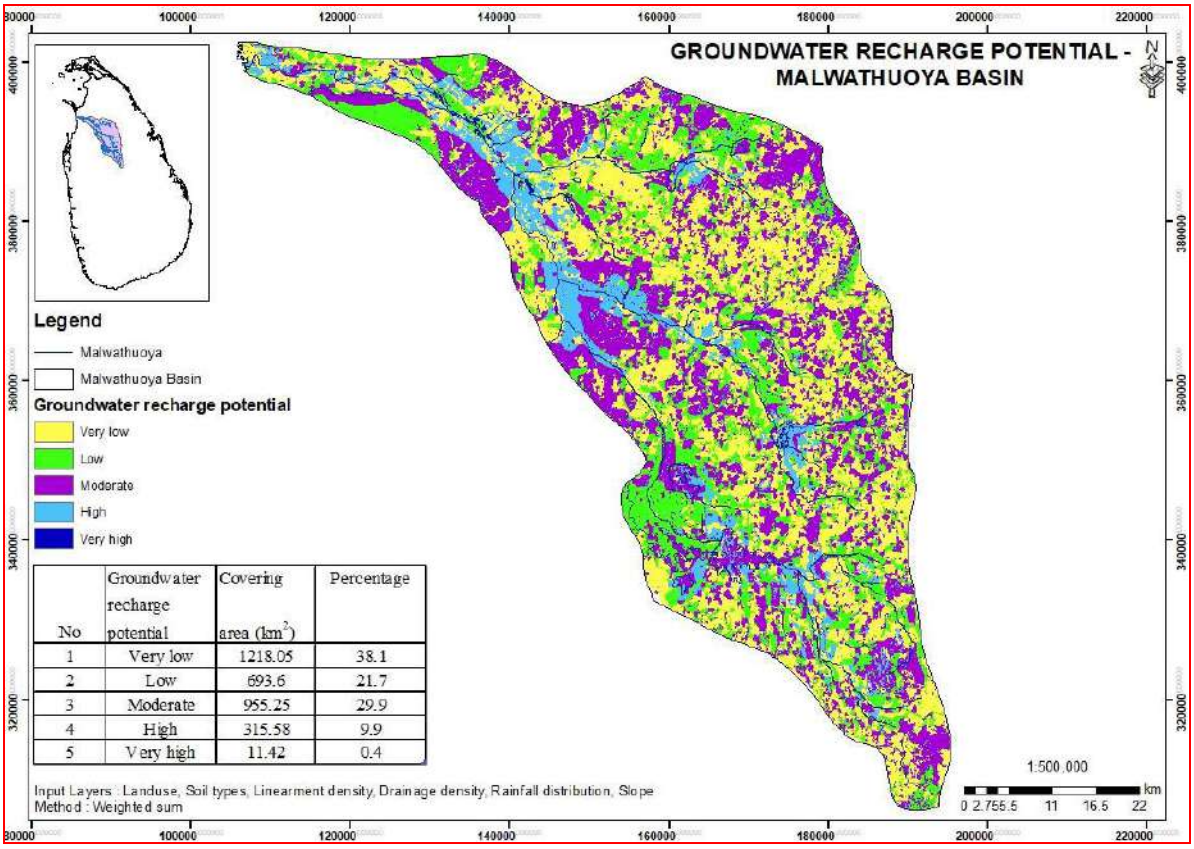


Figure 5.14: Groundwater Recharge Potential Map of Kelani River Basin

5.4 Groundwater Recharge Potential Map- Jaffna Peninsula

The criteria adopted to prepare the recharge potential maps for the study areas is not applicable to the Jaffna peninsula, as the factors considered cannot be used for ranking due to the uniformity of the features in the peninsula. The factors considered in the preparation of recharge potential maps for the other areas are as follows:

I. Average rainfall
II. Soil map
III. Digital Elevation Model
IV. Land use
V. Stream network of the basin

The topography of the peninsula is flat with a maximum elevation of about 10 m above MSL with no river basins defined (Figure 5.15). The land area is about of 1000 km2 , and it has a coastline of 160 km [27].

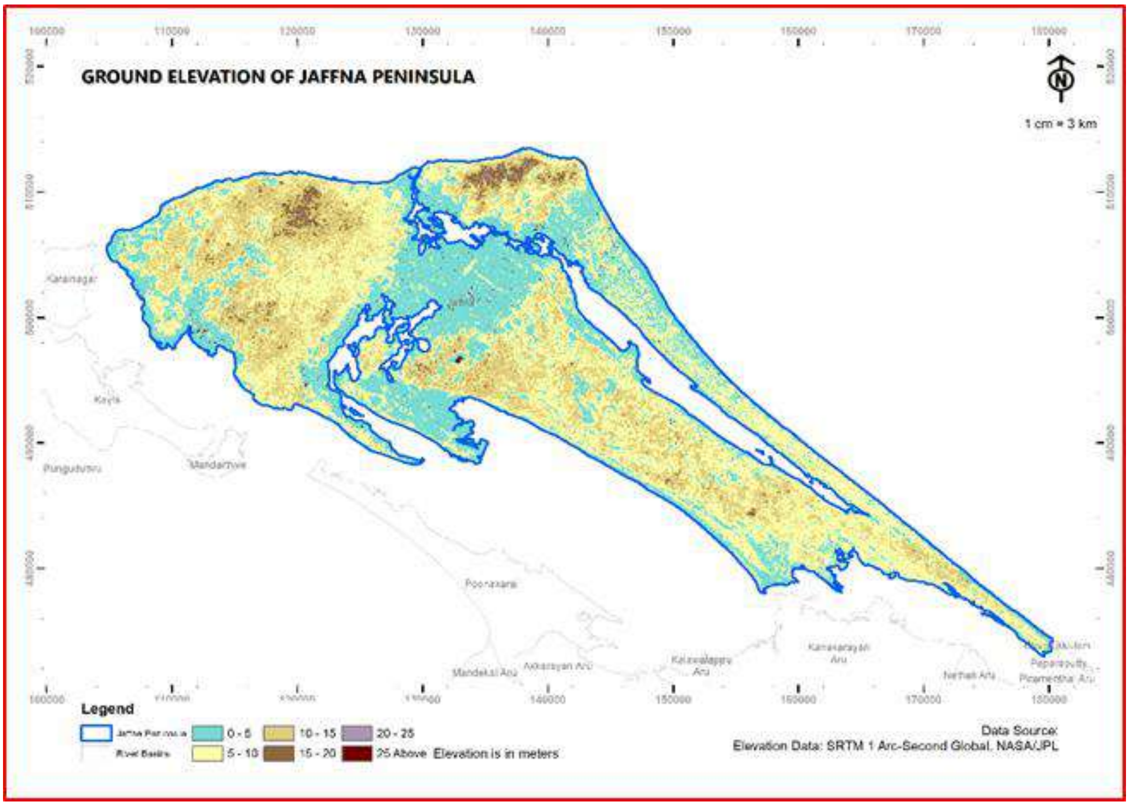


Figure 5.15: DEM Map of Jaffna Peninsula

The types of soil distributed across the area are also confined to four major categories that have somewhat similar properties resulting in the difficulty of giving weightages for ranking (Table 5.3 & Figure 5.16).

Table 5.3: Soil types in the Jaffna peninsula

SOCODE	NAME
10	Calcic Red-Yellow Latosols, flat terrain
11	Solodized Solonetz and Solonchaks; flat terrain
13	Soils on Recent marine calcareous sediments; flat terrain
15	Regosols on Recent beach and dune sands; flat terrain
33	Soils on Recent Marine Calcareous sediments; flat terrain

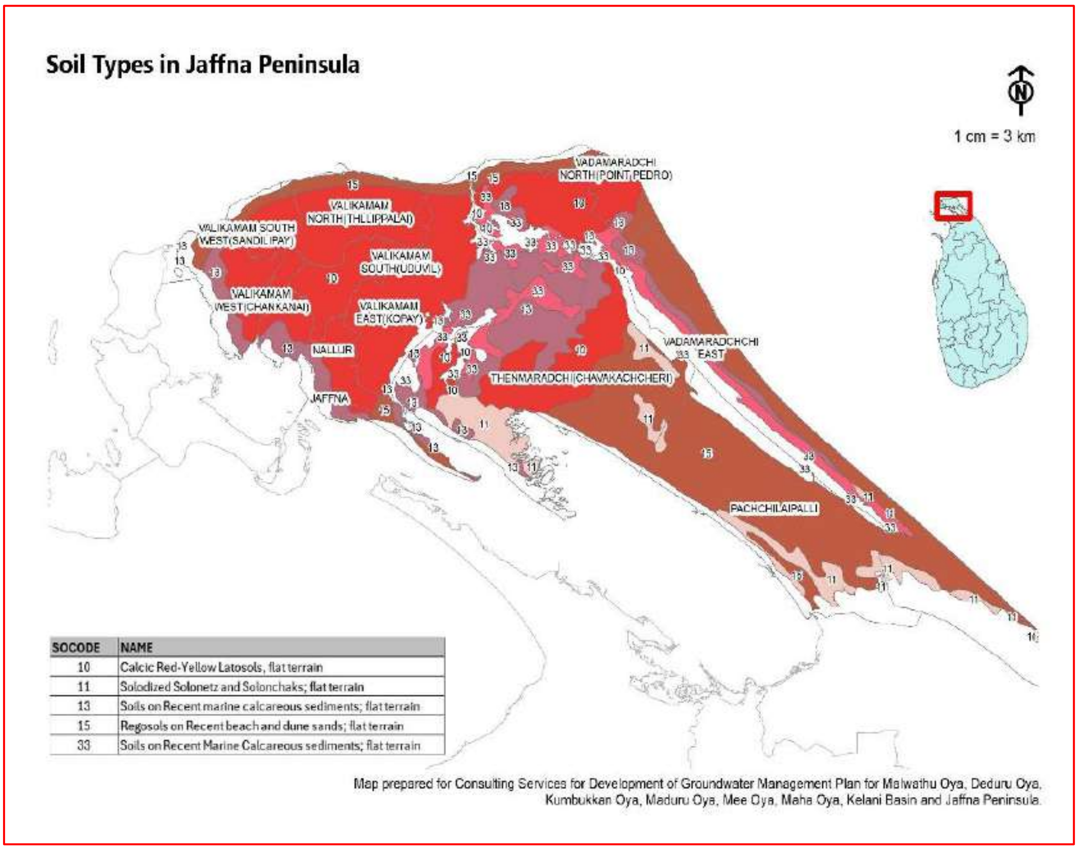


Figure 5.16: Soil Types of Jaffna Peninsula

Major Aquifers

The major aquifers are located in Valikamam, Thenmaradchchi, and Vadamaradchchi areas within Jaffna Peninsula (Figure 5.17).

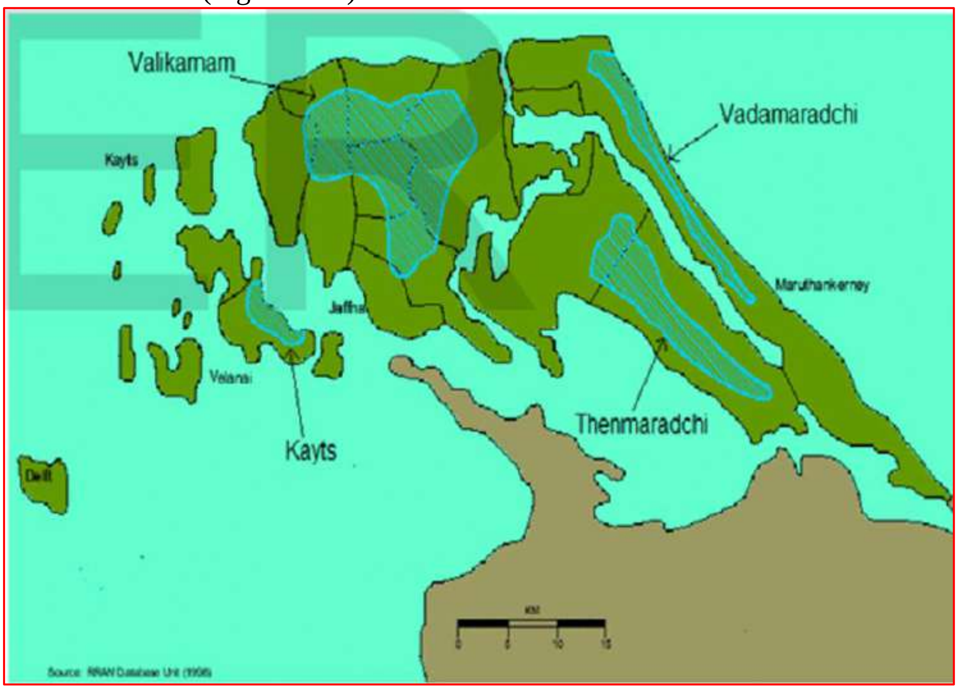


Figure 5.17: Aquifer System of Jaffna Peninsula

The limestone formations with the cover of thin sand layers are functioning as aquifers. The aquifers are recharged by direct infiltration of rainfall. Due to the fractured limestone, the permeability is high, and it leads to rapid groundwater movement (Figure 5.18).

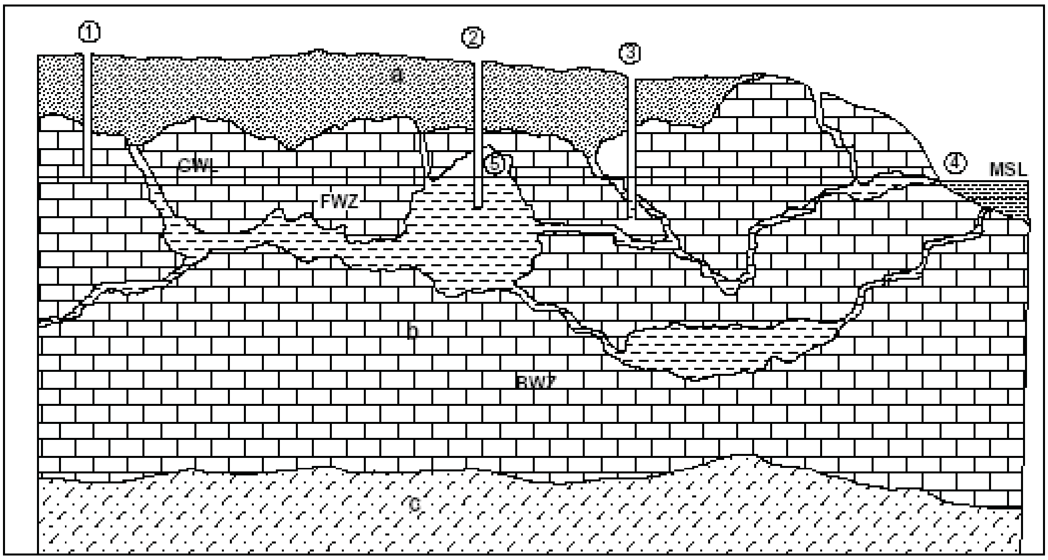


Figure 5.18: Schematic Diagram of Subsurface Hydrogeological System

The studies are showing that 30 to 50 percent of rainfall would be the recharge to groundwater, and of which 15 to 50 per cent shall be lost to sea as subsurface flow. These figures will be reassessed under the water balance study assigned for task -4 of the project.

5.5 Estimation of Potentiality on the Volumes

The volume of recharge depends on many factors that have been taken into consideration during the preparation of recharge potential maps. The volume depends on the type of aquifer (confined or unconfined) and the water balance of the aquifer at a particular time, and the amount of inflow (source water) available at this time. The concept of induced artificial recharge of an unconfined aquifer is shown in Figure 5.19.

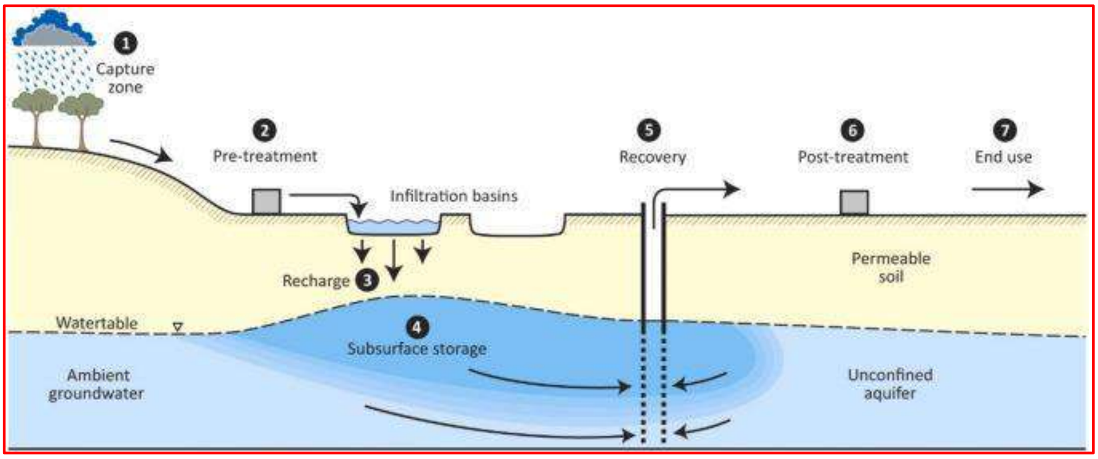
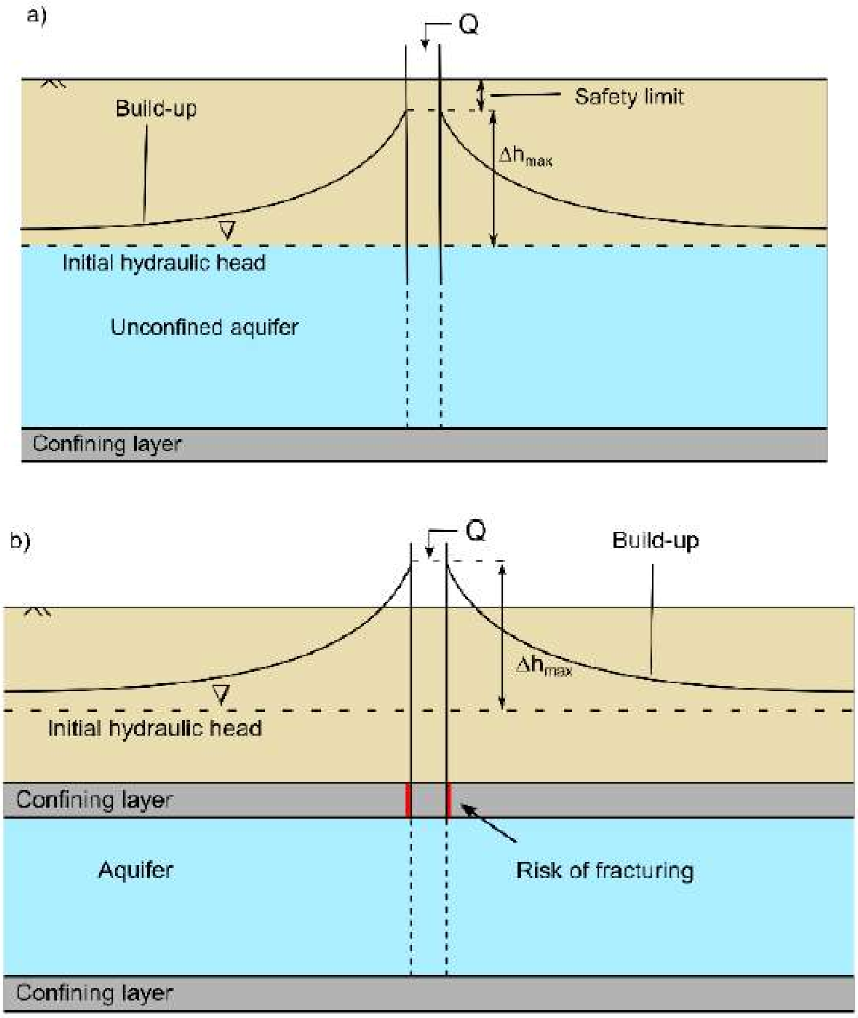


Figure 5.19: Process of Artificial Recharge of an Unconfined Aquifer

The current (existing) water table of an aquifer is a deciding factor of the volume of recharge during the Managed Aquifer Recharge (MAR) program because the artificial volume should not allow the water table to reach a certain depth below ground level that will result water logging conditions. Estimation of potential recharge is complex procedure that require the following data:
Water level monitoring data

- Aquifer properties such as Transmissivity, Hydraulic Conductivity and Storitivity
- Water Balance of the hydrologic unit- area concerned either catchment, basin etc.

Figures 5.20a & 5.20b illustrate the safe limits of different aquifers during artificial recharge programs.



Figures 5.20a & 5.20b: Schematic Illustration of the Concept of Maximum Allowable Head Change

Appendix 1- provides a detailed concept of the artificial recharge program.

5.6 Potential Areas for Recharge of the Study Areas

As per the data derived from the recharge potential maps, the following tables can be prepared for each study area.

5.6.1 Deduru Oya Basin

The land extents under the category of high and very high recharge potential can be given priority in the event of future MAR programs (Figure 5.21).

Groundwater recharge potential

- Very low
- Low
- Moderate
- High
- Very high

No	Groundwater recharge potential	Covering area (km^2)	Percentage
1	Very low	274.85	10
2	Low	896	33
3	Moderate	550.47	20
4	High	918.86	34
5	Very high	69.21	3

Input Layers : Landuse, Soil types, Linearment density, Drainage density, Rainfall distribution, Slope
Method : Weighted sum

Figure 5.21: Potential Area for Recharge – Deduru Oya Basin

5.6.2 Kelani River Basin

The land extents under the category of high and very high recharge potential can be given priority in the event of future MAR programs (Figure 5.22).

Groundwater recharge potential

- Very low
- Low
- Moderate
- High
- Very high

No	Groundwater recharge potential	Covering area (km^2)	Percentage
1	Very low	37.61	1.6
2	Low	117.42	5.1
3	Moderate	681.3	29.7
4	High	1243.84	54.2
5	Very high	216.44	9.4

Input Layers : Landuse, Soil types, Linearment density, Drainage density, Rainfall distribution, Slope
Method : Weighted sum

Figure 5.22: Potential Areas for Recharge – Kelani River Basin

5.6.3 Malwathu Oya Basin

The land extents under the category of high and very high recharge potential can be given priority in the event of future MAR programs (Figure 5.23).

Groundwater recharge potential

- Very low
- Low
- Moderate
- High
- Very high

No	Groundwater recharge potential	Covering area (km^2)	Percentage
1	Very low	1218.05	38.1
2	Low	693.6	21.7
3	Moderate	955.25	29.9
4	High	315.58	9.9
5	Very high	11.42	0.4

Input Layers : Landuse, Soil types, Linearment density, Drainage density, Rainfall distribution, Slope
Method : Weighted sum

Figure 5.23: Potential Areas for Recharge for Malwathu Oya Basin

CHAPTER 6. IDENTIFICATION OF AND ASSESSMENT OF THE CONTAMINANT SOURCES AND THEIR THREAT TO GROUNDWATER QUALITY

6.1. Sources of Groundwater Contamination of River Basins

The sources of groundwater contamination in river basins can be categorized into two main types: geogenic and anthropogenic. Geogenic contamination arises from natural processes such as salinity or arsenic, while anthropogenic contamination is caused by human activities like excess fertilizers, pesticides, industrial chemicals, and sewage effluent. These contaminants can be point sources, which are easily identifiable, or nonpoint sources, which are more difficult to identify and control (Figure 6.1 –Green color: Non-point source and Pink colour: point source) . The mechanisms of pollution and the transport of pollutants in groundwater are crucial for formulating effective prevention and mitigation measures.

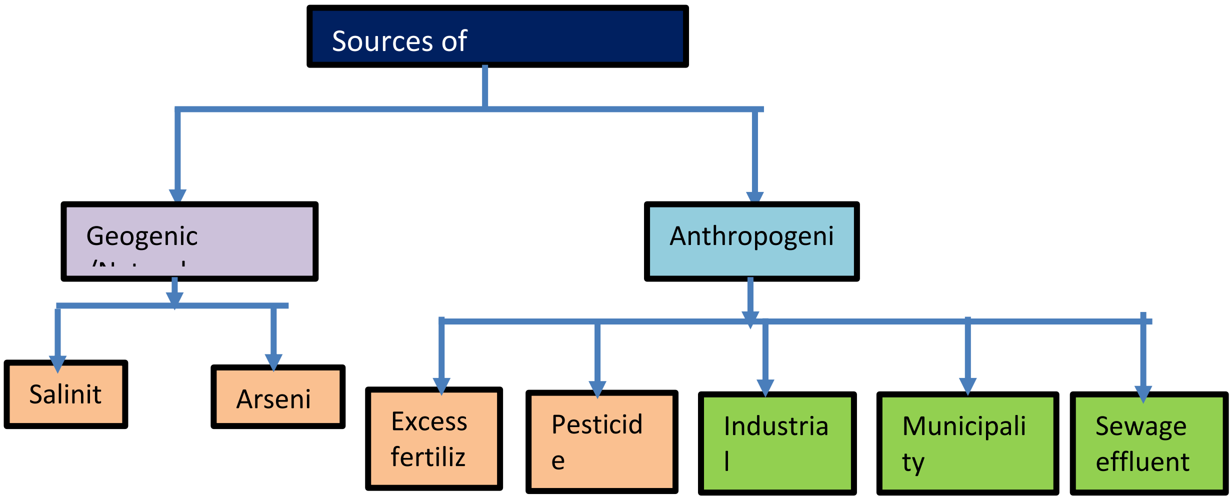


Figure 6.1: Sources of Groundwater Contamination

6.2. Mitigation of Groundwater Contamination

Some of the anthropogenic contaminations such as agricultural pollution as a result of application of fertilizer and pesticide can be controlled by management tools such as imposing of high penalties etc. The point source contamination can be controlled by improving the effluent by employing advance technology and management tools.

6.3. Identification of Contaminants

Integrated approach of stakeholders is important and necessary to mitigate the contamination of groundwater. Disposal/ discharge of industrial waste in the form of solid or liquid plays a prominent role making groundwater contamination, resulting in substandard water quality.

The mining industry poses significant risks to groundwater quality due to various activities. Acid Mine Drainage (AMD) is a major concern, as it can lead to the contamination of groundwater with heavy metals and sulfuric acid. This can result in the death of aquatic life and the degradation of water quality. Additionally, the dewatering process can decrease the surrounding water table and contaminate nearby aquifers.

The discharge of mine effluent and seepage from tailings ponds can also contribute to groundwater contamination. These issues can last for decades, if not centuries, after a mine's closure, and require careful management to mitigate their effects on the environment and communities

6.4. CEA Categorization of Industries

As per the pollution potential, CEA has categorized industries into three groups as follows:

- Category A comprises highly polluting industries,
- Category B includes medium polluting industries, and
- Category C encompasses low-polluting industries.

6.5. Agricultural Contamination

Today, agriculture has been identified as a major source of water pollution in many countries, surpassing both industrial and urban water pollution inputs into water resources (Mateo-Sagasta et al., 2018). And also it is considered a non-point source of pollution that releases agrochemicals, mainly nitrogen (Xu et al., 2020) and phosphorus fertilizers (Sharpley et al., 2015), and pesticide residues (Szöcs et al., 2017) into river systems, in addition to other nutrients and sediments. Similarly, farmers also use pesticides to improve their harvests, often leading to increased pesticide use, which is a concern in Sri Lanka (Aravinna et al., 2017).

Although many hazardous pesticides have been banned (e.g., carbofuran) or restricted (e.g., monocrotophos) as per WHO guidelines, and comprehensive pesticide control procedures are available, excess use of pesticides and unsatisfactory enforcement of policies have resulted in significant environmental contamination (The World Bank, 2013). Total agricultural pesticide use in Sri Lanka has increased by 33.2% from 2000 to 2018 (FAO, 2020a); fertilizer use has increased 61.6% from 2000 to 2015, although consumption did decrease afterwards (FAO, 2020b).

6.5. Assessment of Pollution in Study Areas

A structured questionnaire was prepared to gather data and information during the field survey. Annex-2 provides a copy of the questionnaire.

6.5.1. Kelani River Basin

Point Sources

When examining the point sources of water pollution in the Kelani River basin, several key contributors come to the forefront. These include industries, waste disposal practices, hydrological changes and overexploitation. Given below is a description to see how each of these elements contributes to water pollution in the Kelani River basin.

Industrial Discharge

The Kelani River emerges as a critical focal point of water pollution stemming from industrial activities within its basin. Though widely acknowledged as one of Sri Lanka's most polluted rivers, the Kelani River serves as the main supply of drinking water for Colombo, the country's commercial centre.

According to the Central Environmental Authority (CEA, 2025), the Kelani River basin hosts an extensive industrial presence, numbering over 4671, as given in Table 6.1, and the distribution across the basin is illustrated in Figure 6.2. Figure 6.3 shows the visit of a member of the consultant to the Fonterra dairy products company to assess the method of effluent discharge.

Table 6.1: Industrial Venture Details

Type of license	Number of industries	Categories		
		A	B	C
BOI	240	48	156	88
Locally operated	4431	272	2750	1406

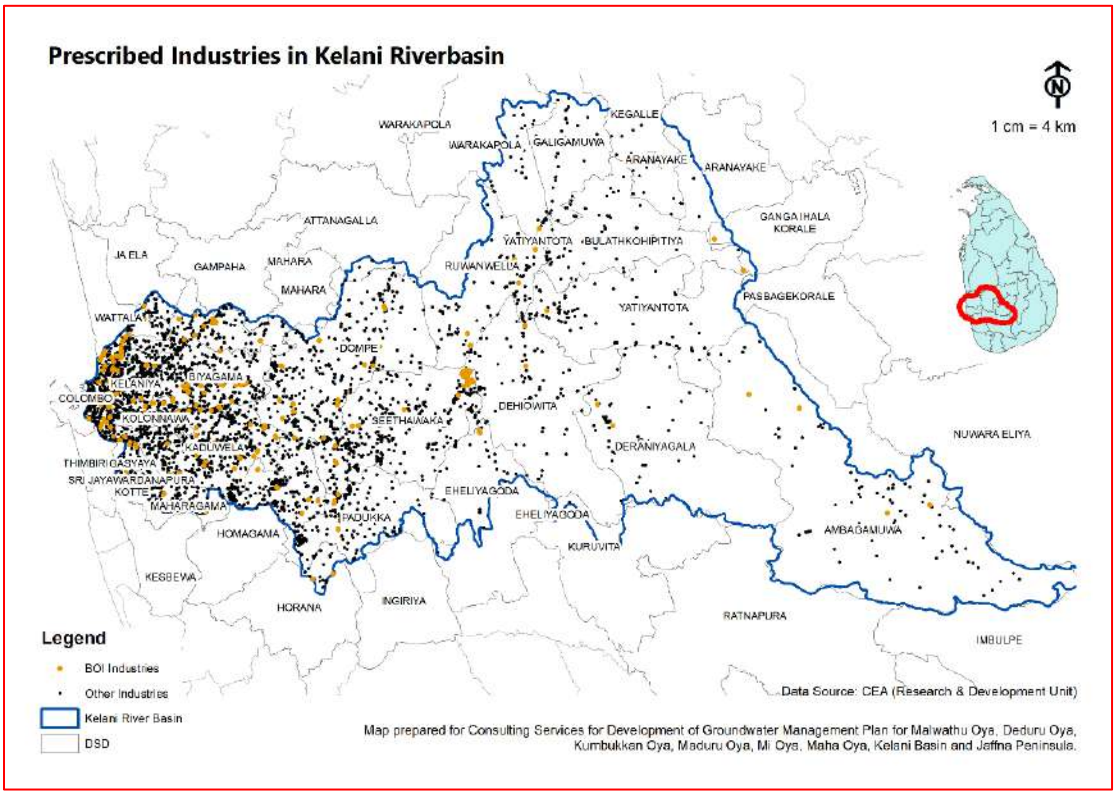


Figure 6.2: Distribution of Industrial and Commercial Ventures in Kelani River Basin

Figure 6.3: Industrial Survey to Assess Discharge of Industrial Effluent

Seethawaka and Biyagama are home to two sizable industrial zones with centralized waste treatment facilities. Furthermore, a significant number of industries line themselves along the river's path and spread outside these specified zones. Numerous enterprises discharge both treated and untreated industrial effluents into the waters of the Kelani River, which serves as the drainage basin for the most densely populated province in the nation.
Interestingly, a number of major industries that produce wastewater are housed in the Biyagama Export Promotion Zone. These industries include those that produce raw rubber, rubber latex, textiles, food and beverage, steel, fertilizer, and other industrial operations (CEA Database).

Improper Waste disposal (Sewage Waste and Solid Waste)

One of the main reasons for water pollution, especially in the lower and mid-reaches of the Kelani River, is the inappropriate disposal of waste, which includes both solid waste and sewage waste. Water bodies can get contaminated as a result of the careless disposal of solid waste and sewage, which is a serious environmental risk. The Kelani River basin's overall ecological health and water quality are being negatively impacted by insufficient waste management techniques, which are exacerbating the problem.

6.5.2. Deduru Oya Basin

Industrial Discharge

The total number of industries in the Deduru Oya basin is 552 as per the CEA industrial database of which the breakdown of different categories in terms of producing pollutants in the production process is given in the table 6.2.

Table 6.2: Industrial Venture Details

Type of License	Number of Industries	Categories		
		A	B	C
BOI	0			
Locally operated	552	5	218	335

It is noted that the representation of Category A is minimal among the total number of industries. Figure 6.4 indicates the distribution of industrial ventures across the basin.

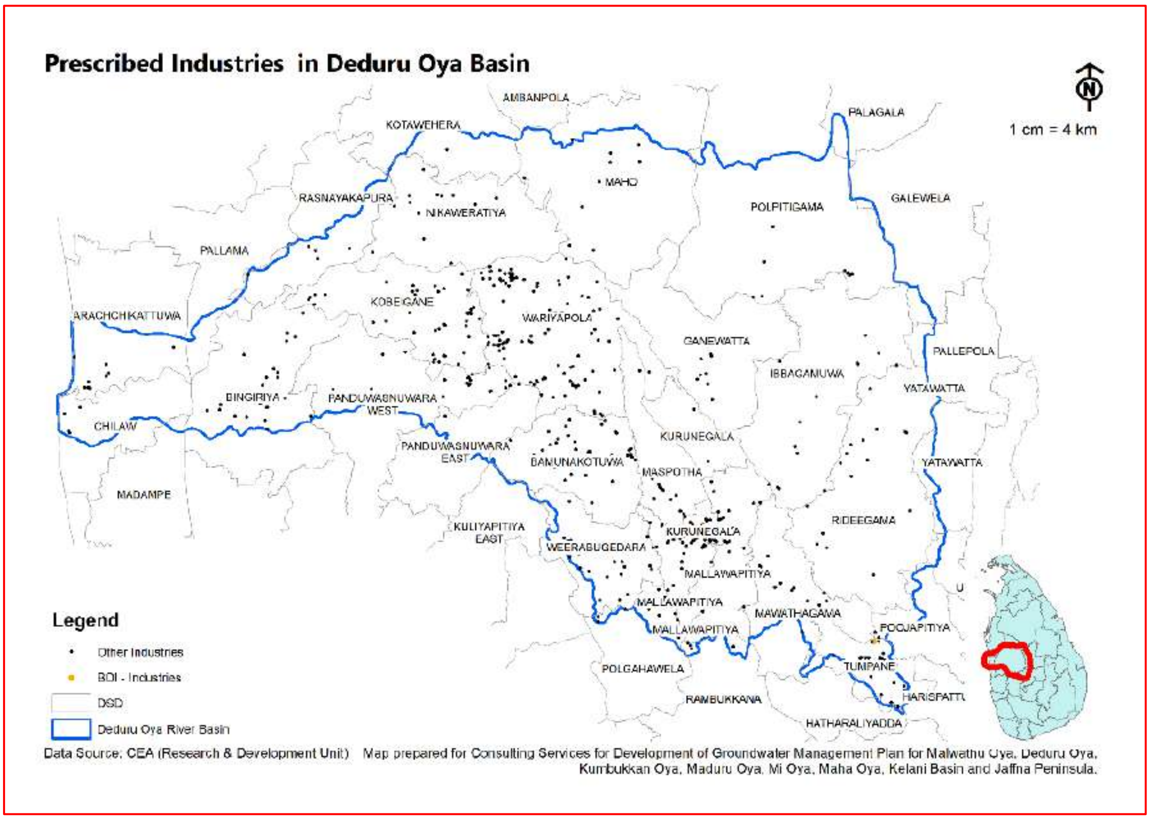


Figure 6.4: Distribution of Industrial and Commercial Ventures in the Deduru Oya Basin

Improper Waste Disposal (Sewage Waste and Solid Waste)

Figure 6.5 illustrates a solid waste disposal site at Sundarapola managed by the Kurunagala Municipal Council. No proper scientific survey has been done before the site is selected. No downstream monitoring program has been established to identify any contaminants leaching out from the site to the groundwater flow.

Figure 6.5: Dumping Yard for Solid Waste

6.5.3. Malwathu Oya Basin

Industrial discharge

The total number of industries in the Malwatu Oya basin is 756, of which 11 industrial ventures are operated under the BOI. The table 6.3 provides a breakdown of different categories in terms of the tendency of producing pollutants in the manufacturing or commercial process.

Table 6.3: Industrial Venture Details

Type of license	Number of industries	Categories		
		A	B	C
BOI	11	1	10	Nil
Locally operated	745	21	491	232

It is noted that the representation of category A is minimal among the total number of industries. Figure 6.6. indicates the distribution of industrial ventures across the basin.

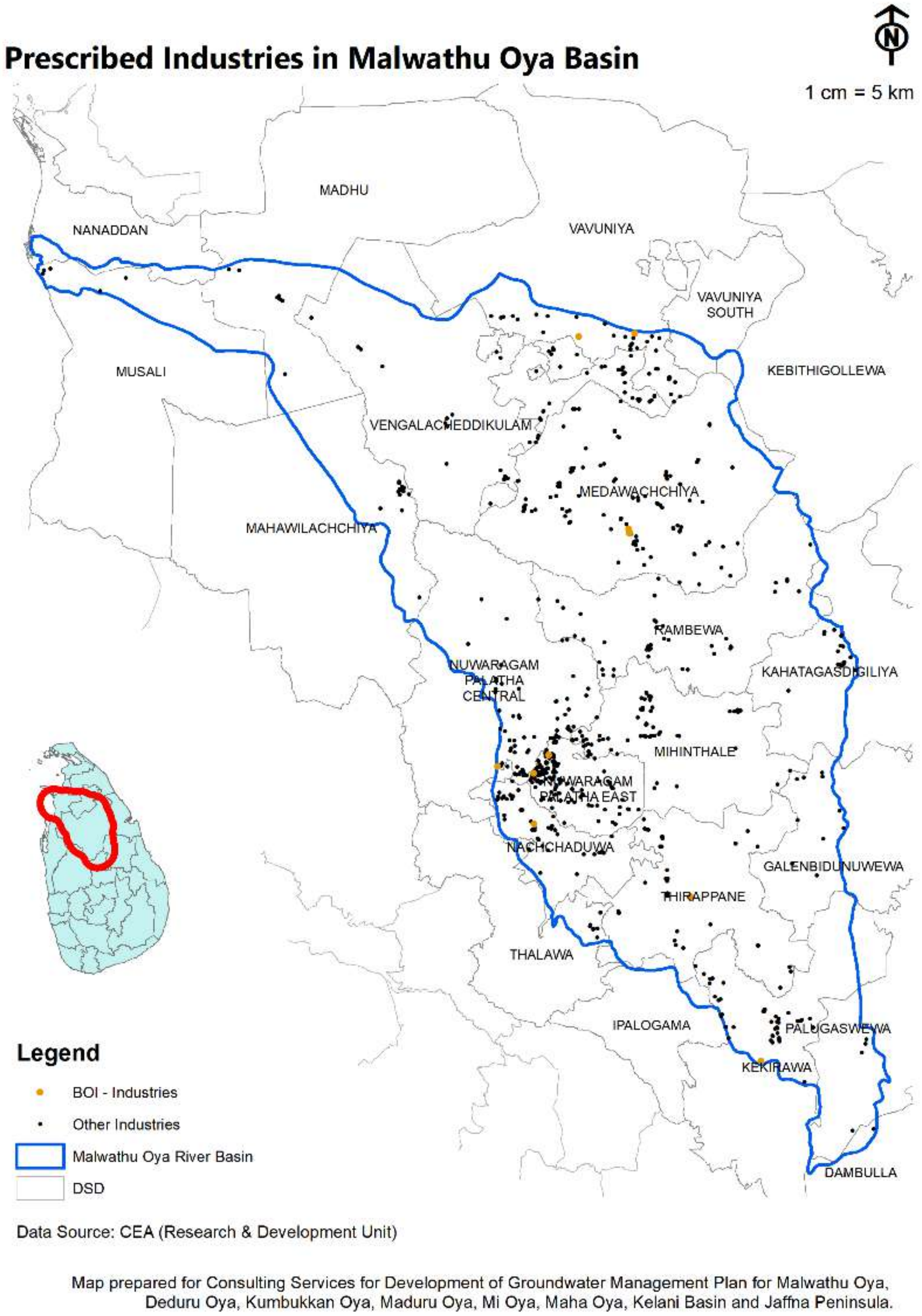


Figure 6.6: Distribution of Industrial and Commercial Ventures in the Malwathu Oya Basin

Effluent of a piggery is discharged to an open ground without any treatment (Figure 6.7).

F

6.5.4. Jaffna Peninsula

Industrial Discharge

The total number of industries in the Jaffna Peninsula basin is 1,079 of which 12 industrial ventures are operated under the BOI facilities. Table 6.4 provides a breakdown of different categories in terms of the tendency of producing pollutants in the manufacturing or commercial process.

Table 6.4: Industrial venture details

Type of license	Number of industries	Categories		
		A	B	C
BOI	12	1	11	Nil
Locally operated	1,068	9	444	615

It is noted that the representation of Category A is minimal among the total number of industries. Figure 6.8 indicates the distribution of industrial ventures across the basin.

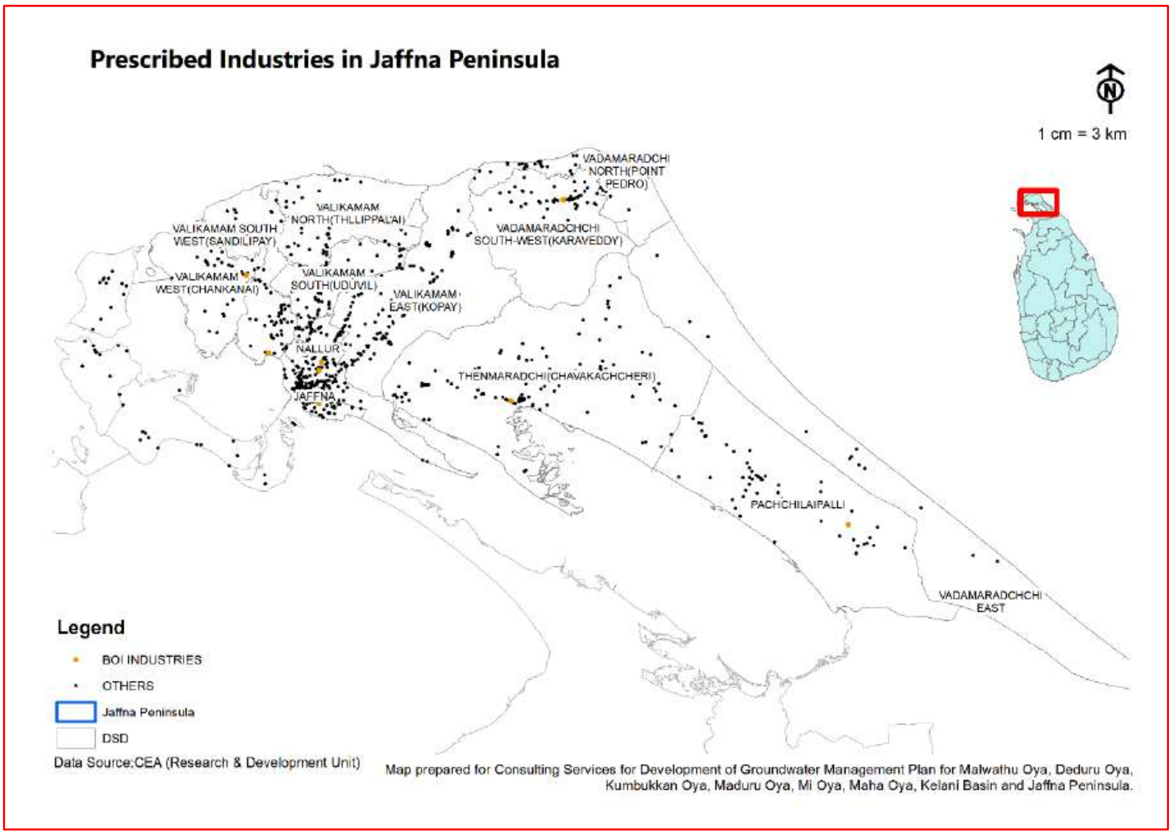


Figure 6.8: Distribution of Industrial and Commercial Ventures in the Jaffna Peninsula

Improper Waste Disposal (Sewage Waste and Solid Waste)

Figure 6.9 illustrates the Kalundi disposal site under the supervision of Jaffna Municipal Council (JMC) for dumping and discharging both solid and liquid waste. As per the information gathered from various sources, JMC carries out uncontrolled dumping, including the emptying of gully bowsers. This has a great impact on the shallow aquifer underneath.

Figure 6.9: Dumping Yard for Solid and Liquid Waste

CHAPTER 7. ASSESSMENT OF FUTURE AQUIFER STRESSES

An assessment of future aquifer stresses and the ground water conditions under different patterns of water demand and water use, recharge availability, rainfall patterns, contamination etc. has been conducted under the current task.

Groundwater stress occurs when the water extraction exceeds the recharge to the corresponding aquifer over a given period. Reduction in groundwater recharge and over-exploitation are typical causes of groundwater stress. Globally, groundwater extractions for irrigation are the prime reason for aquifer depletion. Despite some social and economic benefits of over-extraction, they cannot compensate for the substantial depletion of aquifers that are effectively non-renewable on human timescales. To measure groundwater stress exerted on an aquifer, a few indicators are to be considered, including groundwater footprint (Gleeson et al., 2012), groundwater storage change to recharge (Richey et al., 2015), and groundwater development stress (Alley et al., 2018).

7.1. Calculation of Groundwater Budget

Over a period of interest (which could be a period of 10 years for better justification), a groundwater budget is based on the principle that water inflows and outflows of an aquifer are balanced by a change in groundwater storage. A groundwater budget is therefore expressed as:

Inflow (recharge) = Outflow (discharge) ± change in storage

The recharge and discharge terms of the above equation can be expressed in more detail as components in the following equation.

$$R_p + R_s + R_{gw} + H_{in} = D_{et} + D_s + D_{gw} + H_{out} \pm \Delta S$$

Where:

The Recharge includes such components as diffuse recharge from precipitation (Rp), recharge from surface water (Rs), subsurface inflow from adjacent aquifers (Rgw), and total return flow (Hin) from irrigation, industrial and domestic uses.

The discharge components include evapotranspiration from groundwater (Det), discharge from the aquifer to surface water (Ds) and adjacent aquifers (Dgw), and withdrawals (Hout) for agricultural, industrial, and municipal uses (Fig.7.1). ΔS is the change in storage of the aquifer.

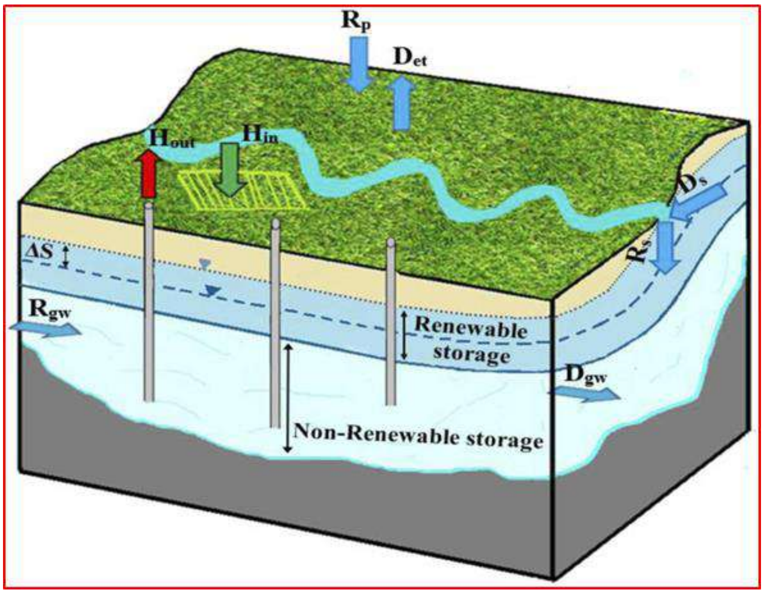


Fig.7.1. Schematic Representation of the Water Balance of an Unconfined Aquifer System

The dark and light blue areas indicate the volumes of renewable and non-renewable storage of the aquifer, respectively. Dotted and dashed lines show levels of the water table at the start and end of the period of interest, respectively, when aquifer storage changes with ΔS. Rp, Rs, and Rgw denote recharge from precipitation, surface water, and adjacent aquifers, respectively; Det, Ds, Dgw, designate evapotranspiration and discharge to surface water and adjacent aquifers, respectively; Hin and Hout are total return flow and withdrawals.

7.2. Calculation and Development of Groundwater Stress Indicators

The groundwater stress indicators have to be based on measurable or observable data relevant to the different components of the water budgets of aquifers. They also have to take into account the accumulated states of selected quantitative parameters, including renewable and non-renewable groundwater storage, total groundwater withdrawal, total return flow, groundwater consumption, natural recharge, and exploitable groundwater resources (Table: 7.1).

Table: 7.1. Simplified Description of Groundwater Variables

Variables	Description
Renewable groundwater storage	Total annual groundwater recharge. In other words, it is the annual water balance computed with data over a long period.
Non-renewable groundwater storage	The volume of groundwater accumulated in the aquifer over a long period (often thousands of years). For many aquifers, it comprises the major storage of the aquifer. This is called the aquifer storage.
Exploitable groundwater	The amount of water that can be annually abstracted from a given aquifer under current socio-economic constraints and ecological conditions.
Groundwater consumption	The portion of extracted water from an aquifer that is lost to the atmosphere through evaporation/transpiration or incorporated into a product or plant and thus not returned to the original aquifer after being withdrawn.

Variables	Description
Total human withdrawals (H_{out})	Anthropogenic or human removals or abstractions of groundwater by springs, wells, and drainage channels for domestic, agricultural, industrial and commercial purposes.
Total return flow (H_{in})	The non-consumed portion of groundwater that is returned to the original water resource after being withdrawn. Irrigation return flow
Total natural recharge (R_T)	Total recharge of groundwater excluding anthropogenic return flow.
Total natural discharge (D_T)	Total discharge from the aquifer to surface water and adjacent aquifers, as well as evapotranspiration.

In order to investigate, interpret and compare the intensity of groundwater stress in hydrological basins, three groundwater stress indicators are presented in Table 7.2. These indicators compare either groundwater withdrawal (WTR, Raskin et al., 1997) or consumption (CTR, Hoekstra et al., 2012) with annual recharge to the aquifer as renewable availability. In contrast, the WTE indicator (Vrba et al., 2006) compares the withdrawal to exploitable groundwater (the amount of water that can be annually abstracted from a given aquifer under current socio-economic constraints and ecological conditions).

Table 7.2. Proposed Indicators of Aquifer Stress

Indicator	Definition	Equation	Reference
WTR	Withdrawal to Renewable Water	$\frac{\text{Withdrawal}}{\text{Renewable storage}}$	(Raskin et al., 1997)
CTR	Consumption to Renewable Water	$\frac{\text{Consumption}}{\text{Renewable storage}}$	(Hoekstra et al., 2012)
WTE	Withdrawal to Exploitable Groundwater	$\frac{\text{Withdrawal}}{\text{Exploitable groundwater}}$	(Vrba et al., 2006)

All three indicators mentioned above provide the threshold of withdrawal/consumption to protect unnecessary stress applied on aquifers by overexploiting them. The computation of stress indicators for the study area needs to compute the water balance which has been listed under the Task 4.

CHAPTER 8: ASSESSMENT OF PRESENT HYDRO-GEOCHEMISTRY OF THE RIVER BASINS

8.1. Definition of Hydrogeochemistry

Hydrogeochemistry is defined as the study of the chemical characteristics of groundwater and its interactions with the geological environment. In other words, the groundwater types show the effects of the chemical reactions that occur between the minerals within the lithologic framework and in the groundwater. The field involves the analysis of the chemical composition of groundwater, including its major and minor ion chemistry, isotopic composition, and the presence of contaminants or other substances.

The scope of hydrogeochemistry is broad and encompasses a range of topics, including:

- ✓ The chemical evolution of groundwater as it interacts with the surrounding rock and environment
- ✓ The impact of human activities on groundwater chemistry and quality
- ✓ The use of hydrogeochemistry in assessing water quality and pollution
- ✓ The application of hydrogeochemical principles in contaminant hydrogeology and remediation

The chemical composition of groundwater is controlled by a range of factors, including:

- ♦ The geology of the aquifer and the surrounding environment
- ♦ The climate and hydrology of the region
- ♦ The presence of contaminants or other substances

The major ion chemistry of groundwater is typically dominated by a few key species, including **calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate**. The concentrations of these species can vary widely depending on the geology and hydrology of the aquifer, and also as a result of anthropogenic activities.

A range of geochemical processes can affect the chemistry of groundwater, including:

- Mineral dissolution and precipitation reactions
- Ion exchange reactions
- Redox reactions
- Sorption and desorption reactions

8.2 Graphical Interpretation of Water Type

Visualization of water quality, like "Piper Diagrams", is good for quick references of the hydrogeochemical facies in river basins or any other different hydrologic units in any dimension.

Facies are identifiable parts of different natures belonging to any genetically related body or system. Hydrogeochemical facies are distinct zones that have cation and anion concentrations describable within defined composition categories. The concept of hydrogeochemical facies has been widely used to explain the distribution and genesis of principal groundwater types along the water flow path.

By analyzing the diamond plot, hydrogeologists can categorize water samples into hydrogeochemical facies on the basis of particular water types. A hydrochemical or groundwater facies is a group of water samples that share similar chemical characteristics based on the concentration and types of dissolved ions present in the water sample. The diagram below demonstrates 4 common facies and where they would fall on the diamond plot (Figure 8.1). A more descriptive water type illustration is given in Figure 8.2.

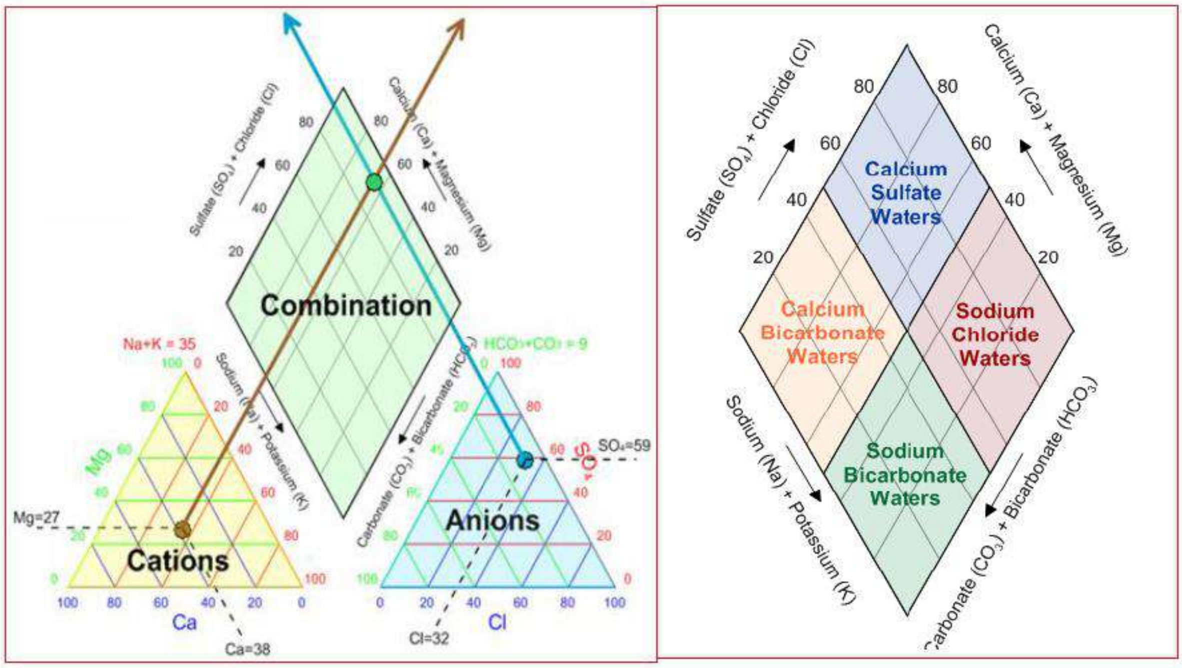


Figure 8.1: Piper Diagram

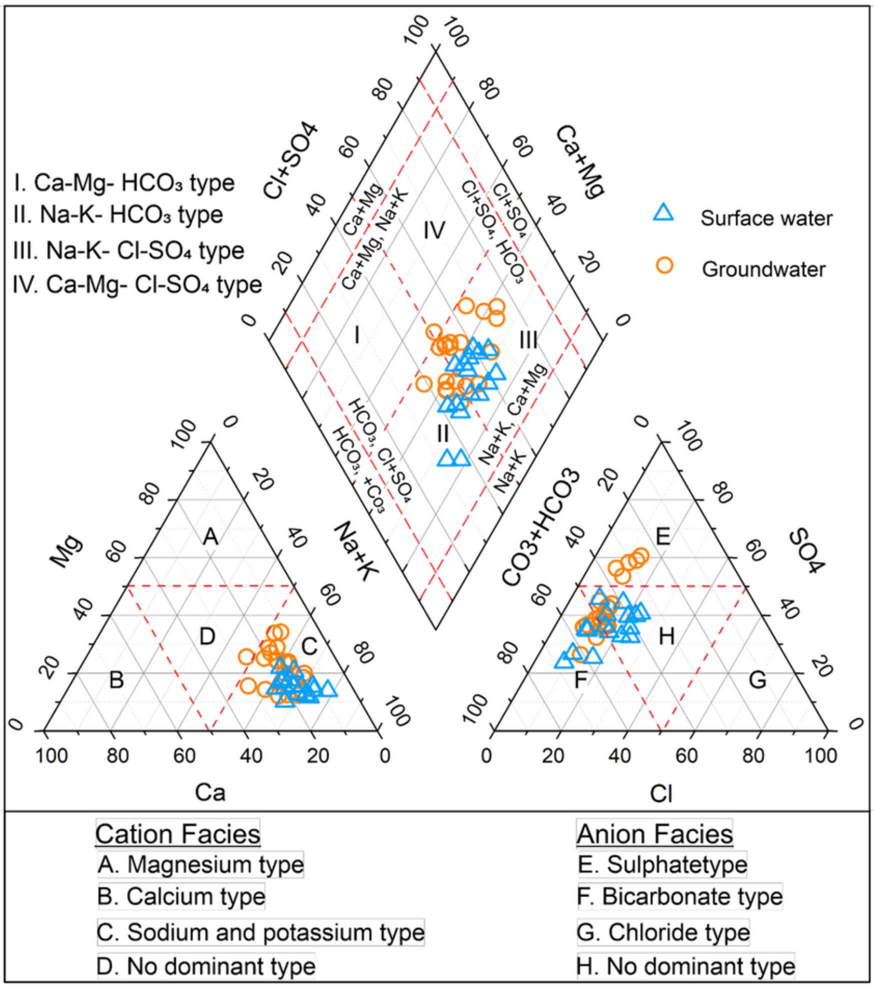


Figure 8.2: More Descriptive Version of the Application of Piper Diagram

8.3. Hydro Geochemical Classification of Groundwater in Sri Lanka

The groundwater geochemical classification for the entire of Sri Lanka was conducted in 1985. Four types of groundwater were observed throughout Sri Lanka with different dominant chemical species, which were calcium (Ca) type, magnesium (Mg) type, sodium-potassium (Na-K) type, and non-dominant cation (NDC) type with further sub-categories such as chloride (Cl), sulfate (SO_4^{-2}), bi-carbonate (HCO_3^-) and non-dominant anion (NDA) types.

Characteristics of the aquifer materials (geology), climate variations, seawater intrusion in the coastal regions, and ion exchange process were highlighted as possible governing factors for these quality changes in water types along the flow paths.

Figure 8.3 illustrates the distribution of these four major water types in Sri Lanka identified during the geochemical classification program. Each type is further subdivided into the C1, SO*, HCO_3 and NDA types. The study areas were plotted on the figure to get an idea about the position of geochemical facies that occurred in the past.

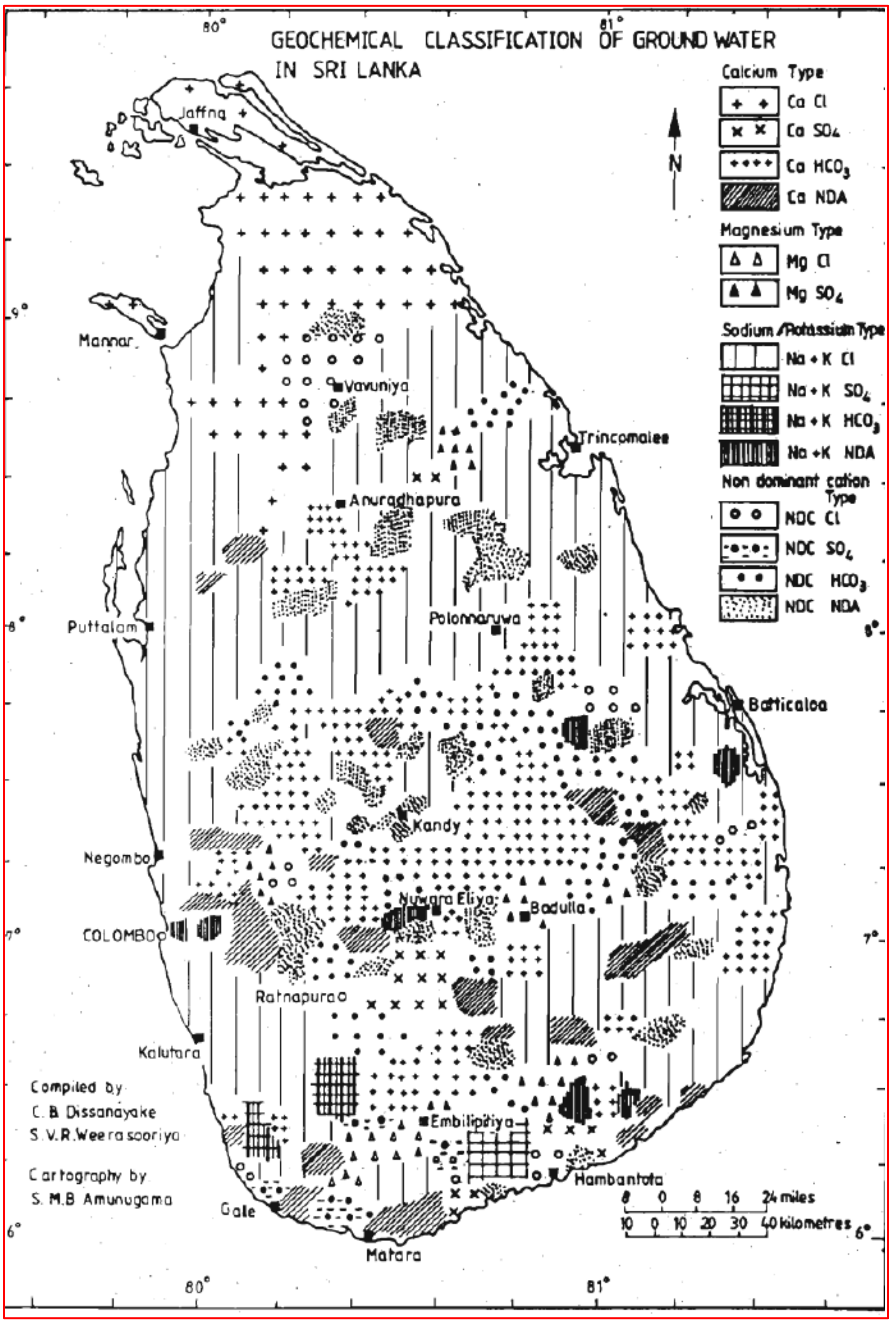


Figure 8.3: Distribution of Four Major Water Types in Sri Lanka

8.4 Assessment of Present Status of Hydrogeochemical Facies of the Four Study Areas

8.4.1. Kelani River Basin

Table 8.1 provides the data of chemical constituents of 48 samples obtained from the WRB to identify geochemical facies.

Table 8.1: Availability of Major Cations and Anions

S/N	Long	Lat	Calcium (as Ca) (mg/l)	Magnesium (as Mg) (mg/l)	Total Iron (as Fe) (mg/l)	Chloride (as Cl) (mg/l)	Sulphate (as SO_4) (mg/l)	Fluoride (as F) (mg/l)	Na (mg/l)	K (mg/l)	HCO_3 (mg/l)
1	79.85417	6.934722	46.4	22.5	17.20	71.8	71.4	0.80			134.0
2	79.86611	6.946667	11.2	9.0	0.08	12.0		0.08			
3	80.02233	6.894833	1.9	1.2	1.90	5.1	0.0	0.10	5.10	1.20	
4	79.86611	6.946667	11.2	9.0	0.08	12.0		0.08			
5	80.03944	6.911389	6.2	0.6	0.00	9.6	4.5	0.20	6.80	2.60	45.4
6	80.11944	6.976944	7.3	4.4	0.60	14.8	19.7	0.10			
7	80.00833	6.877222	19.6	4.7	0.10	9.1	3.5	0.03			
8	80.03833	6.912222	9.7	1.2	0.10	7.2	4.5	0.20	4.40	2.20	71.3
9	80.24778	6.880556	11.1	4.5	0.20	9.6	1.8	0.50			
10	80.11944	6.975556	7.3	4.4	0.40	13.7	5.4	0.50			
11	79.98667	6.930556	11.5	1.5	0.10	4.8	5.3	0.10	27.50	1.60	48.0
12	79.89294	6.98115	6.4	1.0		19.9	6.3	0.04			
13	80.07833	6.9047	6.1	2.4	0.50	7.5	2.1	0.30			
14	80.59472	6.885556	5.6	5.7	0.01	14.7	5.4	0.40			
15	80.11889	6.976111	10.9	6.6	0.50	9.1	9.9	0.20			
16	79.95702	7.03043	15.5	7.0	0.10	14.0	11.0	0.10	110.00	2.00	113.0
17	80.42222	6.931944	15.1	8.0	0.10	9.8	6.8	0.60			
18	80.06528	6.928611	33.1	8.7	0.07	22.9	3.0	0.01			
19	80.59722	6.85	26.6	4.6	0.01	29.5	60.0	0.20	16.00	27.50	
20	80.11917	6.975833	25.5	6.6	1.10	59.1	12.3	0.30			
21	79.99583	6.929167	13.6	16.7	2.50	14.8	8.0	0.30			
22	80.10556	6.927222	25.2	10.4	0.01	7.9	9.0	2.00			155.0
23	79.9264	6.937033	16.3	6.1	1.30	47.8	6.2	0.30			
24	80.59444	6.887778	15.2	11.5	0.01	24.6	29.7	0.18	26.00	4.80	
25	80.05639	6.911944	37.2	3.4	0.40	10.0	10.3	1.20			
26	79.90694	6.997222	14.7	4.4	1.40	13.7	5.3	0.20			
27	79.98994	6.984111	11.5	16.4	2.50	45.3	62.0	0.01	96.00	24.00	
28	80.595	6.885556	11.4	11.5	0.01	39.4	20.8	0.04	10.00	4.80	
29	79.94722	6.96	22.4	104.0	0.04	24.4		0.29			
30	79.90583	6.914722	41.2	10.9	0.20	19.8	10.2	0.50			
31	79.87483	6.960633	41.2	14.5	0.03	220.0	46.6				
32	79.85417	6.934722	46.4	22.5	17.20	71.8	71.4	0.80			134.0
33	79.8825	6.956111	42.5	17.5	0.50	120.0	21.4	0.10	75.00		205.0
34	79.93087	6.95136	156.0	71.0	1.70	896.0	240.0	0.01			
35	79.88334	6.89254	175.0	89.2	0.50	1310.0	128.0	0.30			
36	80.67748	6.79776	13.0	17.0		13.0	ND	ND			
37	80.31623	6.99346	2.0	1.0		6.0	ND	0.05			
38	80.26113	7.0267	5.0	2.0		17.0	ND	0.01			
39	80.23232	6.95358									
40	80.3264	7.098733	2.0	2.0		9.0	ND	0.25			
41	80.62786	6.88284	3.0	2.0		10.0	ND	0.24			
42	80.14534	6.868232	41.0	5.0	0.40	7.0	1.0	ND			
43	79.91743	6.92533	27.0	9.0	0.40	15.0	4.0	0.80			
44	80.1628	7.059122	26.0	19.0	0.60	6.0	ND	ND			
45	80.2667	6.910766	106.0	28.0	7.0	0.40	6.0	1.0	0.24		
46	80.33705	6.93559	2.0	1.0		9.0	ND	0.01			
47	80.28038	7.19592	24.0	5.0		7.0	1.0	0.07			
48	80.41596	6.99585	8.0	2.0		6.0	2.0	0.01			

As per the data availability, it is seen that there are only four records that can be used to process to identify water types and to prepare the geochemical facies of the basin. This number is not quite sufficient to make a Piper graphical presentation to visualize the variation of the chemical properties along the flow path.

8.4.2. Malwathu Oya Basin

Table 8.2: Availability of Major Cations and Anions

S/N	Longitude	Latitude	Calcium (as Ca) (mg/l)	Magnesium (as Mg) (mg/l)	Chloride (as Cl) (mg/l)	Sulphate (as SO_4) (mg/l)	Na (mg/l)	K (mg/l)	HCO_3 (mg/l)
1	80.01549	8.85757	67	32	206	15			
2	80.88167	8.02674	76	101	770	33			
3	80.26638	8.58611	83	96	845	90			
4	80.52403	8.39489	98	46	219	2			
5	80.48554	8.49347	51	46	89	13			
6	80.43635	8.18771	67	35	166	16			
7	80.17120	8.78394	55	82	347	98			
8	80.24848	8.76018	16	17	46	55			
9	80.42135	8.41999	265	250	385	90			
10	80.70626	8.05627	52	62	339	30			
11	80.63406	8.09175	12	49	266	34			
12	80.68901	8.15239	205	26	317	79			
13	80.55378	8.13288	22	31	57	43			
14	80.60904	8.08457	67	32	206	15			
15	80.60167	8.24793	32	72	463	79			
16	80.56225	8.31131	23	58	424	52			
17	80.65161	8.29195	17	48	52	12			
18	80.64416	8.46947	49	35	55	20			
19	80.61038	8.53659	31	47	57	39			
20	80.48337	8.71213	18	50	164	126			
21	80.11334	8.79749	92	102	2794	175	0.2	ND	
22	80.01382	8.79614	161	65	1395	180	ND	0.2	
23	80.01127	8.78898	153	73	788	119	22.1	0.2	
24	80.05149	8.77852	115	58	570	32	18.2	0.6	
25	80.10738	8.77371	104	63	310	44	13.3	0.3	
26	80.40224	8.33101	30	112	192	53	ND	0.3	
27	80.51606	8.22229	49	95	267	45	ND	0.1	
28	80.55112	8.36201	51	8	47	13	ND	0.9	
29	80.33799	8.73044	47	28	57	84	22.8	1.7	
30	79.95181	8.83622	20	13	167	62	ND	ND	
31	80.46311	8.29049	108	60	370	31	21.5	1.1	
32	80.46351	8.55297	48	56	135	39	ND	0.4	
33	80.31661	8.64283	281	118	2924	500	3.2	0.6	
34	80.29620	8.65699	28	27	150	24	1.3	0.6	
35	80.58360	8.14099	26	57	133	1	ND	ND	
36	79.95612	8.91025	32	127	1280	126	ND	0.1	
37	79.98454	8.73755	151	79	1321	93	ND	ND	
38	79.95247	8.80785	86	113	2253	220	ND	ND	
39	79.98407	8.85560	185	88	1501	230	ND	ND	
40	80.30093	8.64168	52.2	114.6	200	21			451.4
41	80.38411	8.38048	44	38	29	23			
42	80.49611	8.45917	74.2	18.7	118	6.6			503.86

S/N	Longitude	Latitude	Calcium (as Ca) (mg/l)	Magnesium (as Mg) (mg/l)	Chloride (as Cl) (mg/l)	Sulphate (as SO_4) (mg/l)	Na (mg/l)	K (mg/l)	HCO_3 (mg/l)
43	80.47778	8.47083	52.4	64.8	198	26.7			460
44	80.27917	8.67500	22.6	34.3	24.6	22.3			456.28
45	80.31944	8.68389	60.4	11.4	29.5	22.8			361.12
46	80.37628	8.72183	54.8	30.8	44.5	24.2			605.12
47	80.60373	8.59735	31	47.9	151	19.9			723.46
48	80.65455	8.53032	31.2	45.9	453	84			633.18
49	80.59750	8.48694	24	37.6	40.3	29.2			461.16
50	80.65368	8.23148	55.2	48.1	337	69.5			405.04
51	80.41778	8.54694	102	76.7	262	73.4			640.5
52	80.59194	8.09194	53	33	205	30	72	4.6	305
53	80.32778	8.49500	34	26	110	19	96		390
54	80.39444	8.49750	27	34	42	22	56	2.5	414
55	80.54917	8.54111	47.6	50.1	72	35.7			632
56	80.52083	8.52222	7.6	48.5	73.9	4.7	68	22	

The availability of some basic cations and anions such as bicarbonate for the preparation of the Piper diagram in order to identify the hydrogeochemical facies is not sufficient. Only four complete records are available as per the Table 8.2 which are not adequate.

CHAPTER 9. GROUNDWATER MONITORING & RECHARGE SHEDULING

It has been identified that it is important to find a suitable mechanism to enhance the recharge after rainfall if the rainfall-recharge phenomenon cannot be coexistence due to groundwater level is too shallow during the natural recharge by the rainfall. The real time monitoring data has shown that the water level of most of the wells are very shallow so it is only a small amount of water of the rainfall is subject to the natural recharge.

9.1 Time Lag Effect of Precipitation on Groundwater Level

The time lag effect of precipitation on groundwater levels is a critical aspect of hydrology and water resource management.

The lag between rainfall and recharge refers to the delay in the water reaching the groundwater table a fter rainfall. This lag can vary based on several factors, including the type of precipitation, the type of soil, the permeability of the geological formations, and the rate of evaporation. A shorter lag time means that the water infiltrates quickly, leading to a higher peak discharge and a steeper rising limb in the hydrograph. Conversely, a longer lag time indicates slower infiltration, resulting in a gentler hydrograph and a lower peak discharge. Understanding this lag is crucial for predicting flood risks and managing water resources effectively (Figure 9.1)

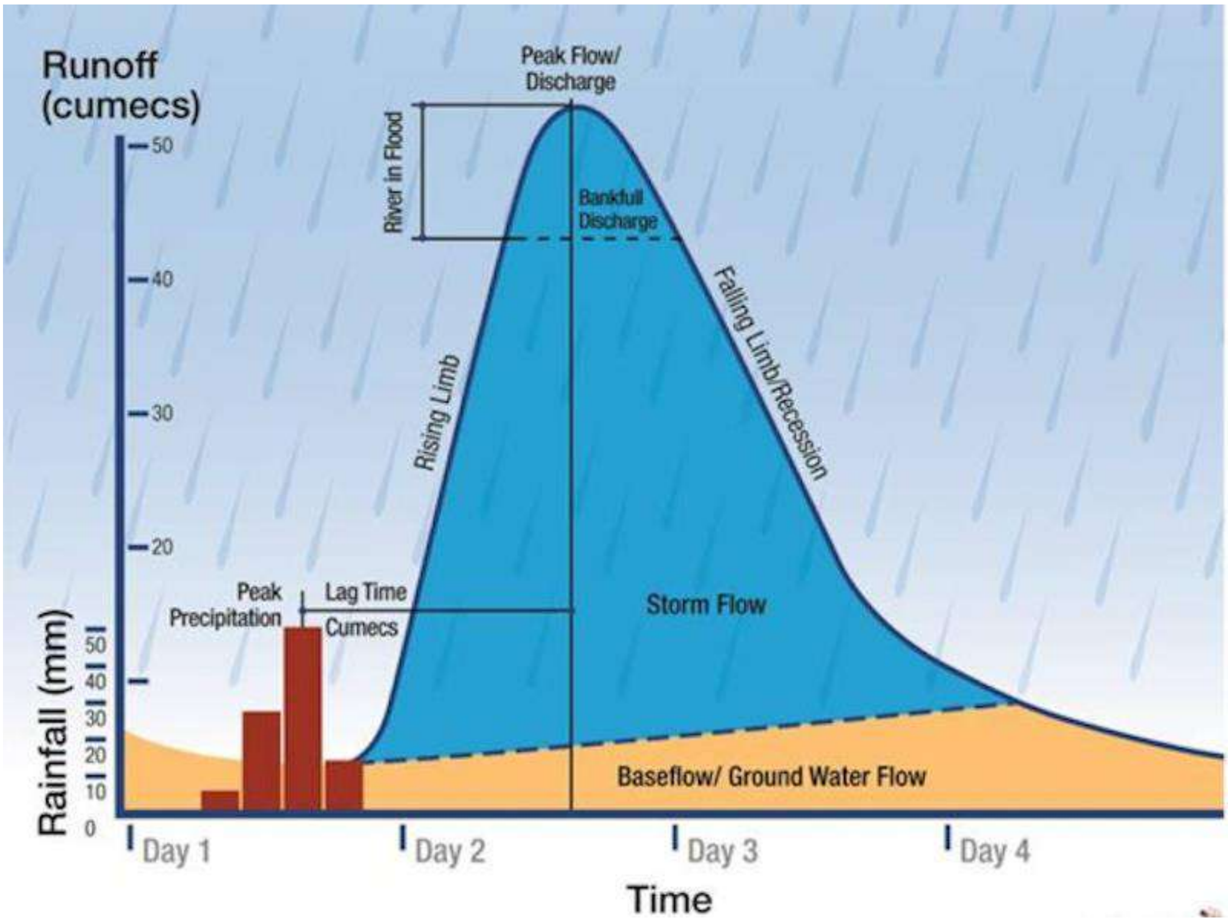


Figure 9.1: Hydrograph Indicating Lag Time Between Precipitation and Recharge

9.2. Groundwater Monitoring and Designing of Recharge Programs

Groundwater monitoring data is important in the process of identifying the lag time and also for making programs such as storm water management, in which a part of storm water is scheduled to be used as a source water for artificial recharge for groundwater supply management in meeting the additional demand in the water supply.

Groundwater monitoring programs are classified into different systems according to the functions that they perform. Primary or reference monitoring system illustrated in Table 9.1 is the most suitable method for understanding the recharge of groundwater level with respect to the precipitation.

Table 9.1: Classification of Groundwater Monitoring Systems by Function

SYSTEM	BASIC FUNCTION	WELL LOCATIONS
Primary (Reference Monitoring)	Evaluation of general groundwater behaviour: • trends resulting from land-use change and climatic variation • processes such as recharge, flow and diffuse contamination	• In uniform areas with respect to hydrogeology and land use
Secondary (Protection Monitoring)	Protection against potential impacts of the following: • strategic groundwater resource • wellfields/springheads for public water supply • urban infrastructure from land subsidence • archaeological sites against rising water table • groundwater-dependent ecosystems	• Around areas/ facilities/ features requiring protection
Tertiary (Pollution Containment)	Early warning of groundwater impacts from: • intensive agricultural land use • industrial sites • solid waste landfills • land reclamation areas • quarries and mines	• Immediately down- and up-hydraulic gradient from hazard

Once the objective of the monitoring program is identified, the operational part of the system should be clearly understood to meet the original objectives. Network design is a principal criterion in identifying the recharge trends in an area, which provides valuable information on rainfall-recharge relationship.

Table 9.3: Basic Success Rules for Groundwater Monitoring Programs

NETWORK DESIGN	• objectives must be defined and program adapted accordingly • groundwater flow system must be understood • sampling locations and monitoring parameters must be selected by objectives
SYSTEM IMPLEMENTATION	• appropriately-constructed observation and abstraction wells must be used • field equipment and laboratory facilities must be appropriate to objectives • complete operational protocol and data handling system must be established • groundwater and surface water monitoring should be integrated where applicable
DATA INTERPRETATION	• data quality must be regularly checked through internal and external controls • decision makers should be provided with interpreted management-relevant datasets • program should be periodically evaluated and reviewed

As per the information available for the selected four study areas, only Malwathu Oya basin and Jaffna peninsula have sufficient monitoring data to analyse the rainfall and recharge relationship. The sub sections 9.2.1 and 9.2.2 will provide the occurrence of recharge as seen with the real-time groundwater monitoring data

9.2.1. Jaffna Peninsula

9.2.1.1. Study Area Description

Jaffna peninsula is selected for this study, as shown in (Fig. 1a), which covers approximately 1000 km^2. The topography gradually varies from sea level to 15 to 20 m from the West to the eastern boundary. The average annual rainfall of the area is approximately 2500 mm and around 69% of that rainfall occurs in November to January.

9.2.1.2. Groundwater Monitoring Data

Figure 9.2 illustrates the real-time groundwater monitoring points in the Jaffna Peninsula as per the WRB website.

Figure 9.2: Positions of real time groundwater Monitoring points

Hydrographs of the monitoring wells together with the rainfall were assessed of which three are given below. The numbers indicated in the figure represent the following hydrographs. These wells have very shallow water tables even during g the dry spells and also the response to rain fall events are very quick.

Figure 9.3a: hydrograph of well no JAF-MON-044

Figure 9.3b: hydrograph of well no JAF-MON-055

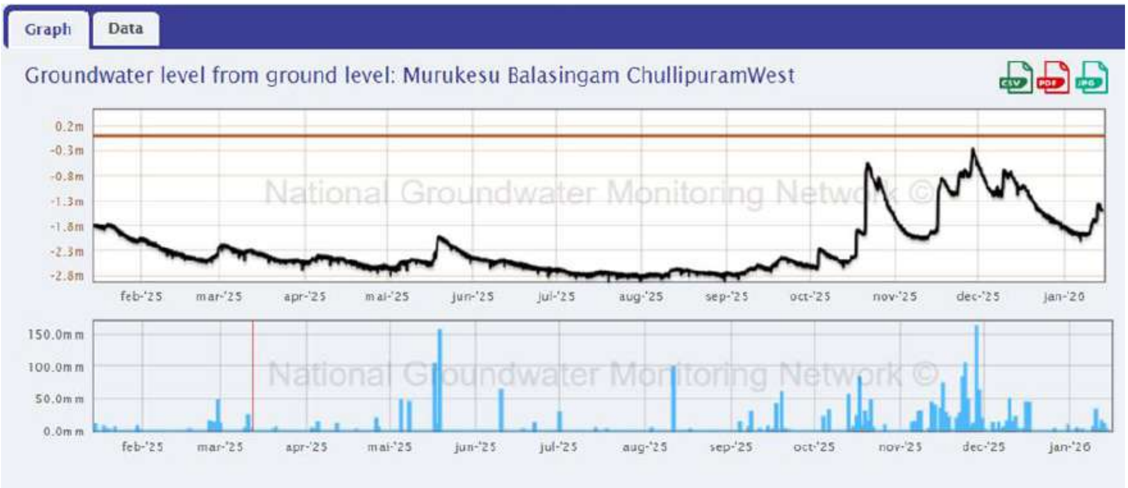


Figure 9.3c: hydrograph of well no JAF-MON-018

9.2.2. Malwathu Oya Basin

9.2.2.1. Study Area Description

The basin is situated entirely in the Dry Zone of the country. The average annual rainfall of the catchment is around 1,350 mm and the average discharge to the sea has been estimated as 260 MCM per annum (Irrigation Department).

9.2.1.2. Groundwater monitoring data

Figure 9.4 illustrates the real-time groundwater monitoring points in the Malwathu Oya basin as per the WRB website. Hydrographs of the monitoring wells together with the rainfall were assessed of which three are given below. The numbers indicated in the figure represent the following hydrographs from 5a to 5d. These wells have very shallow water tables even during the dry spells and also the response to rain fall events are very quick.

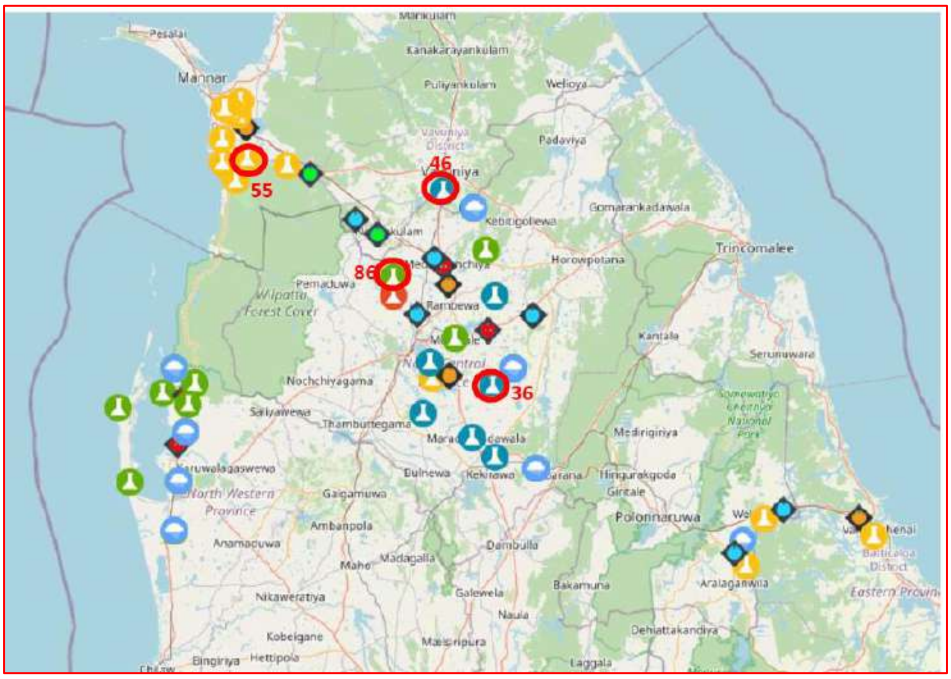


Figure 9.4: Positions of real-time Groundwater Monitoring Points

Figure 9.5a: Hydrograph of well no MAL-MON-036

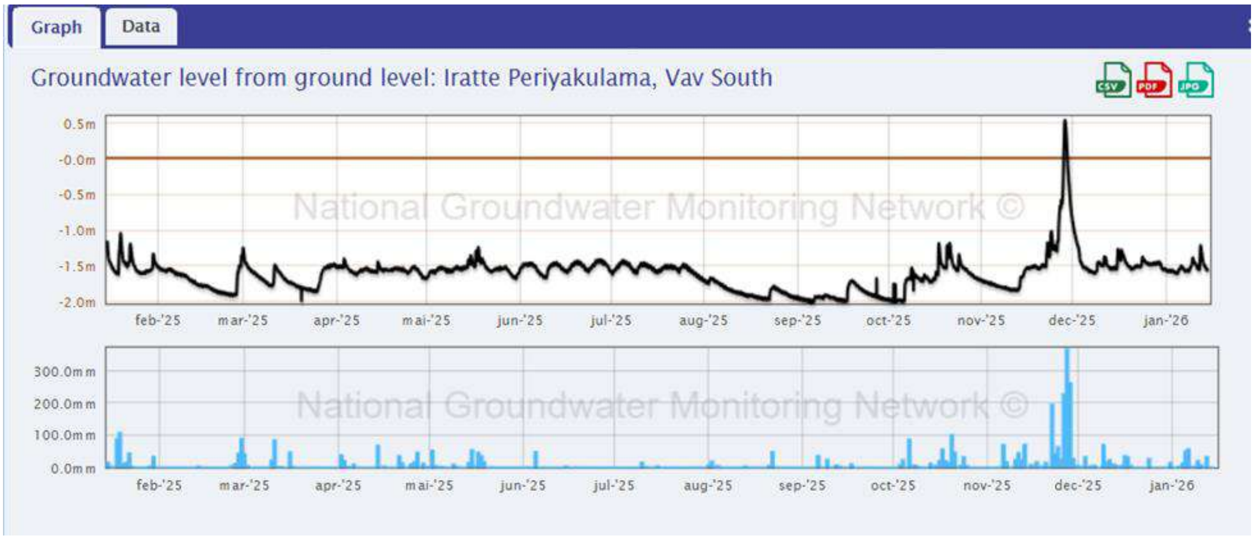


Figure 9.5b: Hydrograph of well no MAL-MON-046

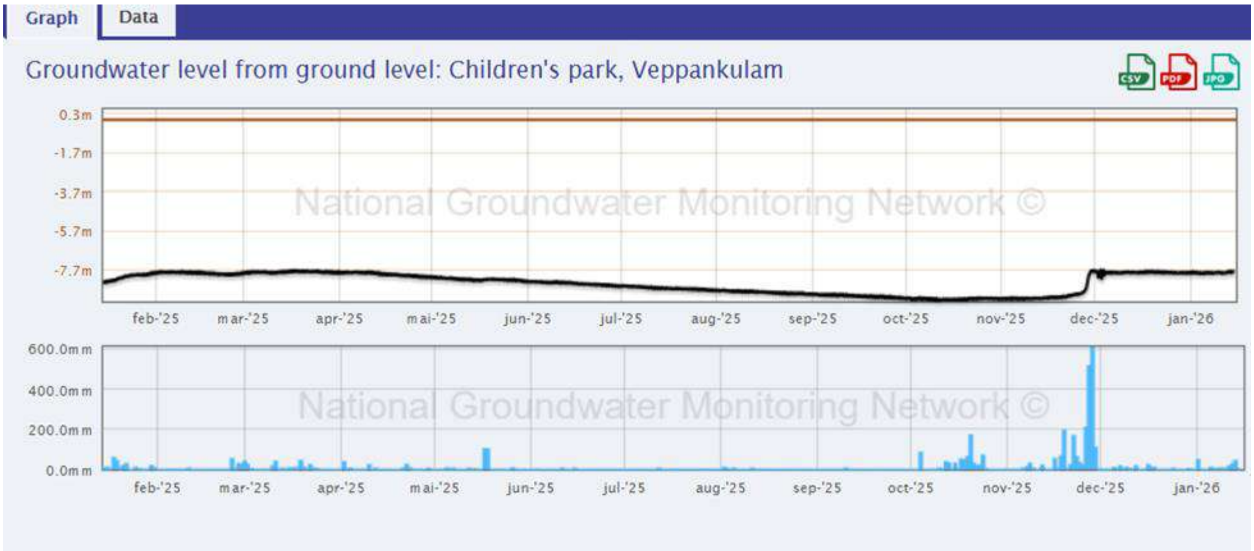


Figure 9.5c: Hydrograph of well no MAL-MON-055

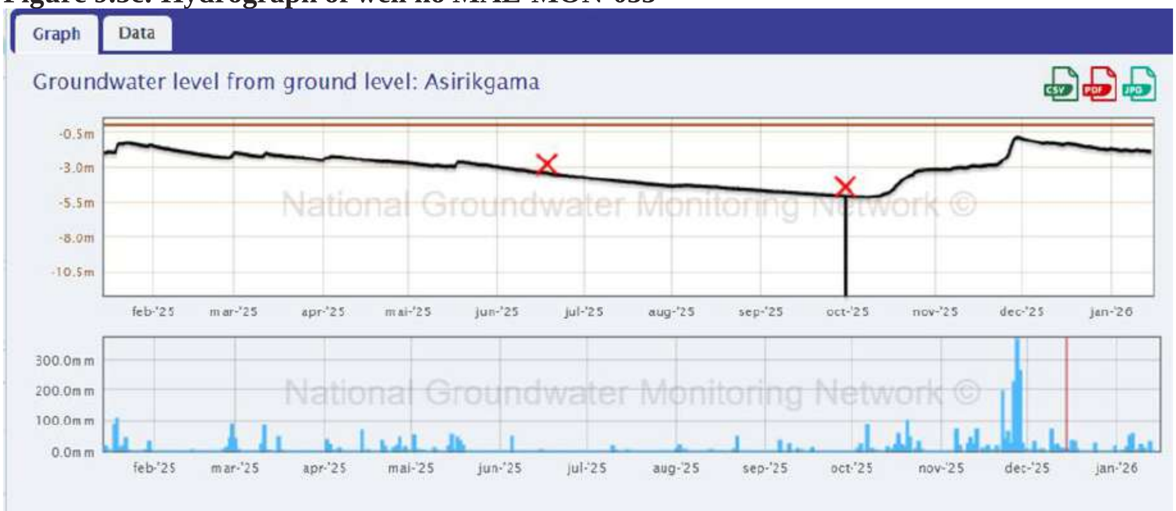


Figure 9.5d: Hydrograph of Well no MAL-MON-086

9.2. Coping with the Lagging Period of Recharge and Rainfall

Artificial recharge options such as recharge ponds and injection wells are the solutions for enhancing the recharge during rainfall events. Recharge ponds allow water to slowly infiltrate through the soil into the unconfined aquifer under the ground. Injection wells use artificial pressure that is created from the water column to push the water into the ground.

1. Surface infiltration systems
2. Well injection systems

The annex-1 provides an insight of the theoretical aspect of artificial recharge with some important points to be considered.

The design and engineering aspect depends on the methodology to be adopted as per the ground conditions where the MAR program is to be designed. The figure 9.6 is an illustration of aquifer storage and recovery application (ASR) where an infiltration basin is used for recharge and recovery is performed at a later stage in a specific time period as per the requirement.

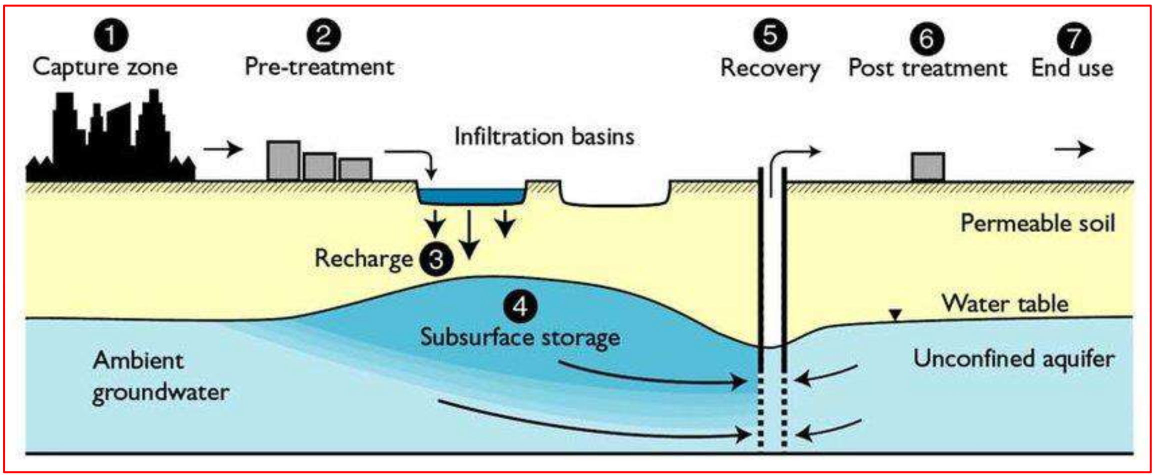


Figure 9.6: Schematic Diagram of ASR Program

The Annex-3 presents a summary of a feasibility study conducted by the consultant to identify the possibilities of applying the MAR program to the existing Naraammala WSS managed by NWSDB, as a case study to illustrate the implications.

CHAPTER 10 - SUMMARY OF WORK

10.1. Computation of Water Use

The quantification of the usage of groundwater for different purposes was completed. Further refinement is required as some of the data received seems to have some errors, such as information received for agro wells and domestic usage. Further, the information on groundwater use by large farms is not comprehensive, which will be addressed during the water balance study.

10.2 Assessment of Groundwater Recharge Potential Zones

A comprehensive evaluation of the main contributory factors was conducted and integrated using GIS & RS tools. Potential recharge zones have been identified at the basin scale. Further work at the field level is necessary to finalize at the local level.

10.3 Contaminant Sources and Their Threat to Groundwater Quality

Main sources of groundwater contamination were assessed in collaboration with the relevant institutions. Site visits were conducted to identify how the contaminants are disposed of or discharged and to see whether such disposals are in compliance with the guidelines of the CEA.

10.4. Assessment of Future Aquifer Stresses

Groundwater Stress Indicators were developed. Stress indicators will be calculated based on the computation of water balance at the catchment/basin scale.

10.5 Assessment of Present Hydro-Geochemistry

An attempt was made to identify the water types and geochemical facies at the basin level. Some of the basic data were not available, as noted in the chapter. Further data search is needed.

10.6 Groundwater Monitoring & Recharge Scheduling

Real time monitoring data of the Jaffna peninsula and Malwathu Oya basin were assessed to identify rainfall – recharge phenomena. Most of the wells in both areas show shallow water levels, indicating that there is no sufficient space for natural recharge soon after rainfall events. Some theoretical requirements of the MAR programs are given in the annex-1, whilst the Annex -3 provides a report on a feasibility study conducted by the consultant.

ANNEX-1

THEORITICAL ASPECTS PERTAINING TO MANAGED AQUIFER RECHARGE

THEORITICAL ASPECTS PERTAINING TO MANAGED AQUIFER RECHARGE

1.1. Technical requirements

The following are the technical requirements for managed aquifer recharge (MAR):

A) Identifying the objective of the MAR is required, which could be for:
   I. Water quality improvement
   II. Increasing the storage to compensate for the depleting water table
   III. Water banking, to be used later

B) Local hydrogeological context of the aquifer/s to be recharged needs to be ascertained, including:
   I. Identifying the type of aquifer (i.e. confined or unconfined)
   II. Assessment of aquifer characteristics (Aquifer should be properly characterized by identifying the hydraulic parameters)
   III. Currently recommended safe yield of well/s of the schemes
   IV. Measures taken for adaptation or resilience to climate change risks

C) Hydrochemical context should be found out, which includes:
   I. Water quality of native water (i.e. water in the aquifer), including dissolved oxygen
   II. Water quality of the source, including the dissolved oxygen

   The water quality parameters of both source and native water should include major cations and anions, heavy metals, and organic compounds.

D) Geochemical context of the geological formation should be taken into consideration, which includes:
   I. Minerals that are in equilibrium with the native water
   II. Minerals that can form different complexes with source water in the long run

E) Type of source water
   A variety of source waters are used for aquifer recharging around the world, namely:
   - Surface runoff, storm water
   - River/Lake water
   - Rooftop Collected rainwater
   - Desalinated water
   - Treated wastewater

F) Infiltration methods for recharging: Define the methods to be adopted for recharging aquifers

1.2. Importance of MAR Concept

MAR and Water Banking

The importance of the MAR concept lies in enhancing the capacity of water supply schemes sourced from groundwater and improving the water quality of groundwater affected by various factors, such as land use and seawater intrusion resulting from over-pumping of coastal aquifers, particularly during low rainfall periods.

It is important to assess such situations and propose to introduce some applications of MAR, such as Aquifer Storage and Recovery (ASR) and Aquifer Storage Transfer and Recovery (ASTR), the water banking method, to increase storage (if technically feasible) when there are sufficient resources and use them in times of need.

In Sri Lanka, there are a large number of water supply schemes fed by shallow and deep wells located in the dry zone, which are affected during the dry periods. Most of the wells are located near or around tanks, which can be recharged when the tanks have a reasonable quantity of water.

Further to the above, suitable mechanisms should be developed to address the rainfall - recharge lagging time to enhance the recharge of subsurface aquifers.

Requirement of Pretreatment

Pretreatment of source water is important because it might carry a significant amount of physical (suspended particles) constituents and also chemical constituents in the dissolved form of high concentration, like free ammonia, fluoride, iron, etc., affecting the quality of the host water (native water). Further, the pathogens are also another contaminant of source water that could affect the host water.

1.3. Conceptual MAR Models Considered

Selection criteria for the appropriate recharge method

All MAR schemes are premised on the assumption that there is a suitable aquifer for the recharge of water. A suitable aquifer for MAR is defined here as an aquifer having permeability and storage characteristics appropriate to accept a sufficient rate and volume of water to realise the scheme objectives within the practicable costs of establishing the scheme.

Given this aquifer prerequisite, when selecting the MAR recharge method, considerations of a range of additional site-specific conditions are required, including:

- Lithological profile of the system, with respect to infiltration characteristics of the soil and surficial sediments;
- Confinement status of the target aquifer (unconfined, semi-confined, confined);

- Hydrogeological characteristics of the entire system (both above, within and below the target aquifer);
- Geomorphological characteristics of the land, with respect to the landform and nature of sediments or rock (e.g. sand dunes and swales, shallow bedrock ridges or volcanic intrusions beneath alluvial aquifers);
- Source-water quality may also influence recharge method selection as well as dictate the likely requirements for pre-treatment, which can add a high cost and impact on the feasibility of the various methods;
- The cost of land will determine the expansiveness of the scheme (i.e. rural versus urban settings);
- Investigation costs, which vary depending on method and site configuration, may also have a bearing on the type of recharge method selected if more than one option is available for any particular site.

1.4. MAR Technological Concepts

Managed aquifer recharge (MAR), or intentional groundwater replenishment, is a means of improving water security by using aquifers to store water for subsequent recovery or environmental benefit. This is achieved through injection wells, infiltration basins and galleries for rainwater, storm water, reclaimed water, mains water and water from other aquifers that is subsequently recovered for all types of uses.

MAR must be adapted to local hydrogeological conditions as well as to the source water type and the required end-use. It must also be adapted to the specific conditions of the capture zone. Lastly, MAR must be implemented within the existing legal and water management framework.

According to Dillon et al. (2010), each MAR type is described by seven components as shown in the figure below.

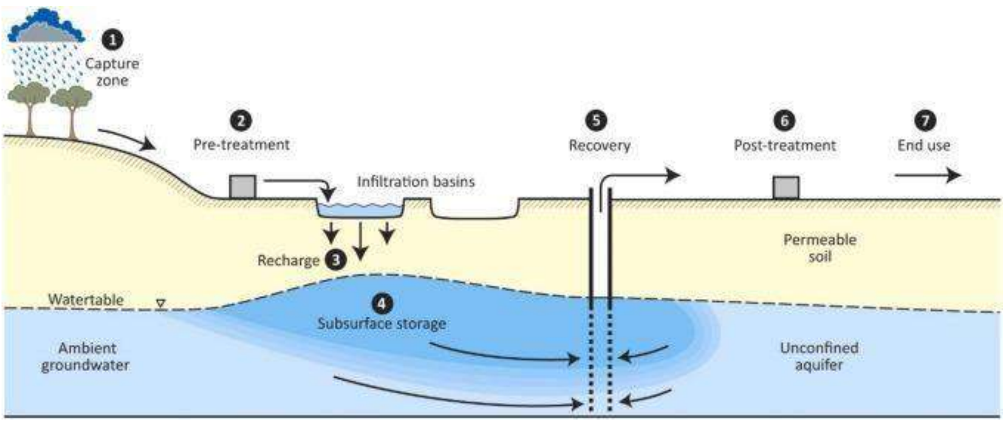


Figure A.1: Components of MAR types

1.5. Methodology for Injection Capacity Estimation

Methodology Overview

Injection capacity is defined as the maximum volume of water that can be injected into an aquifer using a well pumped at a constant rate for given operational parameters (i.e., injection duration, number and spatial arrangement of wells, and well radius) under the constraint of a maximum allowable hydraulic head change. In order to determine the injection capacity, we first need to determine the injection rate. To estimate the injection rate that maximizes the injection capacity of a well over a certain duration, we use the Theis (1935) solution, which gives the hydraulic head change at any point in space and time as:

$$\Delta h(r,t) = \frac{Q}{4\pi T} E_1\left(\frac{r^2 S}{4Tt}\right) \qquad (1)$$

where Δh (L) is the hydraulic head change, r (L) is the distance from the well to the evaluation point, t (T) is the time from the start of injection, Q (L3 T-1) is the injection rate, T (L2 T-1) is the transmissivity, S (-) is the storativity, and E_1 is the exponential integral function (also known as well function), defined by

$$E_1(u) = \int_u^\infty \frac{e^{-x}}{x} dx \qquad (2)$$

where u > 0. Equation 1 is valid both for extraction (Q < 0) and injection (Q > 0). Since both cases are mathematically equivalent aside from the sign, we will only develop the injection case (i.e., both Δh and Q will be positive).

At any time during the injection process, Δh is larger at the well than at any other point in the aquifer. Therefore, it is at the injection well that the maximum allowable head change (Δh_{max} will first be reached. Furthermore, since Δh has positive correlation with Q and t, the injection rate that maximizes injection capacity (Q^{max}_{sw} (the subscript "sw" stands for "single well") will be the one for which $\Delta h = \Delta h_{max}$ at the injection well at the end of the injection period (i.e., $t = t_{inj}$, orange line in Figure A.2). This statement provides an equation for Q^{max}_{sw} as

$$\frac{Q^{max}_{sw}}{4\pi T} E_1\left(\frac{r_w^2 S}{4T t_{inj}}\right) = \Delta h_{max} \qquad (3)$$

Where r_w(L) is well radius. Solving Q^{max}_{sw} gives

$$Q^{max}_{sw} = \frac{4\pi T \Delta h_{max}}{E_1\left(\frac{r_w^2 S}{4T t_{inj}}\right)} \qquad (4)$$

The single well injection capacity (V_{sw}^{max} is then given by

$$V_{sw}^{max} = Q_{sw}^{max} \times t_{inj} = \frac{4\pi T \Delta h_{max} t_{inj}}{E_1\left(\frac{r_w^2 S}{4T t_{inj}}\right)} \quad (5)$$

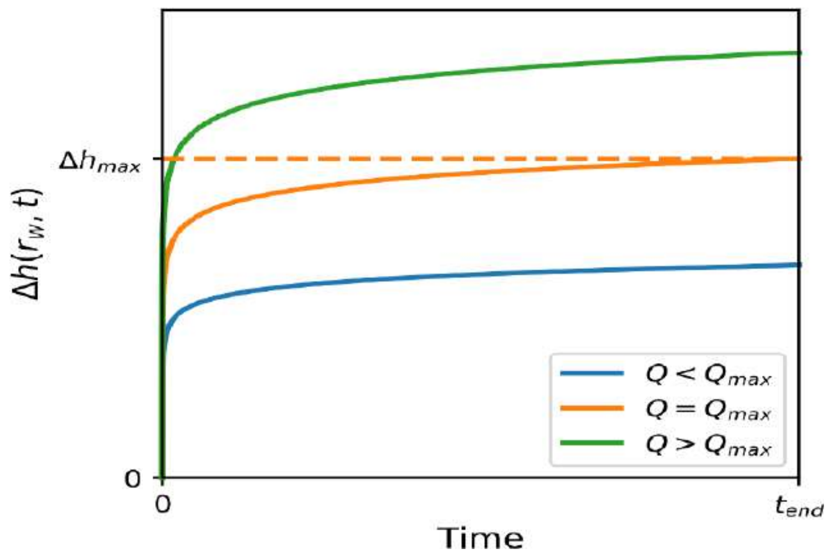


Figure A.2: Illustration of the Theis principal

The above Illustration of the Theis principle for an optimal combination of pumping rates is one for which $\Delta h = \Delta h_{max}$ at t= t_{inj} at the well where t_{inj} is the time at the end of injection (t_{inj}=t_{end})

Parameters estimation

The proposed method requires five parameters: transmissivity, allowable head change, injection duration, storativity and well radius to calculate the injection capacity of any well at any point in an aquifer. In this section, we describe each of these parameters and, where necessary, explain how they were estimated for each study site. A flow chart depiction of the five parameters and factors on which they depend is shown in Figure A.3.

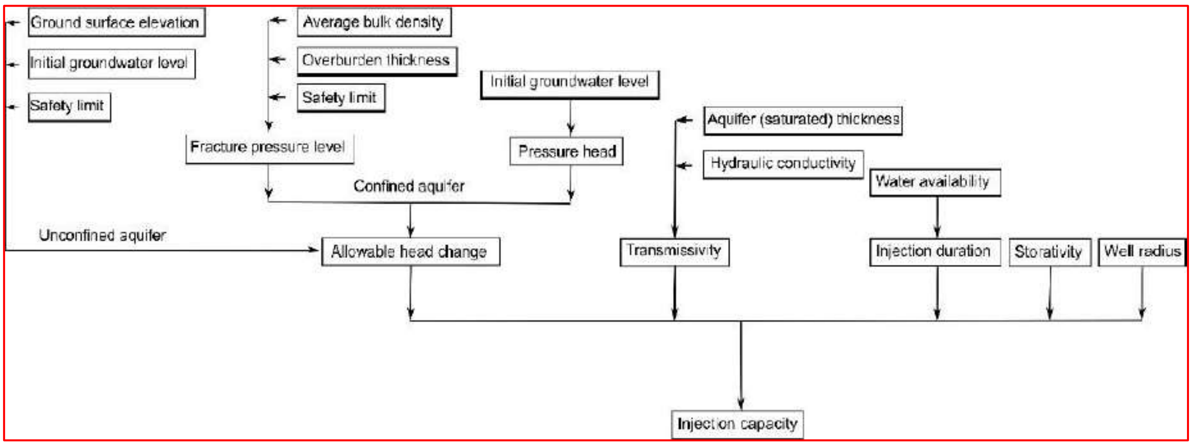


Figure A.3. Schematics illustrating the concept of maximum allowable head change

The flow chart shows the important parameters and procedures required to estimate the injection capacity of unconfined and confined aquifers.

Transmissivity

Transmissivity (hydraulic conductivity multiplied by aquifer thickness) is a critical parameter that controls the injection capacity; transmissivity is shown to have an approximately positive linear influence on the value of injection capacity (Shandilya et al., in progress).

Allowable head change

Allowable head change is the permissible height of hydraulic head that can be allowed to rise above the initial condition without causing any undesirable change such as surface flooding, flowing artesian wells, and fracturing of confining units. The allowable head change estimation procedure is dependent on whether an aquifer is confined or unconfined. In this section, we therefore describe the allowable head change calculation for unconfined and confined aquifers separately. In unconfined aquifers, we primarily need to know the ground surface elevation and the initial (before the start of injection operation) hydraulic head. We also include a safety limit in the calculation to consider the potential risk of flooding.

The allowable head change for an unconfined aquifer can be expressed as

$$\Delta h'_{max} = \textit{(Ground surface elevation – Safety limit) – Initial Hydraulic head}$$

For the Buffalo aquifer, which is mostly an open agricultural area and has very few settlements, we select 2.5 m below the ground surface as the safety limit. Thus, the allowable head change in the unconfined portion of the Buffalo aquifer is calculated considering that the depth to groundwater level in the injection wells at the end of the injection period is not less than 2.5 m below the ground surface. If the injection wells are located near settlements, the value of the safety limit should be selected in accordance with the depth of basements and building foundations, which is normally deeper than the soil root zone. For this scenario, we would propose to select a deeper (~5 m) safety limit (Dudding et al., 2006; Hodgkin, 2004).

In confined aquifers, the allowable head change is essentially constrained by the fracture pressure head of the upper confining layer. Thus, the injection pressure should always be lower than the amount of pressure that the upper confining layer can withstand without generating fractures. For aquifer storage purposes, the fracture pressure head can be estimated using a simple formula presented in Zoback (2010) and Szulczewski et al. (2012). The method requires knowing the bulk density and thickness of the upper confining layer and the overburden material. The expression for fracture pressure head is given as

where v is the Poisson ratio of overburden material, ρ_0 is the average bulk density of overburden, ρ_w is the density of water, D is the depth to the bottom of the confining layer, h_p is the pore water height, p_0 is the atmospheric pressure, and g is the acceleration due to gravity. However, if we want to cap the fracture pressure head to prevent fracturing of the confining layer, we need to include some safety limit in the calculation. This will give the value of the allowable pressure head

Allowable pressure head = Fracture pressure head x (1-SL)

where SL is the safety limit (in %). In the expression, if we use a 15% safety limit, the allowable pressure head in the injection well is at 85% of the fracture pressure head (Hodgkin, 2004). We use the bulk density data and the thickness of each overburden layer to calculate the fracture pressure head. Now, the expression for allowable head in confined aquifer can be written as:

Allowable head = Aquifer top elevation + allowable pressure head

where "aquifer top elevation" is the upper elevation of the aquifer surface above the reference mean sea level. The allowable head represents the maximum elevation up to which injection pressure can be allowed to rise in the aquifer. After having the value of allowable head and initial hydraulic head, the calculation of allowable head change (Δh_{max}) can be defined as

Δh_{max} *= Allowable head –Initial hydraulic head*

For confined aquifers, the allowable head change can cause flowing well conditions (where hydraulic head is higher than ground level) very close to the injection well. If one wants to avoid any risk of flowing well conditions, the allowable head should be set to the ground level. However, this may lead to too strict of a criterion with reduced injection capacity. Note that the head rise is a maximum at the injection well, and the head decreases rapidly from the injection well.

Injection duration

The injection duration refers to the time period over which water will be injected for the purpose of aquifer storage and recovery. This will depend on the well efficiency, the volume of surplus available water, and local ASR needs. If we assume an ideal condition of continuous well operation without any operational failure, then the maximum injection duration becomes a function of water availability. Depending on the site condition, sources of excess available water include surface water (reservoir, pond, lake, river, etc.), adjacent aquifers, and treated wastewater or storm water. When the source is rainfall stored in a reservoir, lake, or pond, the injection duration depends on precipitation as well as surface storage potential. When river water is the source, the injection duration may depend on the time during which discharge is more than the environmental and other agricultural needs. Thus, the injection duration may be highly variable depending on the context and objective.

Storativity

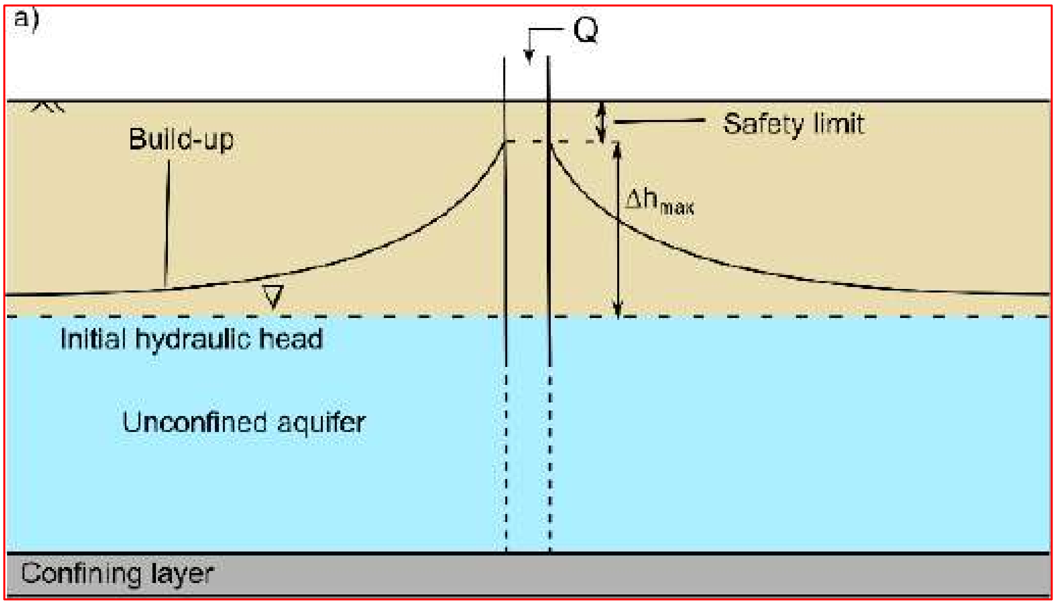
Storativity is another important aquifer parameter, which is needed for estimating the well- based injection capacity of an aquifer. It is a coefficient that measures the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer. Storativity is a dimensionless quantity, and is always greater than 0. Similar to transmissivity, storativity varies in space, and its value can be obtained from aquifer tests.

Well radius

Well radius refers to the radius of a wellbore pipe. Generally, the well radius is on the order of several centimeters and depends on the application. The best way to select a well radius for an injection capacity estimation is to check the radius of the operational wells and their respective use in the nearby areas.

1.5.1. Conceptual model of recharge

Figures A.4a & A.4b illustrate the concept of recharge with respect to the recharge copes for both unconfined and confined aquifers, respectively. A proper understanding of the behaviour of the cones are vital important to control the recharge capacity.



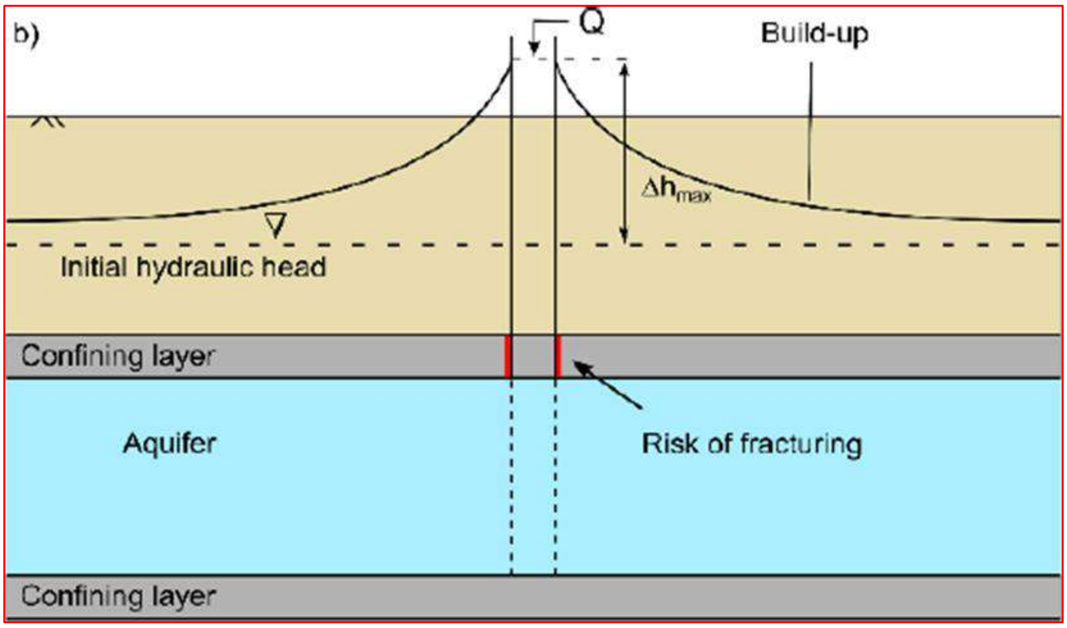


Figure A.4a & A.4b: Conceptual model of recharge phenomena for both unconfined and confined aquifers.

ANNEX-2

INDUSTRIAL SURVEY QUESTIONNAIRE

INDUSTRIAL SURVEY QUESTIONNAIRE

1. **Name of the Industry ………………………………………………………………….**

2. **Nature of the Industry: …………………………………………………………………**

3. **No. of Employees: ………………………………………**

4. **No. of staff grade employees: …………………………….**

5. **Water Supply Source:** Groundwater from the wells within the industry

Surface Water extracted by the industry		NWSDB water supply scheme	
LA water supply scheme		Both Groundwater and surface water	

6. **Quantity of water extracted/used per day (m^3/day): ………………………………….**

7. **What are the effluents discharged from the industry**?

   …………………………………………………………………………………………….

8. **Is the treated effluent tested for chemical parameters before being released?**

9. **If yes for the question 13, what are the parameters being tested?**

………………………………………………………………………………………………

10. **If no for question 13, why is the treated effluent not tested?**

………………………………………………………………………………………………..

11. **Volume of effluents released per day (m^3/day): ………………………………………..**

12. **Are these effluents treated before being released to the environment?.............................**

13. **What is the treatment process? ……………………………………………………….…**

    ……………………………………………………………………………………………....

14. **How do you manage your Solid waste?**

    Dispose of within the industry premises

    LA collects the solid waste

15. **Where does LA dispose of solid waste? ……………………………………………..…….**

    ……………………………………………………………………………………………..

16. **Have you obtained an EPL Certificate and renewed it every year? Yes…… No………**

ANNEX - 3

A CASE STUDY OF MAR

FEASIBILITY OF MANAGED AQUIFER RECHARGE IN NARAMMALA – A CASE STUDY OF MAR

A proposal for MAR for Narammala WSS, which was investigated and feasibility was examined by the Consultants under a different consultancy assignment, is presented below, in order to illustrate the possibility and the implications and requirements in implementing a MAR system.

Narammala water supply scheme is sourced from groundwater extracted from four boreholes as depicted in the Fig. 1.1. Two of the boreholes-34/120 & 34/212- are located in Dampelessa, one, 34/545, is in Walakumbura whilst the other borehole, 34/655 is at Royal Pond. The well at Walakumbura shows poor water quality caused as a result of high turbidity and also excess iron. Further, the yield of the well reported a decreasing trend over the last few years. As such, it has been planned to consider this well to introduce a MAR program to improve both water quality and the quantity.

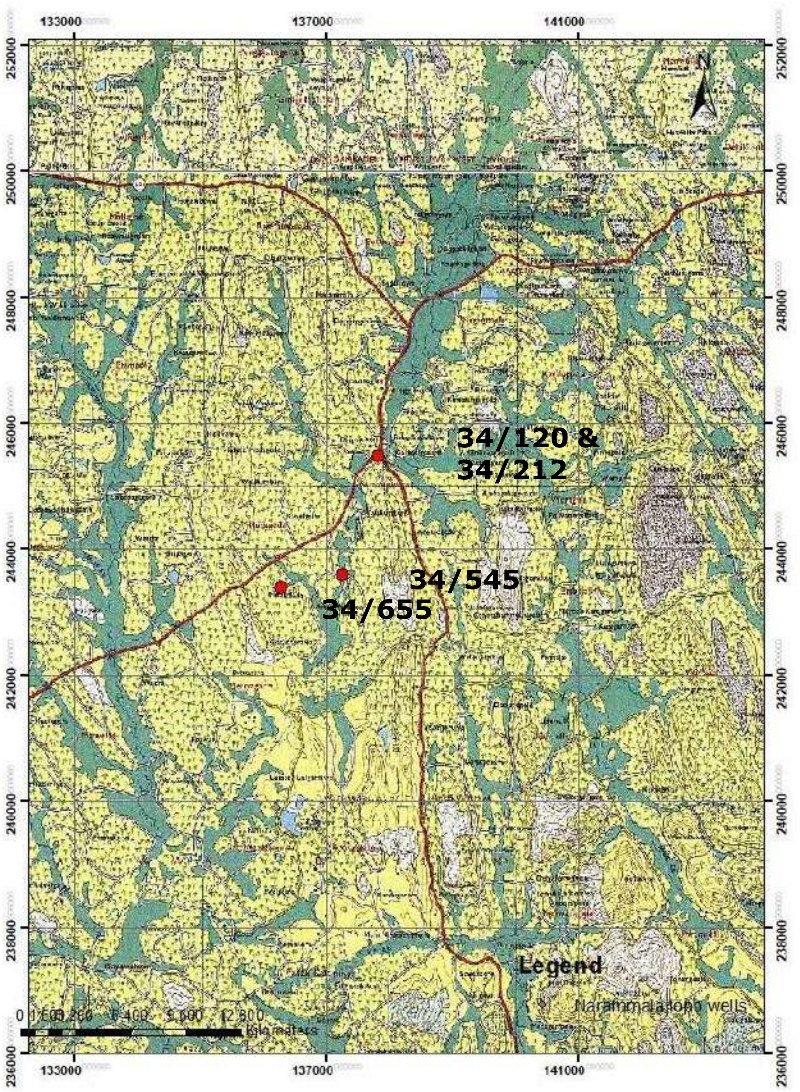


Figure 1.1: Well Distribution of Narammala Water Supply Scheme

1.1. Existing Water Supply

Presently, water is being extracted from 2 boreholes using submersible pumps, and is pumped into a groundwater reservoir of capacity 450 m3, which is located at a higher elevation.

The treatment is only chlorination at this reservoir. The water is being distributed from this reservoir under gravity into the distribution system.

One more borehole (at Walakumbura) is not used due to poor quality and low yield. Borehole has been recently constructed, and still to be commissioned.

The table 1.1 provides a summary of the current status of water supply of the Narammala scheme. Discussion with the OIC of the Narammala scheme revealed that the discharge level of the production well No. 24/545 changed drastically to 8 m^3/d. Further it was understood that at present the well is not functioning due to poor yield.

Table: 1.1 Details of the Water Supply Scheme as of May 2022

WELL ID	Y	X	Latitude	Longitude	Year of construction	Recomonded safe yield (m^3/d)	Current production (m^3/d)	Current number of connections
34/120	137820	245458	7.41154	80.21043	2000	1000 l/min (60m3/h) for 12hrs (720m3/day)	46 m3/h for 20hrs (920m3/day)	4450
34/212	137822	245456	7.41152	80.21045	2003		44 m3/h for 20hrs (880m3/day)	
34/545	137263	243605	7.39477	80.2054	2016	600 l/min (36m3/h) for16 hrs (576m3/day)	14 m3/h for 20hrs (280m3/day)	
34/655	136291	243378	7.39271	80.1966	2021	800 l/min (48m3/h) for 16hrs (768m3/day)	40 m3/h for 20hrs (800m3/day)	

During the dry period the demand is about 3500 m3/day which reportedly reduces to 2800 m3/day during the rainy period.

The operations of the borehole pumps are connected with SCADA system, except for the borehole at Walakumbura. Accordingly, the pumps of two boreholes are being operated from OIC office in Narammala town through SCADA, and pump at Walakumbura borehole (if used) is operated manually by an operator.

1.2. Future Water Demand

The Table 1.2 below provides the estimate made by the sector study conducted in 2018-2019. The demand then estimated has deviated from the actual requirement as per the details obtained from the office of NWSDB of Narammala.

Table 1.2 – Water Demand Projection - Narammala Water Supply Scheme

Source	WTP loca	2018 Production, m3/day	capacity, m3/day	2020	2025	2030	2050	2030 deficit	2050 deficit
BH	No	1,858		1,402	1,519	1,585	1,700	183	298

1.3. Geology and Hydrogeology

The simplified geology of the area is given in the Fig 1.2. Four wells are shown in the map, of which three wells, (with ID numbers 34/120, 34/212 & 34/545) are located in a same fault plane whereas the other is in a different geological environment. All wells have penetrated to the same geological units: undifferentiated Charnokitic Biotite Gneisses.

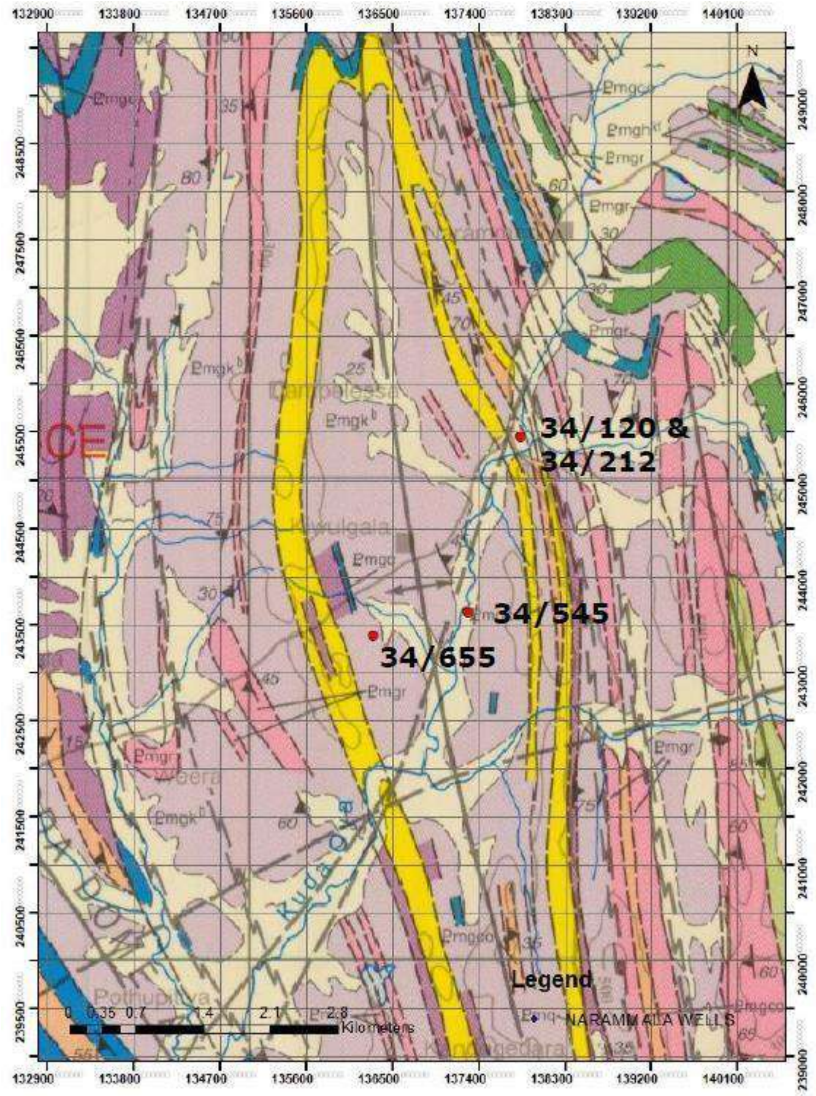


Figure 1.2: Simplified Geology in the Area

1.3.1 Hydrogeology

Main hydrogeological feature of the area is regolith underlain by weathered and fractured hard rock which can be interpreted as consisting of both primary and secondary porosity aquifer system. Hard rock hydrogeology could be present in different form as given in the Fig. 1.3. The site specific hydrogeological context is very important in general and in the hard rock terrain in particular. Hydrogeological characteristic of this aquifer has to be established as no data is available in this area. It is good exercise as a trial MAR program so this could be rolled out to the other schemes that are in a similar hydrogeological environment.

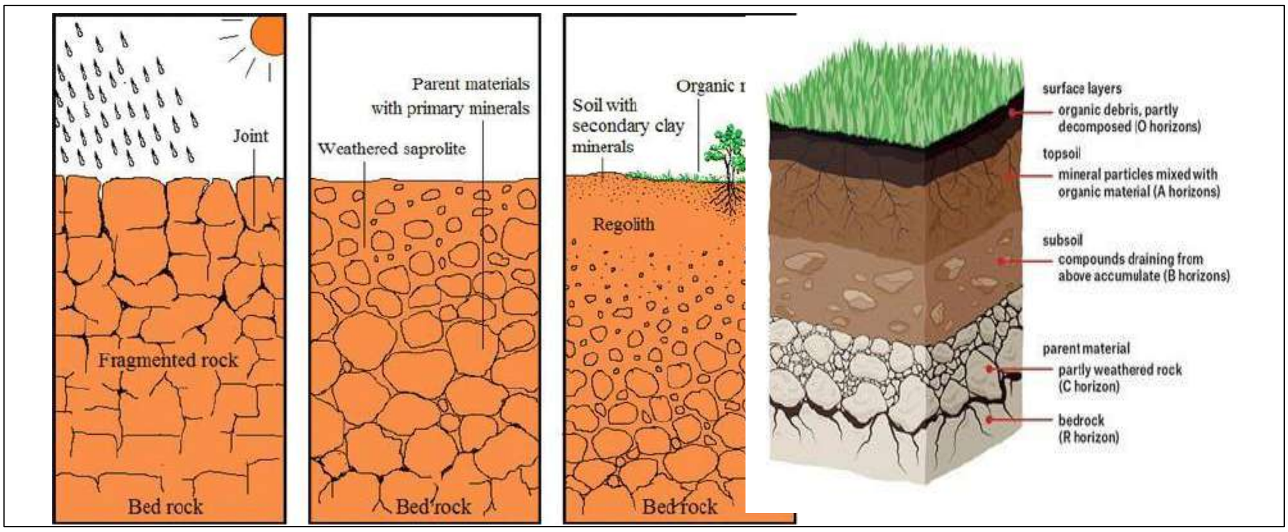


Figure 1.3: Different forms of hard rock hydrogeology

1.4. Source Water

A perennial stream was identified in the village of Walakumbura that can be used to obtain source water. The stream flows at the rate of around 15 l/s that could be used to inject water into the proposed injection well. This stream, (Fig 1.4) a tributary of Kuda Oya, originates from a spring about 1km upstream of the proposed location for constructing the weir. Kuda Oya flows into Maha Oya further down. The records of the flow of this stream is not available as there is no flow gauge installed in the upstream or downstream.

Figure 1.5: Stream flow near the proposed location for the weir

During the field work and discussion with people it was learnt that this particular stream is perennial even during prolonged drought period. An evaluation was performed on the question of the sustainability of the source of the source water. The geological map is clearly indicating that the stream originates from a long band of quartzite that runs several kilometers in the N-W direction (Ref. Fig 1.6).

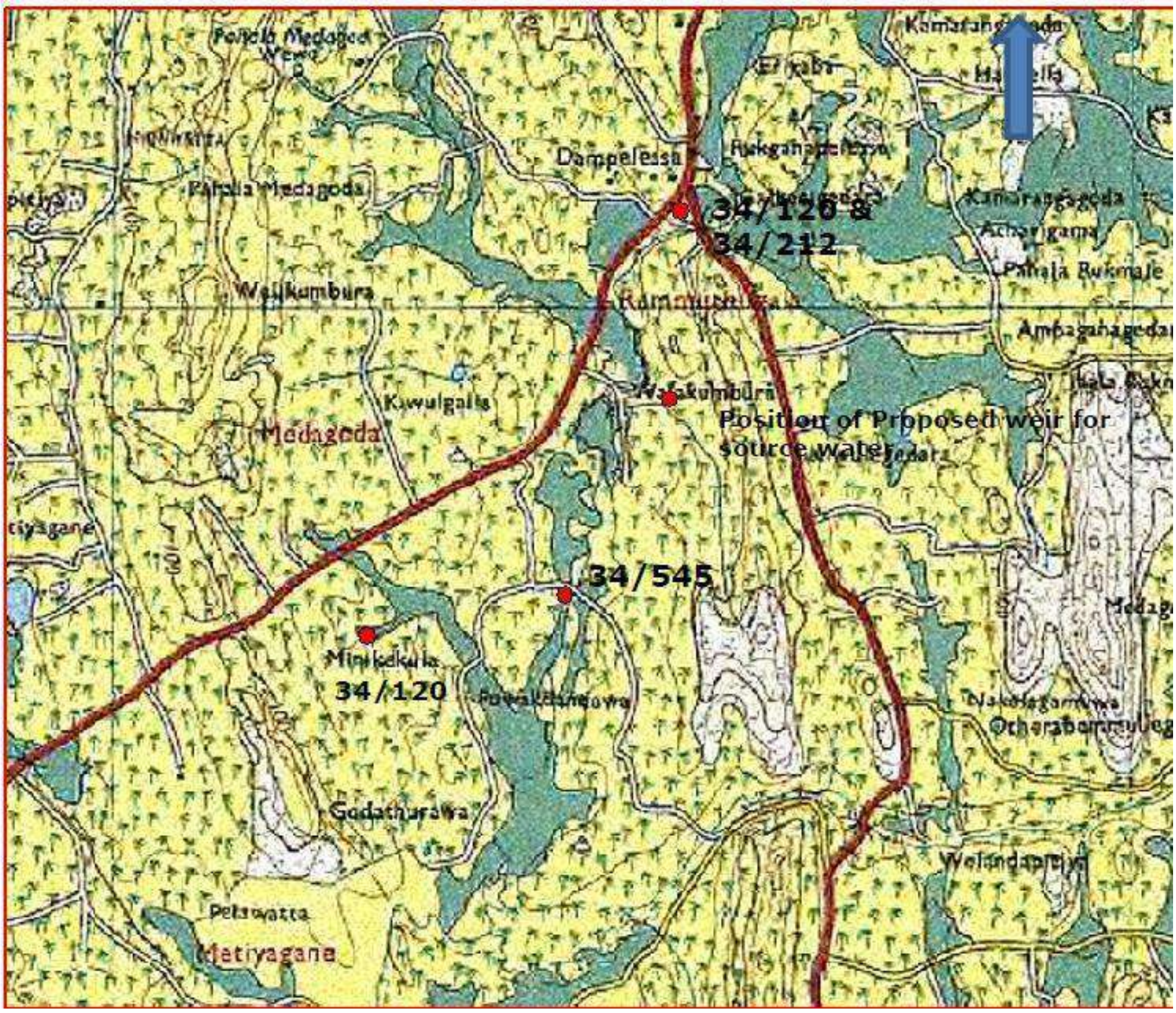


Figure 1.6: Topography of Location of Source for Obtaining Source Water

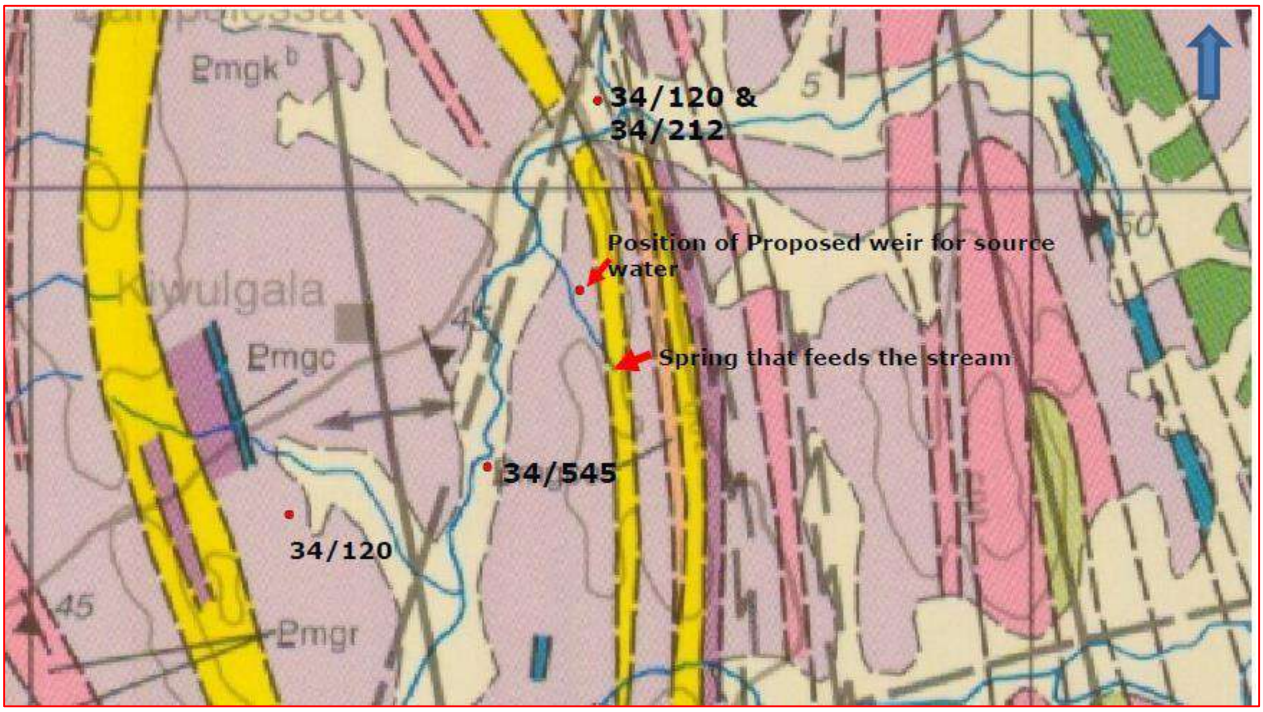


Figure 1.7: Geology of Location of Source for Obtaining Source Water

Hydrological Setting -Rainfall

The rainfall data of the Dampalassa weather station near Narammala, 2 km away from the project area is presented in the table 5.3 and its variation over the last 6 years illustrates in the Fig. 1.8. The rainfall events seem to be consistent during the South West monsoon and 2nd inter monsoon, i.e. April, May and June and also September and October respectively indicating that the aquifers gets its recharge during these months. No monitoring data is available to assess this phenomenon in order to see how deep aquifers respond to the recharge.

Table 1.3: Rainfall Data

Year	January	Februuary	March	April	May	June	July	August	Septembe	October	November	December
2016	0	4.6	128.7	247.7	632.5	95.8	29.2	16.9	0	169.4	287.3	47
2017	59.6	32.7	178	42.2	227	145	19.4	65.8	213.8	310.8	245	90
2018	0	43.7	107.9	293.2	553.8	225.7	52.8	61.6	117.1	601.1	296.7	17.9
2019	0	0	24.5	269	8.2	172.4	57.5	190	195.9	464.5	260	
2020	11.8	0	48.1	352.5	183	125.7	95.9	119.8	453.8	89.9	347.3	120
2021	129.6	0	208.9	153.8	556.7	233.3	109.3	113	184.3	442.8	657.7	38.2
2022	0.8	8.7	72.7	303.6	366.6	145.8						

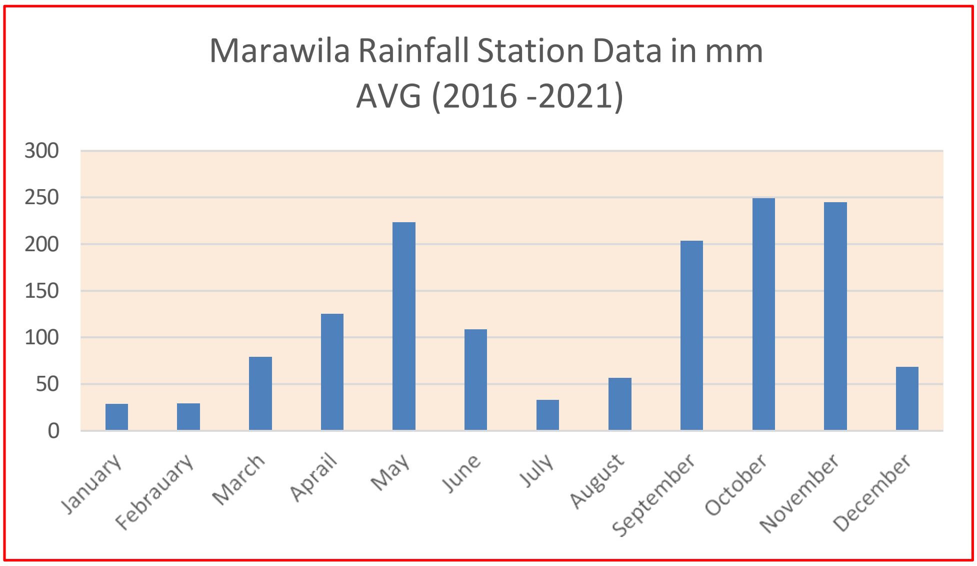


Figure: 1.8: Rainfall Variation Between 2016 - 2021

Water Quality

Table 1.5 provides the results of the water quality of the water sample collected from the source. The chemical parameters are extremely good with a little high value of the turbidity. This value will increase during the high flow of the stream in the rainfall events. The pre- treatment plan has to consider this factor when the plant is designed.

Table 1.5: Water quality of the stream water (Source Water)

	Requirements (SLS 614:2013 Part 01 Maximum)	**Results**
PHYSICAL QUALITY		
Colour (Hazen Unit)	15	8
Turbidity (N.T.U.)	2	3.1
CHEMICAL QUALITY		
PH	6.5-8.5	7
Electrical Conductivity (micros/cm)	-	74
	Results in mg/l	
Chloride (as Cl)	250	14
Total Alkalinity (as $CaCo_3$)	200	30
Total Hardness (as $CaCo_3$)	250	33
Free Ammonia (as NH_3)	0.06	<0.01
Nitrate (as NO_3)	50	0.4
Nitride (as NO_2)	3	0.04
Fluoride (as F)	1	0.09
Total Phosphate (as PO_4^{3-})	2	<0.01
Total Iron (as Fe)	0.3	0.16
Sulphate (as SO_4^{2-})	250	<1

1.5. Receiving (host) Water

Water quality of the host is not available but it is reported that the water of the well has high turbidity and with high iron concentrations.

1.6. Ownership of Source & Approvals Required

Construction of a barrage across the small stream (Maguru Oy) that flows beside the existing borehole at Welikumbura and recharging the aquifer needs to be avoided due to farmers' objections, although it is feasible and economical. Their concerns on possible inundation of their paddy fields in a little rain due to the proposed barrage across Maguru Oya have been considered, and the proposal was abandoned.

However, villages endorsed the proposal to construct a barrage upstream of Maguru Oya before Welikumbura Yaya and transport the collected water in the barrage to the borehole through a pipe. Mr. Hemachandra Athugala, a villager, agreed to construct barrages across the stream within his private lands (lands of both sides of the Maguru Oya stream at this location are owned by him). He agreed to provide access to this location of the stream through his land and bear the area of his land that goes underwater. Villagers proposed these locations for the construction of a barrage, as this will benefit both villagers and farmers, as they can share the excess water in the barrage during the dry season for paddy cultivation and other purposes.

The construction of any structure across Maguru Oya needs to be legal, and hence, the ownership of the Maguru Oya needs to be cleared, and the formal approval obtained for the construction of a barrage that is endorsed by villagers in the upstream. It is well-known that the stream is owned by the Divisional Secretary, and obtaining permission to extract water from the stream for recharging will not be an issue.

However, arrangements should be made to transfer the affected land area of Mr. Hemachandra Athugala required for the construction of the barrage, water storage and access from the public road to the barrage.

1.7. Suitable MAR Conceptual Model

The injection-type recharge is the most appropriate method for the MAR program at the Walakumbura pumping site.

1.7.1. Injection Type

The selection of this type was basically due to the subsurface geological and hydrogeological conditions of the aquifer underlain in the area concerned. As mentioned under the section of geology and hydrogeology, the subsurface lithological sequence is the regolith underlain by weathered and hard rock with isolated fracture systems below a depth of 22m. No discharge of water has been recorded up to the depth of 22mbgl where the hard rock has been encountered.

The hard rock MAR programs are not common in the world due to the uncertainty of the subsurface hydrogeological conditions, because of the difficulty of tracing of the orientations of the fracture network that belongs to the secondary porosity. It is very important to develop a proper system to cope with this difficulty as around 95 % of the country is underlain by hard rock. The Fig. 5.9 depicts a diagram giving the most likely subsurface conditions encountered in the hard rock arena in the country.

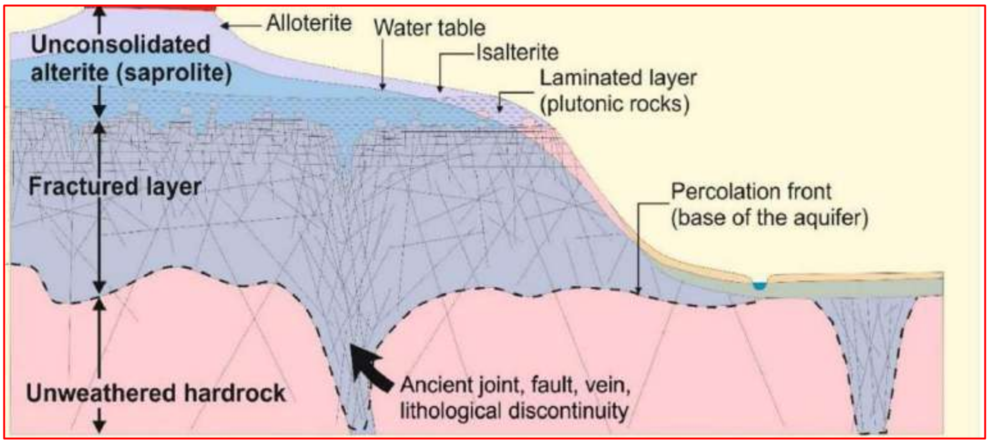


Figure 1.9: Subsurface Settings of the Hard Rock Arena

The description of the lithology with respect to the drill cuttings obtained from the well has not been logged in detail (Note: Original log prepared by the well site geologist, but the depths at which the water strikes occurred have been marked. A conceptual model of lithology is given in the Fig. 1.10, indicating the overburden followed by the weathered and fractured layers. It has shown that six fracture systems occur at discrete levels in isolation from each other and can be mentioned as confined aquifers. Static water level was at 3.8m below ground level, which terminated at the depth of 61 m below ground level.

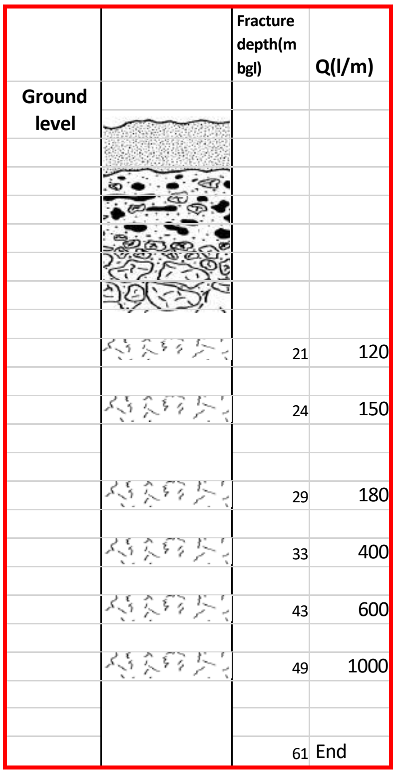


Figure 1.10: Existing Production Well

The understanding of the hydraulics of the fracture systems encountered is complex, so the whole system is taken as one unit instead of considering separate aquifers. Fig. 1.11 indicates the model for considering the characterization of the aquifer for the objective of MAR.

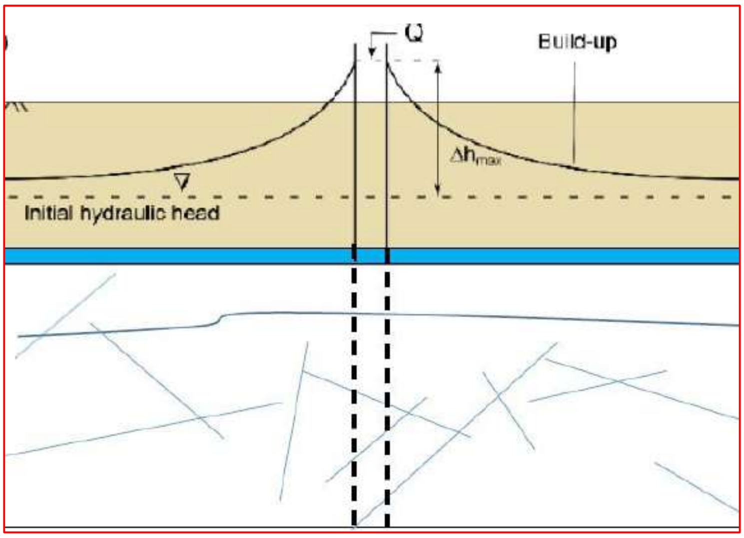


Figure 1.11: MAR Model of Injection Type

The present well can be taken as the recovery well for the MAR program. The injection well should be reasonably close to the existing production well to keep the hydraulic connections intact between the two. Injection well, Recovery well and the Monitoring wells should be placed based on the results of the geophysical survey.

1.8. Preliminary Work Plan

Before the implementation program is organized, the following activities are to be carried out to fill the information gaps in order to maintain the quality of the MAR program.

Geophysical Survey

The area is to be surveyed by running a 2D resistivity profile. Six transects are quite sufficient, each approximately 200 -300 m in a different orientation.

Aquifer Performance and Aquifer Test

The available information is not adequate to carry out a proper assessment of the aquifer to be used for the MAR program. Existing production wells should be tested whilst taking a number of existing wells as observation wells to see whether there is a hydraulic connection between shallow and deep aquifers. The lithology of the well is not comprehensive.

The Depth to the Static Water Level of the Well

Water level measurements of some deep wells and well levelling are important to identify the flow direction

Upon the finalization of the geophysical outcomes, locations should be identified in the same fracture network for an injection and monitoring well as well. A lithological profile of the site should be developed.

1.8. Details of Managed Aquifer Recharge System

The components of the proposed MAR system are as follows:

- A weir constructed at the stream (tributary of Kuda Oya), at a location about 500m from the borehole at Walakumbura. This will convey the water into the pre-treatment plant under gravity.
- A pre-treatment arrangement with roughing filter (It is to be noted that, the water sample taken at the visit of the consultant is quite clear with turbidity within limits. However, it is reported that during rainy seasons, the water gets turbid. Hence, a roughing filter is proposed)
- A ground-level storage reservoir to collect the filtered water. (The water from the pre- treatment plant will be conveyed to the reservoir under gravity.)
- Pump station and injection pumps to inject the water into the aquifer.
- One injection borehole at an appropriate distance from the extraction borehole.

- One monitoring bore hole in the aquifer area
- Rehabilitation of the Walakumbura borehole as decided through further investigations

The schematic diagram of the arrangement is presented in Fig.1.12 below.

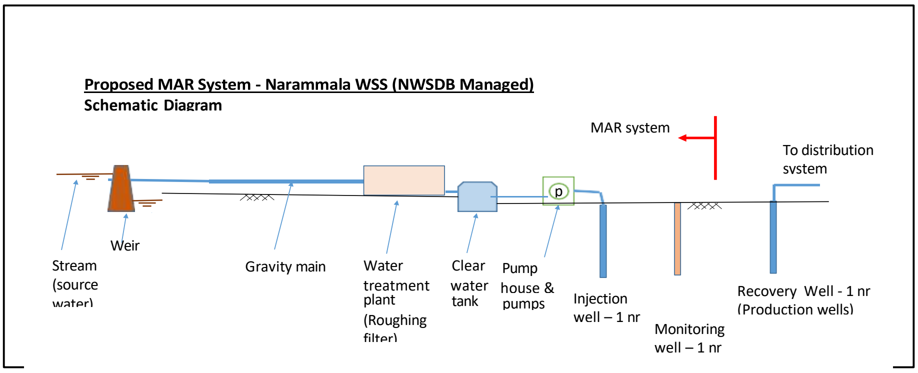


Figure 1.12: Schematic Diagram-Proposed MAR System

1.9. Proposed O&M Arrangement

Since the water supply scheme for Narammala is operated and managed by the NWSDB, the proposed MAR system also could be managed by NWSDB.

The current scheme is presently managed by an OIC stationed at Narammala, and a pump operator and a helper under him.

It was assessed that the new components in the MAR system which needs regular operations (injection pumps, valves of the pre-treatment plant) could be incorporated in the existing SCADA system.

Accordingly, the additional O&M required due to MAR system is minimum (monitoring of operations of pumps and making periodic adjustments, regular periodic cleaning of the weir intake) and could be managed by existing staff for the water supply scheme.

1.10. Environmental Considerations

Four borehole wells supply the Narammala water supply scheme. The demand is estimated at 3500 m^3/day. Current production is 2,880 m^3/day. This means there is a deficit of 620 m^3/day. Recently the well at Walakubura further deteriorated to 8m^3/hr from 14m^3/hr. The proposed plan is to improve the yield of the Walakubura well to meet the water supply demand through MAR.

The water for MAR is to be obtained from a stream flowing very next to the well. This perennial stream starts from a mountain range about 3 km away from the borehole well and flows through paddy fields. As per the information gathered from the community during the site visit, the flow is heavy during the rainy period but considerably reduced in the dry period. The community member said that they have been requesting the authorities to build a weir across the stream connecting two hills to store water for agriculture.

The rainfall in the area is seasonal. April, May, June, September, October and November are the months of high rainfall. Water could not be extracted from the stream for the MAR during the dry period to avoid a negative impact on environmental flow. As such, it is expected that the storage created by the weir to support the MAR plan. Therefore, the demand for water from agriculture and water supply should be considered together if a weir is to be constructed to avoid social and resource allocation issues. Constructing a weir and creating water storage (damming) could result in various environmental impacts, which can be addressed only after a study of the weir design.

Turbidity is a problem in groundwater extracted from the well and the stream. Despite high turbidity in both the well and stream water, there is no evidence that stream water directly connects to water extracted from the well. Turbidity will further increase in the wet season.

Therefore, pre-treatment is recommended. After pre-treatment, water can be used directly to supply rather than injected to enhance groundwater, resulting in water losses. Therefore, from an economic and environmental viewpoint, it is a resource lost.

Furthermore, the continued deterioration yield is not adequately examined as per the available details. It is common that wells lose productivity with time. In this case, it can be quicker due to turbid particles. Water from the tube well is also high in iron content. Redox status of the groundwater shall also be tested as part of the investigation. Some groundwaters eat into the steel parts (corrosion) of the well, including well-strainers, leading to well failures. The presence of iron in groundwater could be due to corrosion.
Therefore, it is recommended to rehabilitate the well and carry out investigations regarding the source of iron before trying MAR.

1.11. Social Considerations

Narammala Urban Water Supply Scheme supplies drinking water to the target GNDs within the Narammala town area. The total number of service connections (HHs) of the scheme is 4,450 and covers 36,220 of the population. There are a substantial number of applications for new connections that cannot be considered due to the lack of water in the sources. Three deep production boreholes in Dampellessa, Welikumbura and Royal Pond provide water to the WS scheme, and the production is inadequate for any expansion and proper supply to the existing consumers. Hence, improvement of the Narammala WS scheme is a felt need in order to improve the socioeconomic well-being of people.

Recharging of the aquifer with Welikumbura borehole and increasing the extractions of water will be the potential temporary solution to address the prevailing service issues. Consultants observed that there is no interaction between NWSDB and the people in Welikumbura village who have opposed the construction of boreholes within their village.

The NWSDB was not tactful to obtain community support during the construction of the borehole by offering service connections. The NWSDB policy provides for the inclusion of HHs in the vicinity of the water sources for the benefits on a priority basis, viz; (i) mitigate the protests of the people in the areas against water extraction (ii) comply with the principles of social justice and equity and (iii) create a sense of ownership among the people in the area to prevent acts of vandalism of scheme components.

According to the NWSDB data, only 25 HHs in Welikumbura GND receive water from the Narammala WS scheme so far. Since the drinking water is scarce in Welikumbura village during dry season the NWSDB should capitalize the situation by offering them service connections and arrange recharging the aquifer with the blessing of people. Extensive mobilization may be able to convince farmers in Welikumbura Yaya who will be beneficiaries of the WS scheme to recharge the borehole from the original location instead of the new barrage in the new location.

Appropriate arrangements together with the farmer's participation are needed to operate the barrage either at the new location or close to the existing production borehole during heavy rain to safeguard the paddy fields. If not, there will be a possibility for serious damage to the paddy cultivation, which is the main source of supplying staple food to the village.
Apart from the above, there are no social issues as the cost of recharging the aquifer will not reflect in the monthly tariff of the consumers, as the scheme is operated under the national Tariff system.

1.12. Project Cost Estimates

1.12.1. Capital Cost

The capital cost estimate for the MAR is presented in Annex B-2. A summary is presented below.

1	Investigation & Designs	2,000,000.00
2	Intake Weir	4,000,000.00
3	Transmission Line 1 (From Intake to Wtp)	6,000,000.00
4	Roughing Filter	27,900,000.00
5	Ground Reservoir	500,000.00
6	Pump House Including Pumps and SCADA System	9,000,000.00
7	Transmission Line 2 (From WTP to Injection Well)	500,000.00
8	Construction of Injection Well	400,000.00
9	Construction of Monitoring Well	250,000.00
10	Rehabilitation of Existing Well As Recovery Well	100,000.00
11	Power Supply	2,000,000.00

	Sub Total 1	52,650,000.00
	Add 10% Detailed Design and Construction Supervision	5,265,000.00
	Sub Total 2	57,915,000.00
	Add 30% contengies	17,374,500.00
	Total	**75,289,500.00**

1.12.2 Operation & Maintenance Cost

The O&M cost estimate is presented in Annex B-3. A summary of the same is presented below.

2	Power cost for injecting	13,780.00
3	Maintenance of transmission system & weir	9,584.00
5	Maintenance of pumps and pump house 2	7,500.00
6	Maintenance of WTP	23,667.00
7	Injection & Monitoring Wells Cleaning / Sand Column Cleaning	10,140.00
8	Cost for Water Sample Testing	4,000.00
10	Administrative Cost	1,000.00
	Total O&M Cost per Month	**69,671.00**

1.13. Observations on the MAR System in Narammala WSS

The foregoing discussions indicate that the current problem in the Narammala Water Supply Scheme is the poor quality and inadequate yield from the boreholes. The MAR is proposed as a remedy for that situation.

The source proposed for the project is from a stream, about 500m away from the well field under consideration for MAR. There is also a possibility of providing water directly from that stream after treatment, into the present storage tank, as already mentioned under the Environmental Considerations above. This also allows using the same pipeline leading from the Walakumbura borehole as a part of the transmission main to convey the water from the pre-treatment plant to the storage reservoir. This could be a cheaper option than the MAR system.