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# Geospatial Modeling for Planning of Water Conservation Structures

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## Abstract

Water is one of the imperious natural resources that sustain the ecosystem and enable human adaptation to variable climatic changes. The water scarcity in rural and urban areas has affected people as a result of deforestation, large-scale paving of surface, inadequate use, and improper storage facility. The study proposes a methodology to delineate potential zones for water conservation structures using remote sensing and GIS to store and augment the water in Kallar basin and Tamiraparani basin of Tamil Nadu, India. These structures as situated in the upstream can be the solutions providing water to the water scare district, Thoothukudi. Various thematic map layers for slope, rainfall, soil, land use / land cover, drainage network, drainage density, lineament, geology, geomorphology, and lineament density have been prepared using conventional and satellite data. By weighted overlaying these thematic layers in the GIS environment, potential structures were delimited. This study focusses to augment the water use by proposing suitable structures like check dams, percolation tanks, recharge pits, subsurface dikes, and farm ponds. The site suitability for various water conservation structures is determined using the reclassified guidelines derived from consolidated guidelines of Integrated Mission for Sustainable Development (IMSD), Indian National Committee on Hydrology (INCOH), and Food and Agricultural Organization (FAO). The accuracy check of the site suitability for all the proposed structure indicated 65-89% correctness.

## Keywords

Water Conservation Structures, Groundwater Augmentation, Kallar Basin, Tamiraparani Basin Remote Sensing, and GIS

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## 1. Introduction

Water is an imperative part of human life, but its accessibility at a suitable quality and quantity is vulnerable to many factors, of which climate plays a prominent role. Direct and indirect influence of climatic change on the hydrological cycle affects surface ground interaction, subsurface hydrology as well as the water quality. The direct consequence is the evaporation of existing surface water and evapotranspiration which impact on precipitation amount, intensity, and timings whereas indirect value affects the storage and flux in reservoirs like lakes, groundwater, soil moisture [1]. The influence of global climatic change on a freshwater source (both groundwater and surface water) is intense. Global warming also contributes to the change in evaporation and groundwater recharge. Other effect of global warming is the sea level rise which increases the severity and frequency of the flood [2]. Diversely, due to increasing solar radiation resulting no or less soil moisture content causes long and severe drought episodes [3].

The water conservation structures suitable for aquifer recharge are the proper adaptation methods countering the variability in the climate change [4]. The water stored during flood period can be used during the drought period of the year [5]. Under

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altering climatic conditions, rainwater harvesting, and artificial recharge are the reliable methods for augmenting the supply of groundwater and surface water for addressing water scarcity. Various catchment solutions such as check dams, percolation pits, recharge shafts, anicuts, nala bunds, ponds etc. to overcome imbalance between water supply and demand has been adopted by many researchers such as [6-11]. The sites for effective recharge of aquifer is the primary role in artificial recharging [4, 12]. Extensive studies have been conducted in different parts of India to delineate potential ground water recharge zones in hard rock terrains [13-17].

GIS is an effective tool to delineate potential water conservation zones and structures in areas where information is limited [18-19]. The multi-temporal, multi-sensor and multi-spectral data of the earth surface can be attained from remote sensing which are very critical for the analysis, prediction, and validation of spatial and temporal information [13, 19-22]. In recent years, remote sensing data alongwith topographical maps, collateral information and limited field checks have been used widely to establish the baseline maps for potential zones [10-11, 23-24].

Numerous methods have developed and applied to delineate potential water conservation structures [6, 21]. Earlier RS/GIS were solely used for the primary analysis of water conservation structures [14, 17, 25-28]. Advanced technology introduced integration of hydrological modeling tools like IHACRES [29], WSPM [30], WMS [31] and SWAT [32-33] including SCS-CN method along with RS/GIS to augment the precision and accuracy to delineate water conservation structures in less cost [9-10, 34-36]. Multi-Criteria Analysis (MCA) like Analytical Hierarchy Process (AHP) was incorporated along with the modeling tools to combine data for different criteria by [19, 32, 37-38] to provide a systematic technique for organizing and analysing complex data.

Factors ranging from biophysical conditions to more assimilated approach including socio-economic conditions were adopted in the studies. Slope, topography, rainfall, land use / land cover, drainage network, drainage density and soil texture encompass in bio-physical criteria [25, 27, 39]. From 21$^{st}$ century, most of the researchers integrated socio-economic parameters like distance to settlement and stream, land capability, roads, pipelines, agronomy and cost along with biophysical parameters as the main criteria to delineate suitable sites of water conservation structures [18, 24, 32, 40-41]. Environmental parameters like lineament density, aquifer thickness, geomorphology etc. are also comprised in some researches [14, 36-37, 42-44]. This research study assimilates RS and GIS to ascertain the suitable water conservation structures in Kallar and Tamiraparani basin.

In India, most of the research used one of the criteria (IMSD, FAO, INCOH) to access the suitability of water conservation structures in the selected catchments. The initial set was proposed by Integrated Mission for Sustainable Development (IMSD) [8-9, 26, 28, 36] which included only biophysical parameters similar to Indian National Community for Hydrology (INCOH) [14, 23, 34, 45]. The criteria in IMSD are more flexible even though the land-use strategies were restrictive in barren, bare soil, and scrublands [18]. Food and Agricultural Organization of United Nation (FAO) included both bio-physical and socio-economic criteria [36, 46-47] along with IMSD. Currently, these guidelines are comprehensive for a wide range to delineate potential water conservation structures and more associated with the local farmers [18]. Suitable integration of RS and GIS-based approach are practiced delineating the potential water conservation sites in various parts of India, along with IMSD and FAO guidelines. These criteria are reclassified according to the suitability for delineating accurate water conservation structures and are illustrated in Table 1.

**Table 1.** Reclassified criteria for selecting water conservation structures.

| S. No | Structure | Rainfall (mm) | Area (Ha) | Slope | Permeability | Runoff Potential | Stream Order | Soil Type | Land Use and Land Cover |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Check Dam | <1000 | 25 - 40 | <15% | Low | Medium / Low | 1-4 | Sandy clay loam | Scrub land / riverbed |
| 2. | Farm Ponds | >200 | 2 - 25 | 0-5% | Very Low | Medium / Low | 1 | Sandy clay loam | Scrub land |
| 3. | Percolation Ponds | <1000 | 40 - 50 | <10% | Medium | Medium / Low | 1-4 | Clay | Scrub land |
| 4. | Subsurface Dykes | <1000 | 50 - 60 | 0-3% | High | Low | 1-4 | - | hard rock and alluvial deposit |
| 5. | Terracing | 200-1000 | - | 20-30% | Low | High | - | Sandy clay, clay loam and sandy loam | Shrub land / bushland with trees |
| 6. | Recharge Pit | 200-1000 | <1 | 2-5% | high | - | - | No drainage alluvial soil | - |
| 7. | Anicuts | < 1000 | 50 - 60 | <10% | low | Medium / Low | 5- 6 | - | - |

## 2. Literature Review

In general, the recharge structures are located about 200-300m upstream of the affected area. They are identified on 1$^{st}$ to 3$^{rd}$ order or at the initial stage of the 4$^{th}$ order stream. Check dams are usually identified in the 1$^{st}$ and 2$^{nd}$ order stream along the foot zone of hills with a gentle slope of 0-5%. The efficacy and feasibility are high in alluvial as well as hard rock terrains. A thick permeable bed and weathered formation zones are the suitable sites to assist groundwater recharge for these structures [10]. Percolation tanks are the prevalent structure located in 1st to 3rd order stream with weathered or fractured zones along the plains and valleys to penetrate the water for abundant recharge. The proficiency / feasibility is more in hard rock formations [4]. A study conducted by [48] presented that percolation tanks can recharge the groundwater up to 70% with proper selection of site and design of tanks. Nala bunds / weirs are identified generally on 1st to 4th order streams along plains and valleys with gentler slope where a large area of land for inundation is not attained. A limited amount of water will be stored in the riverbed for recharge.

The farm ponds are generally identified to store the excess rainfall / runoff on the lower elevation of cultivated land [44, 49-50]. Dykes are mainly constructed for domestic needs. A straight and wide river with thick gravel bed is considered for delineating dikes. Recharge shafts / pits are identified in alluvial terrains along hills, plateaus, water divide areas etc. for direct recharge of the aquifer where the availability of water is perineal. By collecting excess rainfall and increasing area for infiltration, recharge pits provide a good extent of aquifer recharge in hard rock terrains. The excess runoff, groundwater reservoirs, canal water etc. are diverted to dug wells so as to increase the soil moisture content to recharge the aquifer. A detailed study has been conducted for delineating these suitable water conservation structures and the findings are depicted in Table 2.

**Table 2.** Detailed assessment of different methods adopted, and various structures proposed.

| Structure Type | Site | Method | Criteria and Guidelines | Author |
|---|---|---|---|---|
| Check Dams | Kali watershed, Mahi river basin, India. | SCS-CN and GIS | Guidelines: IMSD (NRSA) and FAO<br>Criteria: Bio-physical | [36] |
| | Mahabali basin in Chhattisgarh, India | Integrated study of RS + GIS + Runoff modelling | Guidelines: IMSD<br>Criteria: Bio-physical, Socio-economic | [10] |
| | Vaigai river upper basin, Tamil Nadu, India, | RS + GIS based WOA | Guidelines: CCWB<br>Criteria: Multi-environmental parameters | [43] |
| | Budhil river basin, Himachal Pradesh, India | RS + GIS based morphometric analysis, soil erosion and SYI | Criteria: morphometric analysis-based compound parameters (Cp), soil erosion (SE) and sediment yield index (SYI) | [51] |
| Percolation Tanks | Thane district, Deccan Volcanic Province | RS + GIS | Criteria: hydro-geomorphic | [52] |
| | Hire watershed in Koppal district of Karnataka state, India | RS + GIS + TM Model | Guidelines: IMSD and INCOH<br>Criteria: Bio-physical | [23] |
| | Upper Damodar river basin of West Bengal, India | GIS (Boolean based) + MCDA | Guidelines: FAO<br>Criteria: biophysical, socio-economic, and environmental conditions | [44] |
| Nala Bunds / Weirs | Loni watershed in Uttar Pradesh | RS + GIS (WOM) | Guidelines: IMSD, INCOH [28, 36] | [34] |
| | Karso watershed, Hazaribagh in India | RS + GIS | Guideline: IMSD<br>Criteria: Bio-physical, socio-economic | [28] |
| Farm Ponds | basaltic region for Jordan | Hydrologic modelling + GIS + RS | Criteria: Socio-economic and physical parameters<br>Factors: Soil, topographic suitability, LULC and surface runoff generating potential | [49] |
| | Tuscany-central Italy | SCS-CN + GIS | Criteria: Bio-physical | [50] |
| Recharge Pits | Mirzapur district in Uttar Pradesh, India | RS + GIS | Guideline: IMSD and INCOH | [14] |
| | Vidisha district of Madhya Pradesh, India | RS + GIS + WOA | Criteria: Hard rock terrain with hydro-geomorphic features | [17] |
| Sub-Surface Dykes | Kali sub-watershed, Gujarat, India | SCS-CN + GIS | Guidelines: IMSD (NRSA) and FAO<br>Criteria: Bio-physical | [16], [36] |
| Rooftop Structures | Ranchi, Jharkhand, India | GIS + Empirical equation | Criteria: Hard rock terrain<br>Guideline: CGWB | [11] |
| | Ranchi urban Agglomeration (RUA), India | AHP + GIS | Criteria: Hard rock terrain | [10] |

## 3. About the Study Area

Kallar river originates from Mudukkumindanpatti, Chalikulam reserved forest area, and Tamiraparani river originates from the peak of the Periya Pothigai hills on the eastern slopes of the Western Ghats at an elevation of 1725 m. Kallar basin is located between 8°42'48.883" to 9°10'10.671" N latitude and 77°47'51.732" to 78°12'40.796" E longitude and covers an area of 1509 $Km^2$. Tamiraparani basin is located between 8°28'35.247" to 9°12'8.796" N latitude and 77°8'42.35" to 78°9'34.554" E longitude and covers an area of 5717.08 $Km^2$. Both basins are completely lying within the Tirunelveli and Thoothukudi districts of Tamil Nadu state of southern India (Figure 1). The present study area falls under the Survey of India toposheets (1:50,000 scale) 58G/04, 08, 12, 16; 58H/01, 02, 05, 06, 07, 09, 10, 11, 13, 14; 58K/04; and 58L/01, 02.

Thoothukudi is a major town located in both basins. It is positioned at 8°48'5.687" N, 78°8'16.892" E about 590 Km from Chennai and 190 Km northeast from Trivandrum. According to Census of India, 2011, the population of Thoothukudi is 1,750,176 persons, and population density is 369 person / $Km^2$. The soil is loose with salt pans in the southern and thorny shrubs in the northern region of the city. A tropical climatic condition is experienced in Thoothukudi city categorized by hot summer, moderate winter, and frequent precipitation. A humid summer extends between mid-March and June with maximum and a minimum temperature of 39°C and 32°C respectively is experienced in the city. Adequate rainfall is received during the month of October and November. North-eastern monsoon is the major contributor with 444 mm followed by the summer precipitation of 117.7 mm. 74.6 mm and 63.1 mm rainfall are received in the city during winter and south western monsoon.

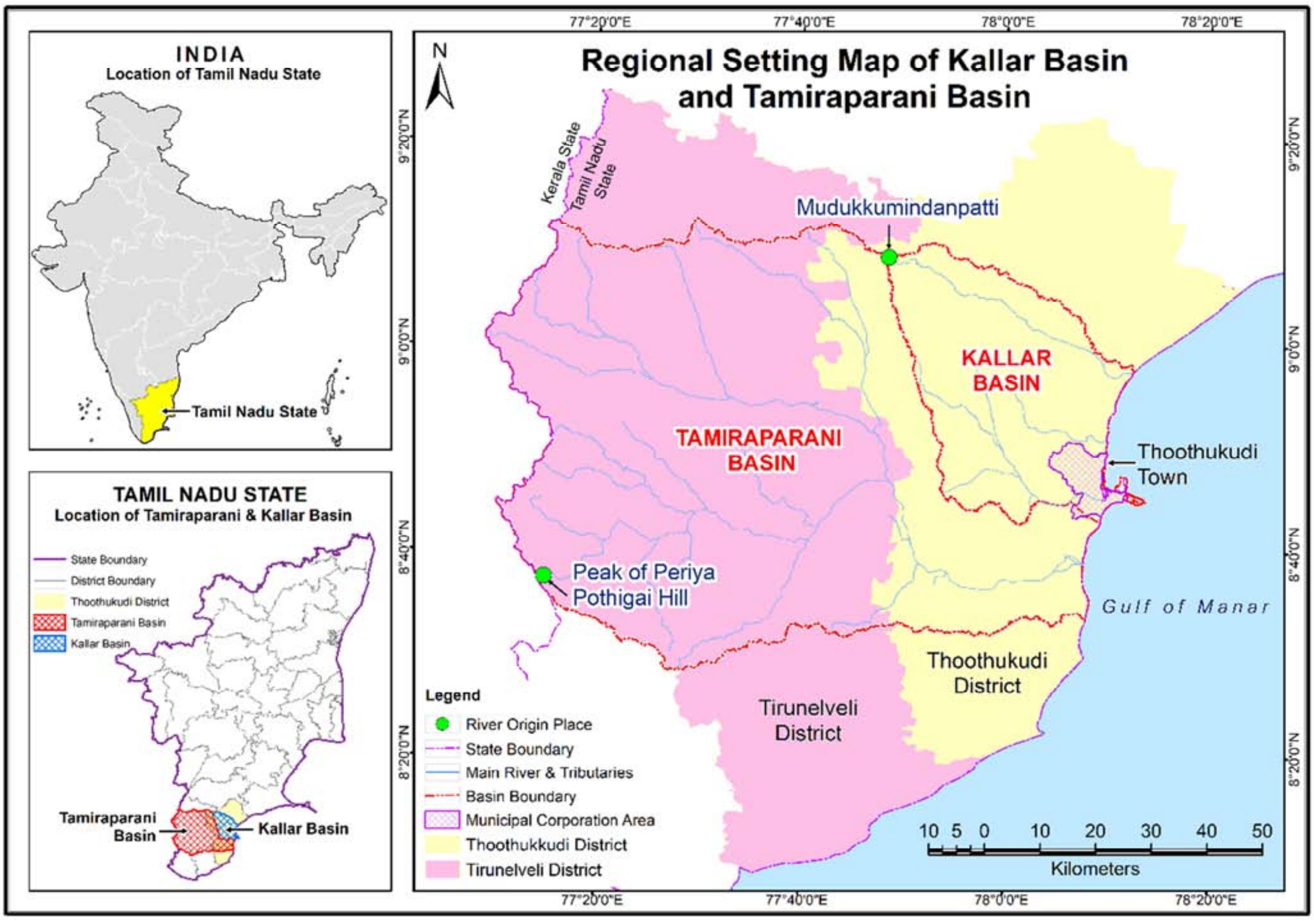


**Figure 1.** Regional setting map for Kallar and Tamiraparani basins.

## 4. Data Used and Methodology

In this study, various basic thematic layers were created from different source including map, field study, satellite imageries and secondary data - district resource maps, topographical maps etc. Using ArcGIS 10.7 software tools, several maps were prepared including slope map, drainage network map, drainage density, geological map, geomorphological map, lineament map, land use land cover map 2020, and soil map. Data used, and their sources are shown in Table 3.

**Table 3.** Data used, sources and methodology.

| S. No. | GIS Data Layer | Data Sources and Methodology |
|---|---|---|
| 1. | SoI Toposheet at 1:50,000 Scale | Survey of India Toposheets, 2005.<br>Toposheet No.: 58G/04, 08, 12, 16; 58H/01, 02, 05, 06, 07, 09, 10, 11, 13, 14; 58K/04; 58L/01, 02<br>Source: http://www.soinakshe.uk.gov.in |
| 2. | Satellite Remote Sensing Data | Landsat-8 OLI (G, R & NIR & PAN merge) data with 15 m spatial resolution, Acquisition date: April 16th, 2020.<br>Source: U. S. Geological Survey (USGS), Earth Explorer.<br>http://earthexplorer.usgs.gov |

| S. No. | GIS Data Layer | Data Sources and Methodology |
|---|---|---|
| 3. | Elevation Data | ALOS PALSAR (DEM) Data: Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) Digital Elevation Model (DEM) Data with 12.5 m spatial resolution. Source: Alaska Satellite Facility, Fairbanks. U. S. state of Alaska. 2004-2015 https://vertex.daac.asf.alaska.edu |
| 4. | Drainage Network and Drainage Density | Drainage network and drainage density has been generated in GIS environment using ALOS PALSAR (DEM) data & ArcHydro tool in ESRI ArcGIS 10.7 software. |
| 5. | Slope Map | Topography, slope, relief maps have been created using Spatial Analyst Extension in ArcGIS 10.7, and ALOS PALSAR (DEM) data with 12.5 m spatial resolution. |
| 6. | Land Use / Land Cover Data | LULC map with level-2 classification scheme has been prepared by using Landsat-8 OLI and PAN sharpened satellite imagery with 15 m spatial resolution of year 2020. These data layers are also updated with best available Google Earth satellite imagery. These data layers are also verified through limited field check. |
| 7. | Soil Map | Soil map has been collected from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), National Soil Survey, State Agricultural Department and updated through Landsat-8 satellite remote sensing data. |
| 8. | Geological Map | Geological quadrangle map has been downloaded from Geological Survey of India (GSI) website, and updated through Landsat-8 satellite imagery, and Survey of India (SoI) Toposheets at 1: 50,000 scales with limited field check. Source: GSI, http://www.portal.gsi.gov.in |
| 9. | Geomorphological Map and Lineament Mapping | Geomorphological map at 1:50,000 scale along with geological structures i.e. lineaments have been prepared using Landsat-8 OLI data, ALOS PALSAR (DEM) data, and other ancillary data i.e. topographical map, geological map. |
| 10. | Rainfall Data | Rainfall data from year 1971 to year 2019 have been collected from Indian Meteorological Department. Source: http://dsp.imdpune.gov.in |

## 4.1. Criteria for Reclassification and Delineation of Potential Water Conservation Structures

This study follows a well-defined identification process to demarcate the structures explicated below. Each thematic layer was carefully studied for defining the influence on groundwater and surface water. The range satisfying the FAO, IMSD and INCOH guidelines were deliberated from various sources. The slope and stream order criteria varied for different water conservation structures according to IMSD, INCOH and FAO guidelines were reclassified as given in Table 1. The stream orders were generated using Strahler's method aided by the spatial analyst tool in ArcGIS 10.7. As per guidelines, less than 3% slope and 1-4 order stream were considered favourable for siting subsurface dykes. Less than 5% slope and first-order stream were suitable for farm ponds. Recharge pits can be sited for slope between 2-5% and 1-2 order stream. Less than 10% slope is satisfactory for siting percolation tanks and anicuts. Similarly, less than 15% slope and 1-4 order streams are adequate for locating check dams. Areas having less than 1000 mm annual average rainfall were cited for locating the potential structures. Shrub land with sandy clay loam soil were preferred for water storage structures like check dams, farm ponds and percolation tanks.

**Table 4.** Assigning percentage influence and ranks for siting water conservation structures in Kallar basin.

| Thematic Layers | Map Weights for GW Recharge (%) | Map Weights for Surface Storage (%) | Individual Features | Ranks for GW Recharge | Ranks for Surface Storage |
|---|---|---|---|---|---|
| Slope | 5 | 15 | < 10% | 5 | 5 |
| | | | 10% - 15% | 4 | 4 |
| | | | 15% - 20% | 3 | 3 |
| | | | 20% - 25% | 2 | 2 |
| | | | 25% - 30% | 1 | 1 |
| Geology | 15 | 5 | Biotite Gneiss | 5 | 5 |
| | | | Charnokite | 3 | 3 |
| | | | Coastal Alluvium | 5 | 5 |
| | | | Fluvial Alluvium | 4 | 4 |
| | | | Sand Dunes | 1 | 1 |
| | | | Sandstone | 1 | 1 |
| Geomorphology | 5 | 5 | River/tank | 5 | 5 |
| | | | Salt Flat | 1 | 1 |
| | | | Duri Crust | 2 | 2 |
| | | | Structural Hills | 2 | 2 |
| | | | Settlements | 3 | 3 |
| | | | Buried Pediments | 2 | 2 |
| | | | Residual Hills | 1 | 1 |
| | | | Pediments- Black cotton soil | 5 | 5 |
| | | | Shallow Pediments | 4 | 4 |

| Thematic Layers | Map Weights for GW Recharge (%) | Map Weights for Surface Storage (%) | Individual Features | Ranks for GW Recharge | Ranks for Surface Storage |
|---|---|---|---|---|---|
| Lineament Density | 20 | 5 | Present | 4 | 4 |
| | | | Absent | 2 | 2 |
| Drainage Density | 15 | 20 | Very Poor | 1 | 1 |
| | | | Poor | 2 | 2 |
| | | | Moderate | 3 | 3 |
| | | | Good | 4 | 4 |
| | | | Excellent | 5 | 5 |
| Soil | 5 | 5 | Sandy Clayey Loam | 4 | 2 |
| | | | Sand | 5 | 1 |
| | | | Loamy Sand | 3 | 3 |
| | | | Clay Loam | 2 | 4 |
| | | | Clay | 1 | 5 |
| | | | Marshy | 2 | 4 |
| Land Use / Land Cover | 15 | 20 | Agricultural land | 5 | 5 |
| | | | Built-up Area | 1 | 1 |
| | | | Forest | 2 | 2 |
| | | | Wastelands | 3 | 3 |
| | | | Tank/Reservoir/Canal | 4 | 4 |
| | | | River/Pond/Lakes | 4 | 4 |
| | | | Wetland | 3 | 3 |
| Rainfall | 5 | 15 | Low | 3 | 3 |
| | | | Moderate | 4 | 4 |
| | | | Excellent | 5 | 5 |
| Projected GW | 15 | 10 | Poor | 2 | 2 |
| | | | Moderate | 3 | 3 |
| | | | Excellent | 5 | 5 |

**Table 5.** Assigning percentage influence and ranks for siting water conservation structures in Tamiraparani basin.

| Thematic Layers | Map Weights for GW Recharge (%) | Map Weights for Surface Storage (%) | Individual Features | Ranks for GW Recharge | Ranks for Surface Storage |
|---|---|---|---|---|---|
| Slope | 5 | 15 | < 10% | 5 | 5 |
| | | | 10% - 15% | 4 | 4 |
| | | | 15% - 20% | 3 | 3 |
| | | | 20% - 25% | 2 | 2 |
| | | | 25% - 30% | 1 | 1 |
| Geology | 15 | 5 | Biotite Gneiss | 5 | 5 |
| | | | Charnokite | 3 | 3 |
| | | | Coastal Alluvium | 5 | 5 |
| | | | Fluvial Alluvium | 4 | 4 |
| | | | Graphite Gneiss | 2 | 2 |
| | | | Sand Dunes | 1 | 1 |
| | | | Sandstone | 1 | 1 |
| Geomorphology | 5 | 5 | River/tank | 5 | 5 |
| | | | Sea Water Intrusion | 1 | 1 |
| | | | Coastal Plain | 2 | 2 |
| | | | Delta | 2 | 2 |
| | | | Valley Fill | 3 | 3 |
| | | | Buried Pediments | 2 | 2 |
| | | | Hills | 1 | 1 |
| | | | Flood Plains | 5 | 5 |
| | | | Shallow Pediments | 4 | 4 |
| Lineament Density | 20 | 5 | Present | 4 | 4 |
| | | | Absent | 2 | 2 |
| Drainage Density | 15 | 20 | Very Poor | 1 | 1 |
| | | | Poor | 2 | 2 |

| Thematic Layers | Map Weights for GW Recharge (%) | Map Weights for Surface Storage (%) | Individual Features | Ranks for GW Recharge | Ranks for Surface Storage |
|---|---|---|---|---|---|
| | | | Moderate | 3 | 3 |
| | | | Good | 4 | 4 |
| | | | Excellent | 5 | 5 |
| Soil | 5 | 5 | Sandy Loam | 5 | 2 |
| | | | Sandy Clayey Loam | 4 | 2 |
| | | | Sandy Clay | 3 | 3 |
| | | | Sand | 5 | 1 |
| | | | Loamy Sand | 3 | 2 |
| | | | Clay Loam | 2 | 4 |
| | | | Clay | 1 | 5 |
| | | | Marshy | 2 | 4 |
| Land Use / Land Cover | 15 | 20 | Agricultural land | 5 | 5 |
| | | | Built-up Area | 1 | 1 |
| | | | Forest | 2 | 2 |
| | | | Wastelands | 3 | 3 |
| | | | Tank/Reservoir/Canal | 4 | 4 |
| | | | River/Pond/Lakes | 4 | 4 |
| | | | Wetland | 3 | 3 |
| Rainfall | 5 | 15 | Low | 3 | 3 |
| | | | Moderate | 4 | 4 |
| | | | Excellent | 5 | 5 |
| Projected GW | 15 | 10 | Very poor | 1 | 1 |
| | | | Poor | 2 | 2 |
| | | | Moderate | 3 | 3 |
| | | | Good | 4 | 4 |
| | | | Excellent | 5 | 5 |

### 4.2. Weighted Overlay Analysis Method

In weighted overlay analysis (WOA), the various thematic layers to identify the favourable zones to delineate water conservation structure can be integrated to a single map in GIS environment using spatial analysis tool as it is an effective fool for multi-criteria decision making. These thematic layers were converted to raster format with high accuracy followed by reclassification with assigned suitable weightages as per the method followed by [17, 43, 53]. The weightages were given according to the influence of groundwater storage and movement along with experts' advice. The final integrated map was derived mathematically as the sum of the weights assigned in percentage to different layers. Higher weights were assigned to the layer with maximum influence and lower weights for low potential magnitude. Remaining feature class falls under intermediate range according to their influence. The sum of the final influencing weighted value on overlay analysis should be 100%. A ranking of 1 to 5 were assigned to induvial features in the thematic layers based on influence of each layer for groundwater potential. Rank 5 denotes excellent potential zone, 4 for very good, 3 for good, 2 for moderate and 1 for poor zone for the prospect of groundwater. The separate weight assigned for each thematic layer for ground water recharge and surface storage in Kallar and Tamiraparani basin is given in Table 4 and Table 5 respectively. The ranks assigned for each individual feature based on their influence is also depicted in the below tables.

## 5. Analysis of Bio-physical Criteria

### 5.1. Slope Analysis

The ALOS PALSAR DEM data with a high spatial resolution of 12.5 m was obtained from the Alaska Satellite Facility (ASF). PALSAR's L-band Synthetic Aperture Radar (SAR) yielded orthorectified (terrain corrected) DEM generated from 2006-2011 with single and double polarization was used in this study. The elevation is ranging from 0 to 256 m for Kallar basin, and 0 to 1868 m for Tamiraparani basin. Slope is one of the key features for the site selection and implementation of water conservation structures which affect the surface and groundwater movement [21]. The water recharge and the runoff are the factors that will be distressed by the slope as the infiltration is inversely proportional to the slope of that area. A break in slope from steep to gentle may increase the infiltration rate of groundwater [9].

The slope (%) for the study area was generated by using ALOS PALSAR DEM data and spatial analyst tool in ArcGIS 10.7 software. According to IMSD [54] guidelines, the slope map of Kallar and Tamiraparani basin were reclassified into 8 classes ranging from 0 to 30% and shown in Table 5. 0-3% slope falls under level surface having high infiltration rate. Areas having 3-5% indicate nearly level surface with small undulations which are considered good for groundwater recharge structures with small runoff. Areas having 5-10% slope were categorized in gentle slope class. 10-15% slope is classified under moderate slope whereas 15-20% slope in strongly sloping class. The area under 20-25% were categorized in moderate steep slope, 25-30% in steep slope and greater than 30% in extreme steep slope with low infiltration rate and high runoff. Kallar basin has plain with a gentle slope towards southeast and Tamiraparani basin has a gentle slope northwest to southeast up to the Bay of Bengal. The percentage of the area falling under each category is also shown in Table 6. More than 90% of the area covered less than 15% slope for Kallar and 84% area covered less than 15% for Tamiraparani basin. The DEM map and slope map of the Kallar and Tamiraparani basins are shown in Figure 2.

**Table 6.** Percentage area covering specified slope for Kallar and Tamiraparani basins.

| Percentage Slope (%) | Description | Percentage Area in Kallar (%) | Percentage Area in Tamiraparani (%) |
|---|---|---|---|
| 0-3 | Level | 28.01 | 22.09 |
| 3-5 | Nearly level | 42.09 | 34.05 |
| 5-10 | Gentle slope | 27.21 | 24.32 |
| 10-15 | Moderate slope | 02.10 | 03.80 |
| 15-20 | Strongly sloping | 00.02 | 01.67 |
| 20-25 | Moderate steep | Less than 0.01 | 01.58 |
| 25-30 | Steep | Less than 0.01 | 01.74 |
| > 30 | Very steep | Less than 0.01 | 10.70 |

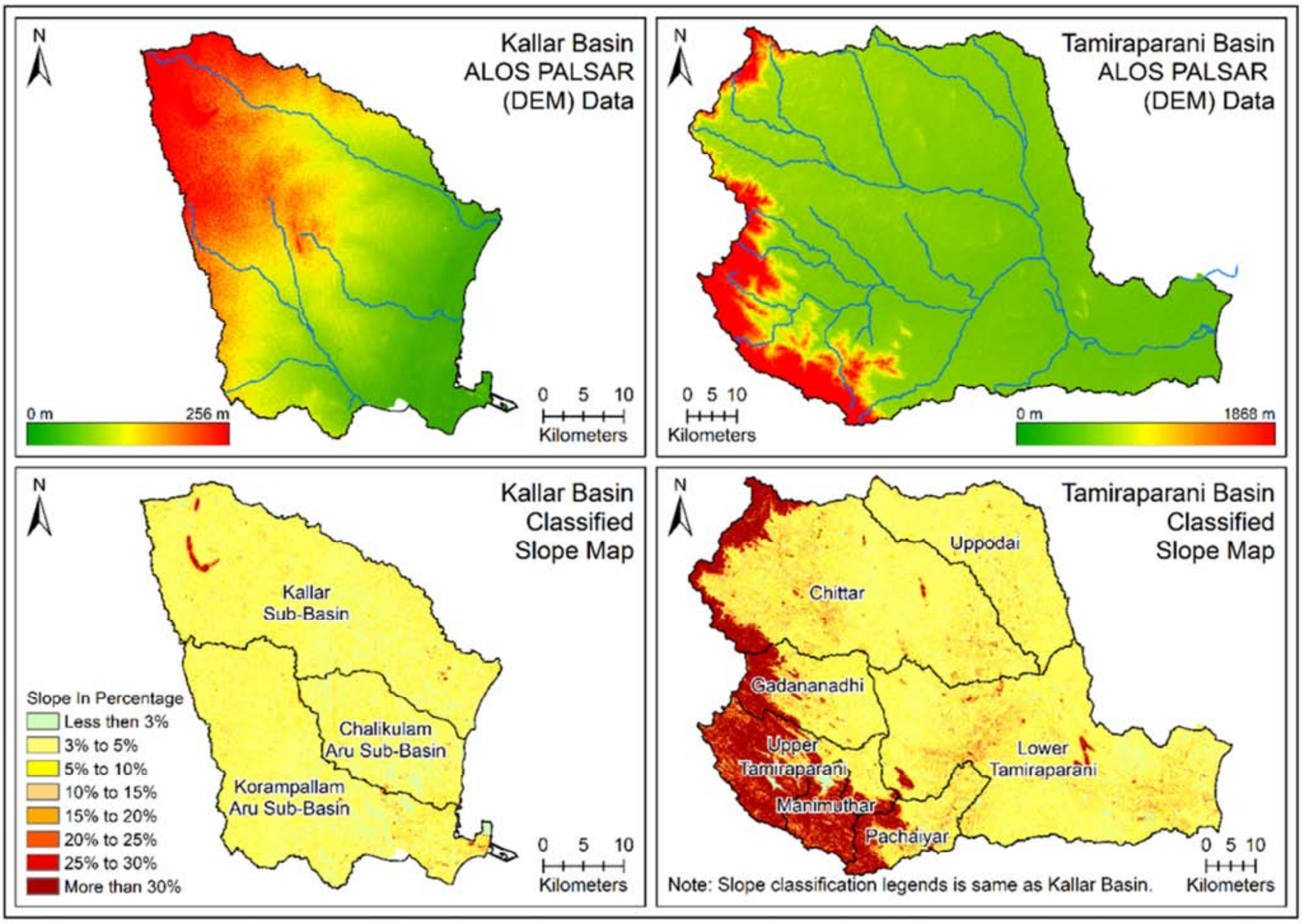


**Figure 2.** Digital Elevation Model (DEM) map and classified slope map of Kallar and Tamiraparani basins.

## 5.2. Drainage Network Analysis

The drainage network map was derived from ALOS PALSAR DEM data of resolution 12.5 m using Strahler method [55]. This method is simple for classifying the stream segment compared to other method suggested by [56-58]. The headstream with no tributaries is measured as the first order stream. Similarly, two first order converges to form a second order stream. Thus, an $n^{th}$ order stream is located downstream at the convergence of two (n-1)th order stream [55]. Thus, the probability of potential GW recharge is more near the higher order streamlines [11]. For appropriate planning of conservation measures in terms of storage and capacity, the stream order is carried out [36]. A dendritic pattern of drainage network is obtained for both the basins as shown in Figure 3. The order ranged from 1-6 with a total drainage length of 2991.81 Km for streams draining towards Kallar basin and 6061.91 Km for streams draining towards Tamiraparani river basin indicating the highest number for high flow accumulation areas and lowest number for the smallest flow accumulation areas (Table 7). More than 50% of the streams are of 1st order contributing for both the basins.

**Table 7.** Length of streams covering Kallar and Tamiraparani basins.

| Stream Order | Length of stream in Kallar Basin (Km) | Percentage length of stream in Kallar Basin (%) | Length of stream in Tamiraparani Basin (Km) | Percentage length of stream in Tamiraparani Basin (%) |
|---|---|---|---|---|
| 6 | 45.48 | 1.50 | 88.50 | 1.46 |
| 5 | 72.70 | 2.40 | 129.12 | 2.10 |
| 4 | 189.98 | 6.30 | 380.08 | 6.27 |
| 3 | 380.56 | 12.72 | 743.19 | 12.25 |
| 2 | 736.88 | 24.62 | 1664.00 | 27.45 |
| 1 | 1566.21 | 52.29 | 3057.02 | 50.43 |
| Sum | 2991.81 | 100.00 | 6061.91 | 100.00 |

Drainage density is the stream length per unit area in region of watershed [55-56, 59] is another element of drainage analysis. Drainage density is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology and structures and relief history of the region can finally use as an indirect indicator to explain, those variables as well as the morphogenesis of landform.

The drainage efficiency is depicted through drainage density range of the watershed. The drainage density depends on the stream length and the catchment area it serves which is an expression of the closeness of the channel spacing. The impact of drainage density was studied by [60] and found that the drainage density can be used to govern the time of travel of water within the watershed. Generally, the low drainage density value is more likely to occur in low relief areas with high permeability and dense vegetation cover. Similarly, high values are developed in high relief areas with low permeability and sparse vegetation [22, 61].

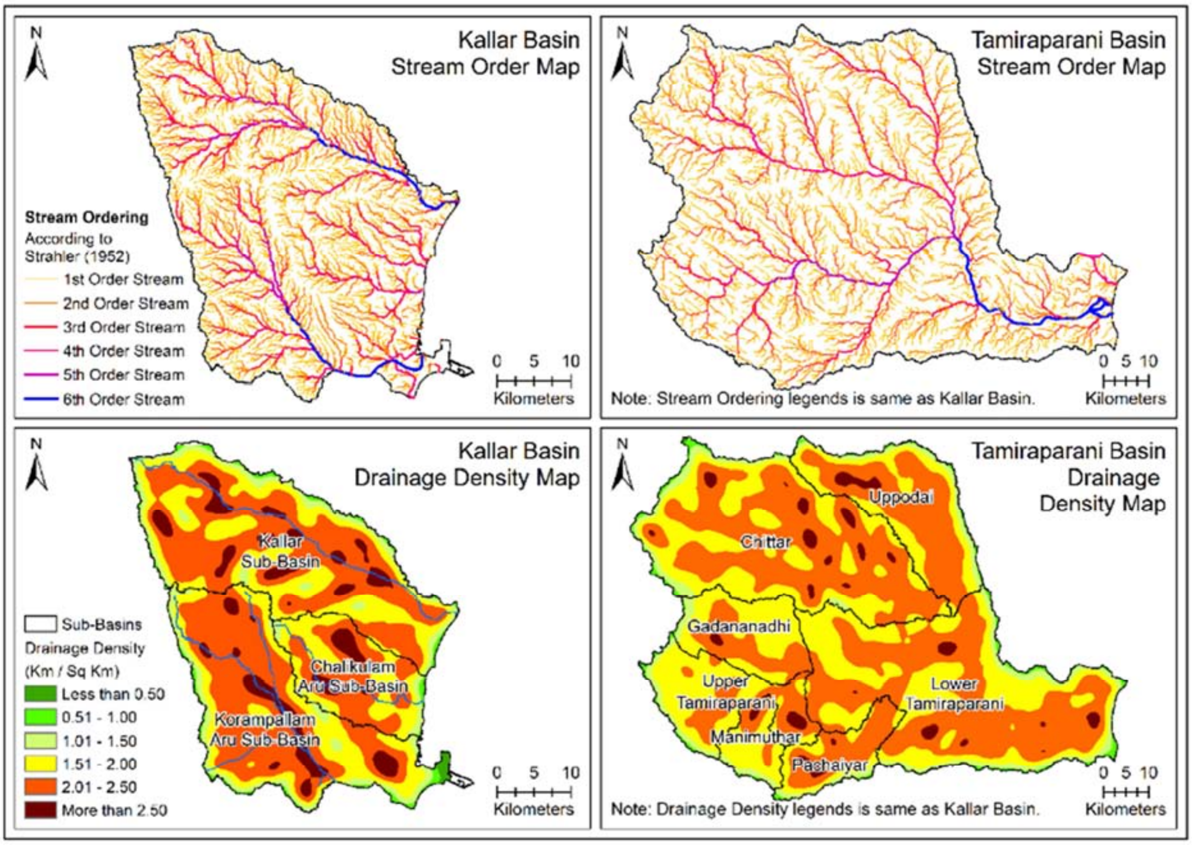


**Figure 3.** Stream order map and drainage density map of Kallar and Tamiraparani basins.

The drainage density directly indicates the potential zones for recharge due to its relationship with water excess and permeability [22]. The drainage systems for both Kallar and Tamiraparani river basins have six order streams, flowing in different directions which interacts with various landscapes. The highest drainage density for Kallar and Tamiraparani are 3.02 and 2.76 Km / Km$^2$ respectively (Figure 3). The range of density value indicates different permeability conditions of the study area. The higher value indicates high infiltration capacity areas whereas small value indicates a poor rate of infiltration [43]. The drainage density map is suitable for locating water conservation structures such as check dams and percolation pits with a 100 m buffer zone.

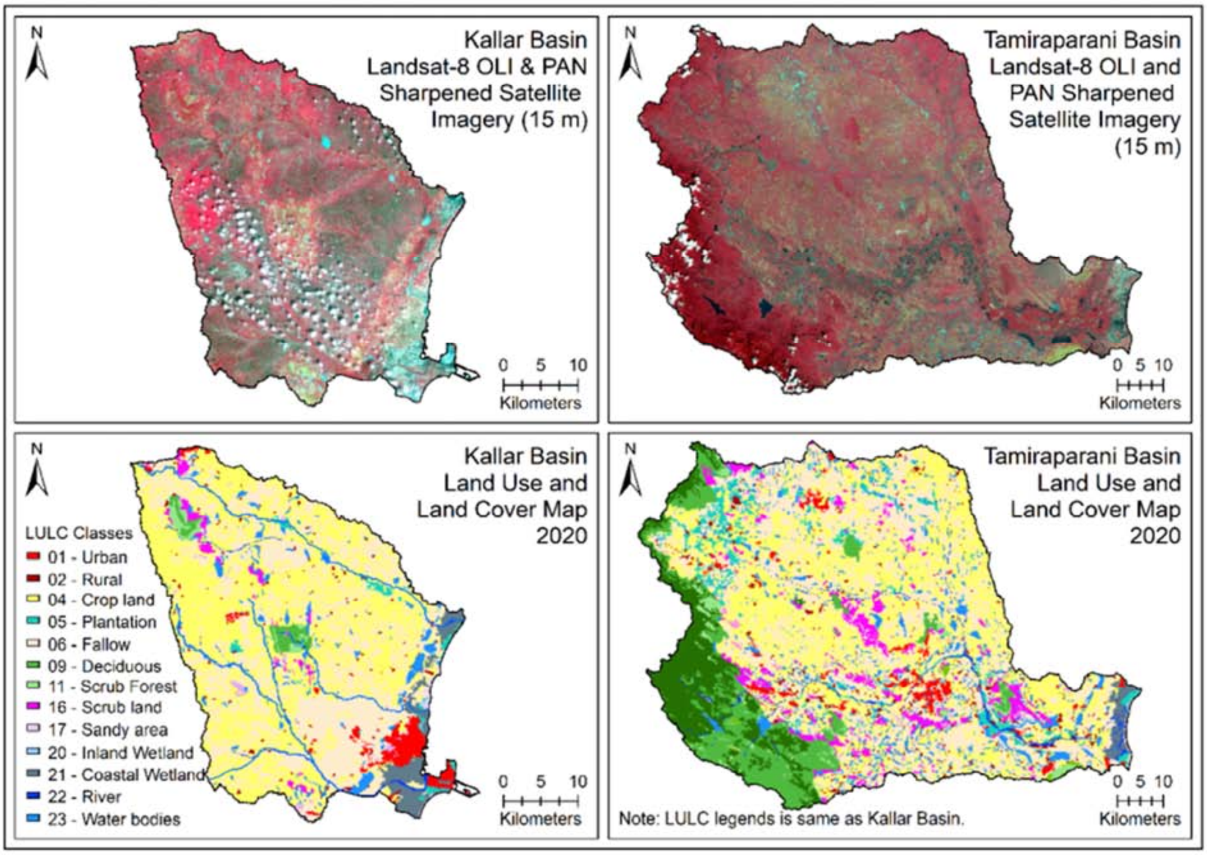


**Figure 4.** Landsat-8 satellite imagery and LULC maps of Kallar and Tamiraparani basins.

## 5.3. Land Use Land Cover Analysis

LULC map gives the direct information about the groundwater potential especially in hard rock terrains. It is the component that controls the excess rainfall and evapotranspiration [16]. Land use land cover map with level-2 classification scheme of the Kallar and Tamiraparani basins have prepared by using Landsat-8 OLI & PAN sharpened satellite imagery with 15 m spatial resolution of year 2020. These data layers are also updated with best available Google Earth satellite imagery. These data layers are also verified through limited field check. Main LULC classes namely barren land with outcrops, barren land, dry cropland, fallow / shrubs, land with cotton soil, salt pan, sand dunes, urban and rural settlement, waste land, hills, and wet crop area were identified in the study area. Landsat-8 satellite imagery and LULC maps of Kallar and Tamiraparani basins are shown in Figure 4.

## 5.4. Soil Texture Analysis

Soil map has been downloaded from National Atlas of India, National Soil Survey, and National Atlas and Thematic Mapping Organization (NATMO), 1981. The soil map has been geometrically registered to the base data to match Landsat-8 OLI satellite imageries. The geo-referenced soil maps have been used to assist in visual classification of satellite imagery for obtaining soil categories. The Survey of India (SoI) toposheets (1:50,000), Landsat-8 OLI & PAN satellite imageries (15 m), and ALOS PALSAR DEM data (12.5 m) have been used for updating the soil categories. The final vector data layers have been stored in a geodatabase. The soil categories have been classified according to Indian Council of Agricultural Research (ICAR) soil group. The soil texture class of the study area is shown in Figure 5.

Soil is one of the factors that has direct impact on the location of water conservation sites. The soil permeability and texture play a critical role for the storage of surface water and deep penetration to augment groundwater. Most part of the river basin is covered by moderately deep, somewhat excessively drained sandy-loam and sandy-clay-loam soil. Deep, imperfectly drained clayey loam soil are found near the riverbeds. Deep, moderately drained clay soil near Korampallam Aru sub-basin. Most part of Kallar basin is covered by sandy clay loam soil. In Tamiraparani basin, most widely seen soil are sandy loam, sandy clay loam and clayey soil as seen in Figure 5.

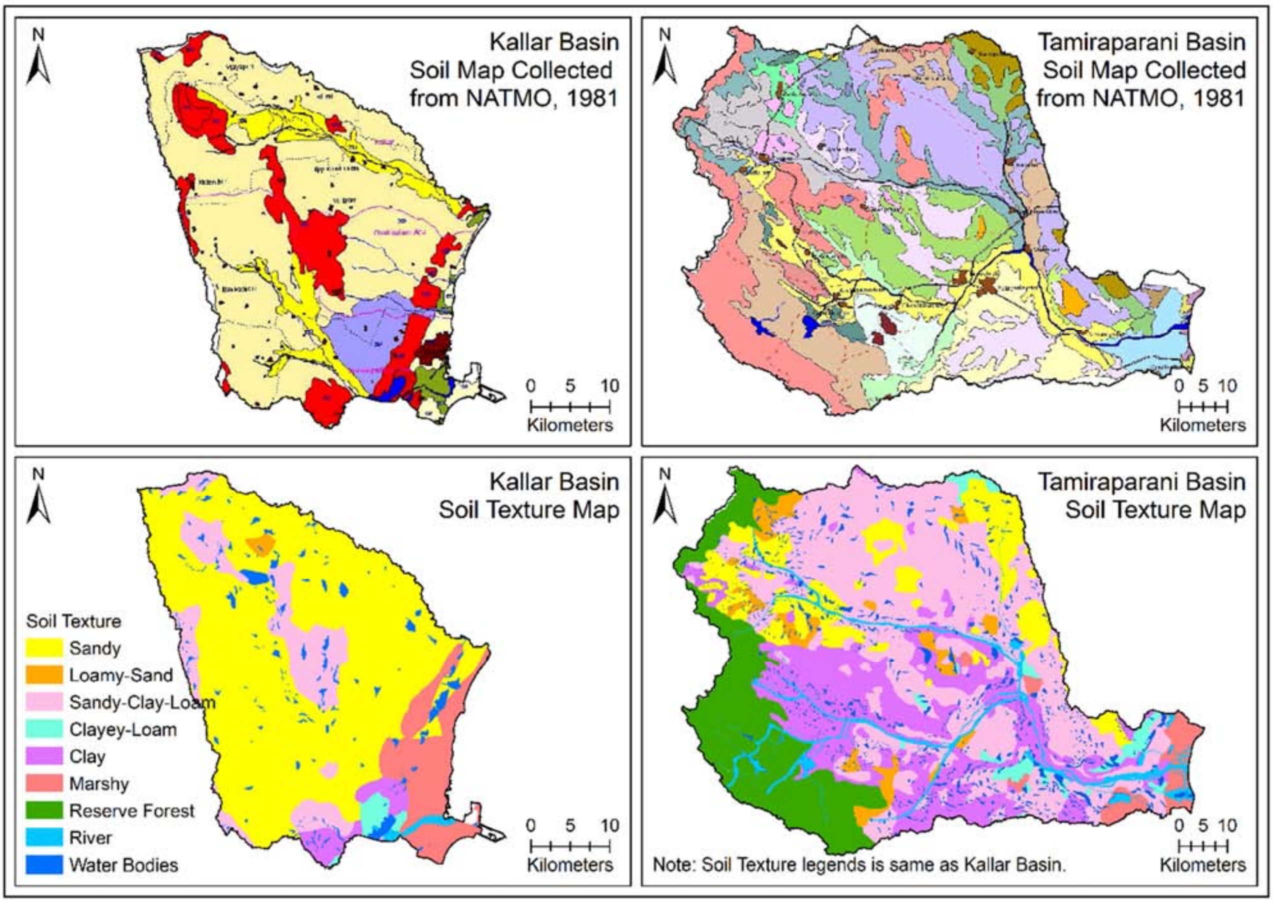


**Figure 5.** Soil texture map of Kallar and Tamiraparani basins.

## 5.5. Geology of the Area

Published geological maps from Geological Survey of India (GSI) (http://www.portal.gsi.gov.in) have been used for the preparation of a geological map of study area. This geological map has been updating through the satellite remote sensing data i.e. Landsat-8 OLI and PAN sharpened satellite imagery (15 m spatial resolution) and ALOS PALSAR DEM data (12.5 m) by using ArcGIS-10.7 software along with limited field check. Other ancillary data like Survey of India (SoI) topographical map at 1:50,000 scales has also used (Figure 6).

Kallar and Tamiraparani basins lay down several geological settings such as Biotite Gneiss, Coastal Alluvium, Charnokite, Limestone, Granite, Graphite Gneiss, Sand Dune etc. Major part of Kallar basin area is traversed by Garetiferous Biotite Gneiss. Besides, Charnokite occupies in small pockets around Ottapidaram. A linear band of quartzite and granite along NS direction and limestone along east and northern part are identified in the Kallar basin area. In Tamiraparani, the Archaean Formation comprises 90% of its areal distribution of rock types including Calc. Gneiss, Limestone, Garetiferous Biotite Gneiss and Charnokite as depicted in Figure 6.

## 5.6. Geomorphology of the Area

Geomorphological map at 1:50,000 scale along with geological structures i.e. lineaments have been prepared using Landsat-8 OLI data, ALOS PALSAR (DEM) data, and other ancillary data i.e. topographical map, geological map with limited field check (Figure 6).

Geomorphology is the scientific study of the nature of landforms on earth surface for the evaluation of water on both surface and ground. The various geomorphic features observed in Kallar and Tamiraparani basins are pediments, shallow pediments, buried pediments, flood plains, forest covered pediments etc. In Kallar basin three landforms such as denudational, fluvial and coastal landforms are identified based on genesis and morphological characteristics. The denudational landform includes residual hills, structural hills, pediments, buried pediments, shallow pediments etc. are mainly covered in Kallar basin. The fluvial landform consists of flood plain and duricrust which is spread limited. The eastern part covers coastal landforms such as salt pans, coastal ridges, sand dunes etc. Tamiraparani basin area is covered by structural hills in the west, pediplain in the middle and coastal plain in the east which is depicted in Figure 6.

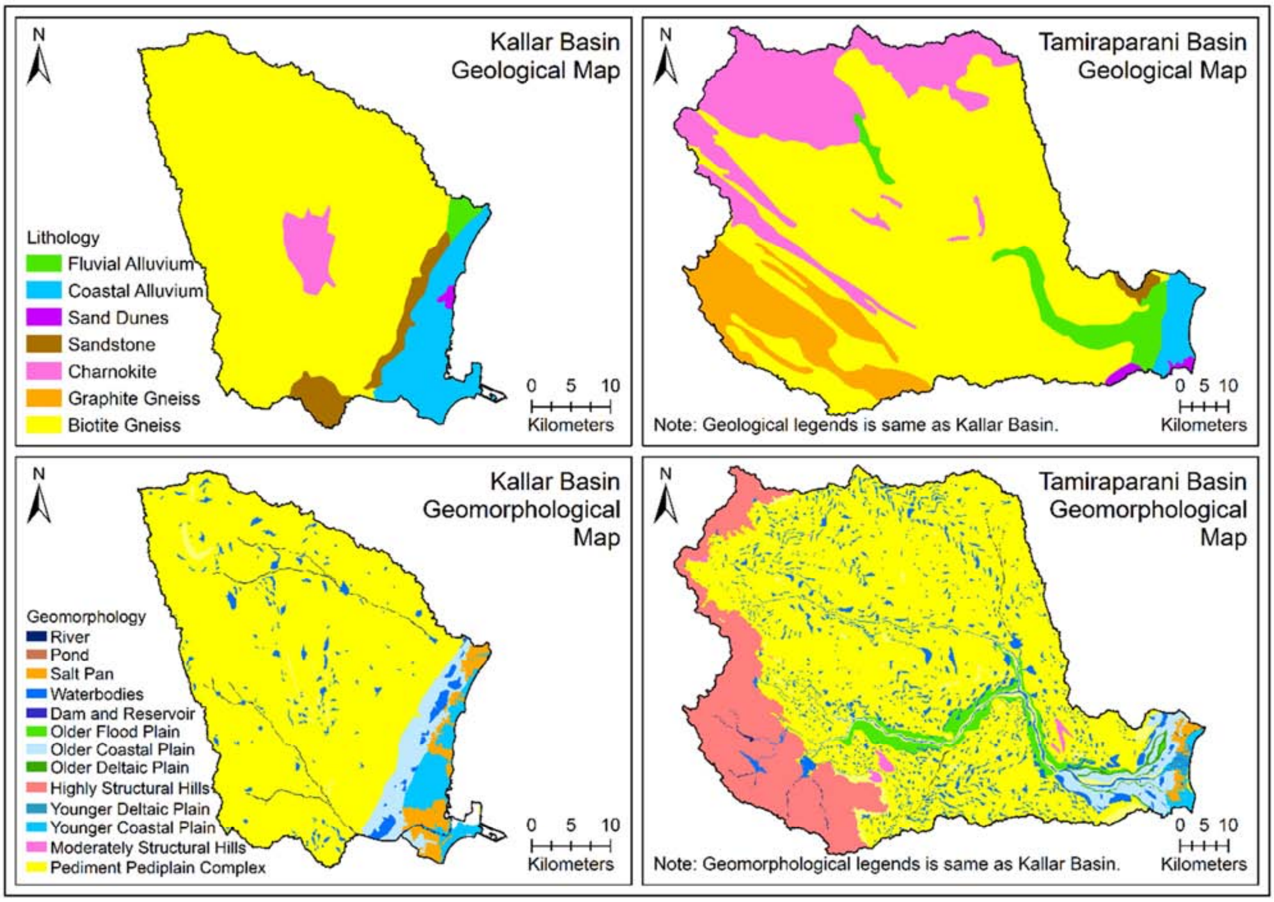


**Figure 6.** Geological map and geomorphological map of Kallar and Tamiraparani basins.

## 5.7. Lineament Analysis

Lineaments are defined as linear features of geological significance extending in length over several Km. These linear features usually represent faults, fractures or shear zones and are identified on satellite images on the basis of tonal contrast, stream / river alignment, and differences in vegetation and knick-points in topography. As the ground water potential is more near lineament zone, faults play a fundamental role in ground water recharge. These faults act as a conduit for deep water percolation. Lineaments particularly joints / fractures and their intersection appear to be potential sites for groundwater exploitation [62]. A well-defined intersection can hold substantial amount of groundwater [4].

The lineament map of the Kallar and Tamiraparani basins have been generated by digital image processing as well as visual interpretation of Landsat-8 OLI satellite imagery (Figure 7). In Kallar basin, the lineament characteristics were mainly found in ENE- WSW, NNW- SSW and WNW- ESE direction and very few in N-S, E-W and NNE-SSW direction. In Tamiraparani, WNW- ESE and NNE- SSW direction faults are generally identified. The lineaments of the Kallar and Tamiraparani basins and ArcGIS 10.7 Spatial Analyst Tools were used for generation of lineament density maps (Figure 7). The higher value indicates higher groundwater recharge and more prospect for groundwater [63]. These maps were again reclassified into two groups present and absent of lineament zone for weighted overlay analysis based on the number of lineaments per $Km^2$.

## 5.8. Annual Average Rainfall

The availability of surface and ground water is directly influenced by the variation in rainfall intensity in the study area and it controls the hydrological processes like stream flow, overland flow, runoff, infiltration rate [43]. For any water resource planning, evaluation, development, and management rainfall over a basin is a pre-requisite. Kallar and Tamiraparani river basin lies within the tropical monsoon zone and based on the hydro-meteorological features the basin is categorized into monsoon period (June-December) and non-monsoon period (January-May). The monsoon period is sub-divided into south-west monsoon (June-September) and North-east monsoon (October-December). Heavy rainfall is attained in the monsoon period which is expected to improve the groundwater recharge and surface water storage. The annual average rainfall data of 48 years from 1971 to 2019 was considered for plotting the map. For Kallar basin, the average annual rainfall ranges from 509.8 - 760.4 mm and for Tamiraparani basin ranges from 385.1 - 1542.4 mm and shown in Figure 8. These values indicate that the Kallar basin is suitable to locate all possible water conservation structures as they lie within the range of annual rainfall in Table 1.

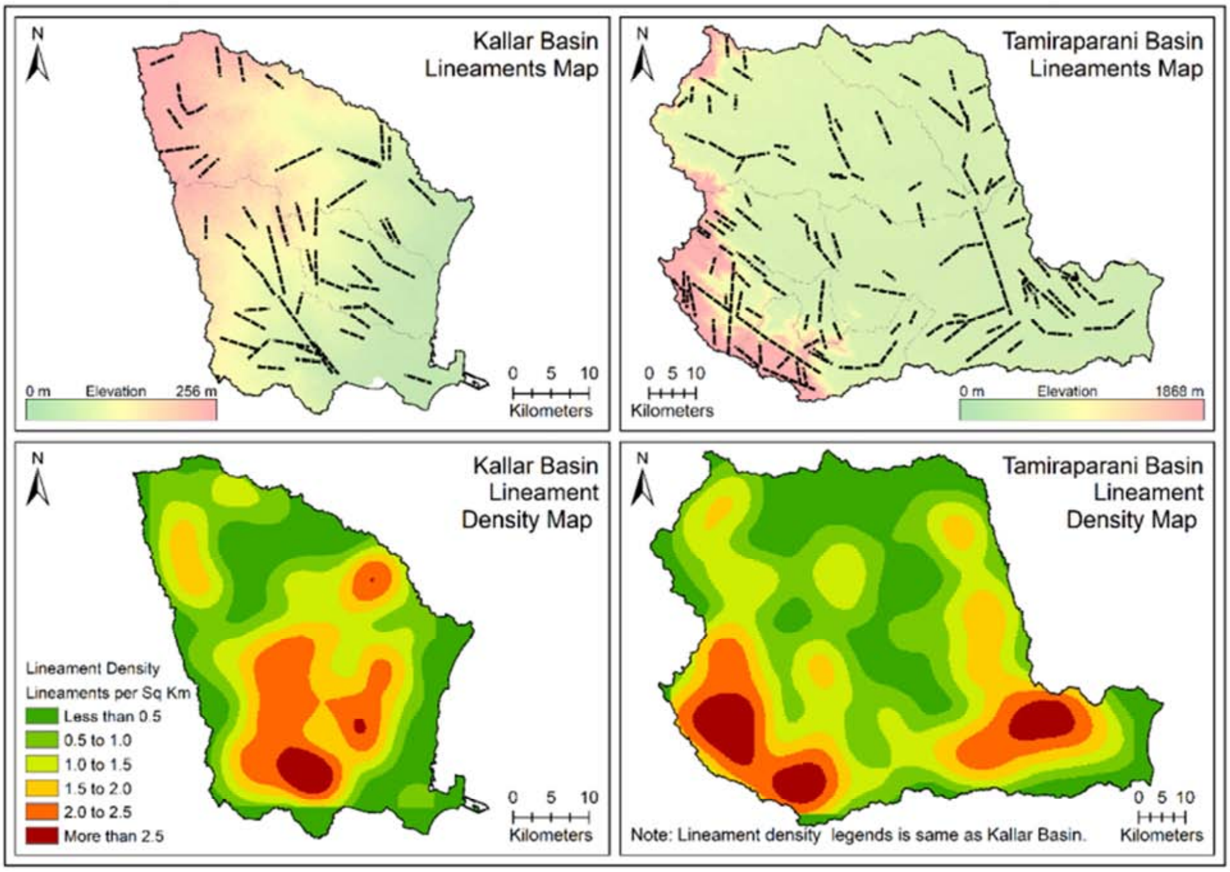


**Figure 7.** Lineament map and lineament density map of Kallar and Tamiraparani basins.

### 5.9. Projected Available Ground Water Resource

The projected available water resource map was generated for the year 1987 - 2017 for Kallar and Tamiraparani basins as shown in Figure 8. Based on the distributed rainfall and ground water assessment for the year of 2009, 2011 and 2013 as these years occurred significant amount of precipitation. An average of 30-year data was identified to find the potential zones for ground water recharge in each sub-basin.

## 6. Result and Discussion

### 6.1. Delineation of Potential Zones

The groundwater recharge potential and the surface storage potential maps were derived from the weighted multiple factors using multi-criteria decision tool in GIS. For groundwater potential zone, the output map generated were classified into five zones such as excellent (2.3%), good (50.49%), moderate (30.0%), poor (14.61%) and very poor (<1%) zone for Tamiraparani basin and excellent (<1%), good (57.25%), moderate (44.65%) and poor (3.4%) for Kallar basin and shown in Figure 9.

For surface storage, the map was classified into five namely excellent (8.6%), good (63.45%), moderate (13.68%), poor (13.79%) and very poor (<1%) zones for Tamiraparani basin and excellent (<1%), good (84.11%), moderate (14.8%) and poor (1%) for Kallar basin as illustrated in Figure 9. The area comprising each category are represented above. The crucial part is to target the excellent and good zones to delineate the potential structures.

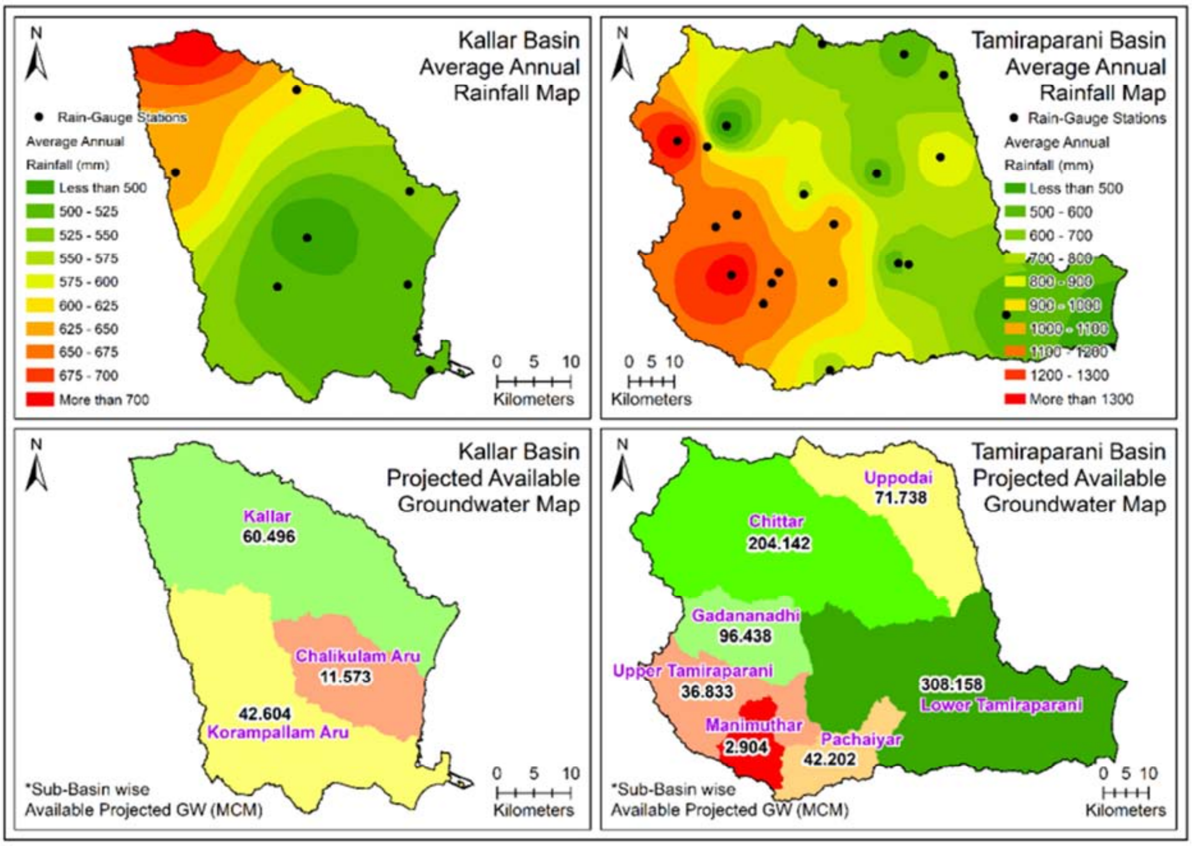


**Figure 8.** Average annual rainfall map and projected available groundwater map of Kallar and Tamiraparani basins.

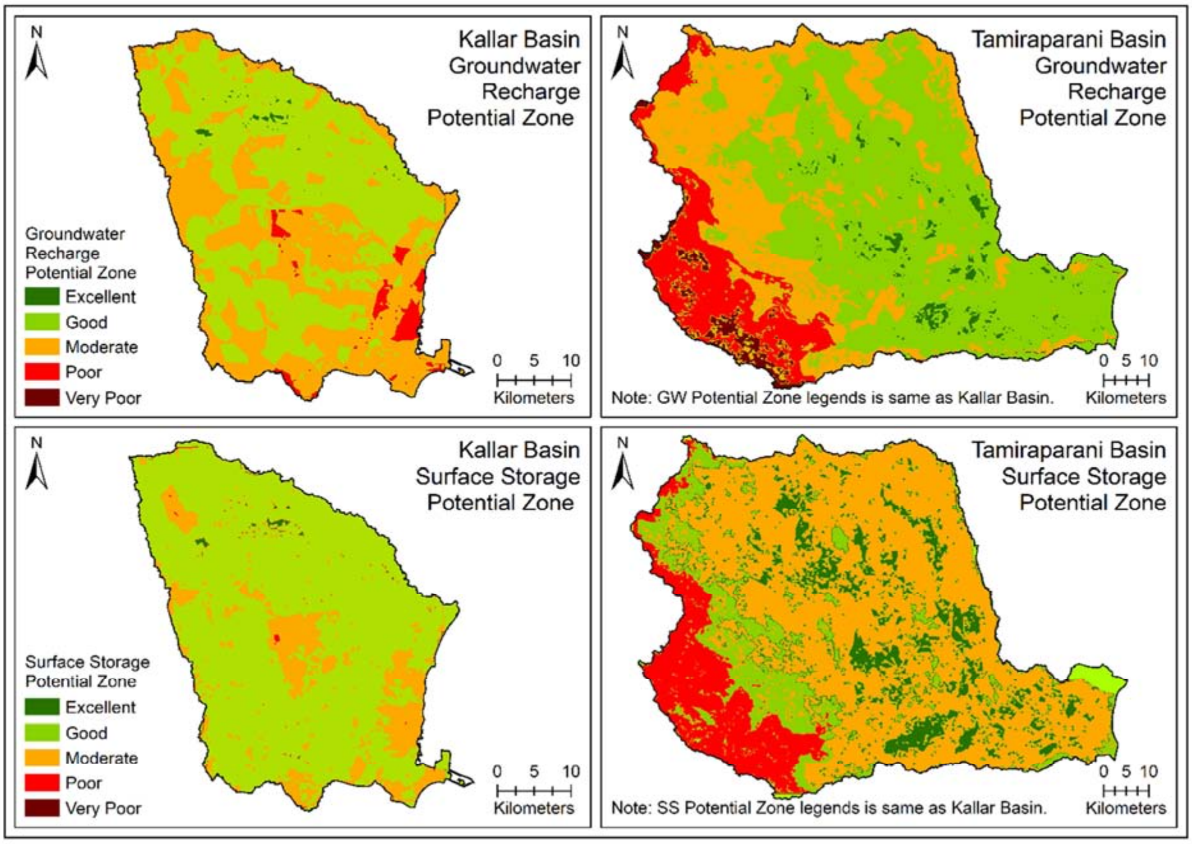


**Figure 9.** Groundwater recharge potential zone and surface storage potential zone of Kallar and Tamiraparani basins.

## 6.2. Delineation of Potential Structures

In the final stage, by careful examination of the community settlement with a buffer zone of 1 Km radius, the water conservation structures are delineated by visual interpretation in Google Earth-Pro. The Kallar basin is divided into 3 major sub-basins including Kallar, Korampallam Aru and Chalikulam Aru. In Kallar basin, an aggregate of 9 check dams, 11 percolation tanks, 13 recharge pits, 9 sub-surface dykes, 10 farm ponds, and 5 anicuts was proposed.

The Kallar sub-basin having an area of 650 $Km^2$ comprise of 5 check dams, 6 percolation ponds, 8 recharge pits, 4 sub-surface dykes, 6 farm ponds and 2 anicuts in the final stage. Korampallam Aru of total area 538.54 $Km^2$ includes 4 check dams, 2 percolation tanks, 4 recharge pits, 4 sub-surface dykes, 3 farm ponds, and 2 anicuts. Chalikulam Aru having an area of 220.03 $Km^2$ has 3 percolation ponds, a recharge pit, sub-surface dykes, farm pond, and an anicut.

Similarly, Tamiraparani basin is subdivided into 7 major sub-basins containing Uppodai, Chittar, Gadananadhi, Upper Tamiraparani, Pachaiyar, Manimuthar, and Lower Tamiraparani. 19 check dams, 15 percolation tanks, 10 recharge pits, 13 sub-surface dykes, 9 farm ponds, 5 anicuts, and 6 contour farming were finally proposed.

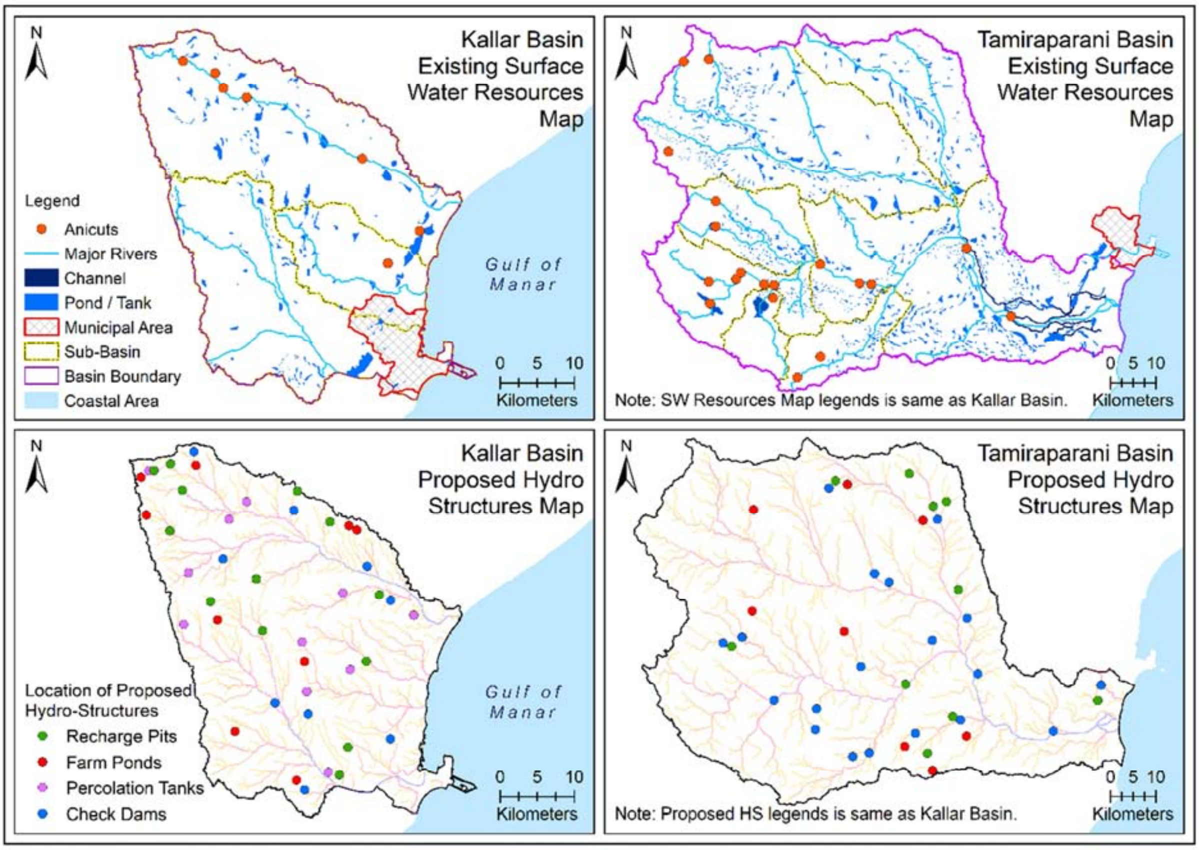


**Figure 10.** Proposed hydro-structures map of Kallar and Tamiraparani basins.

The sub-basin Uppodai with area 716.78 $Km^2$ includes 2 check dams, 5 recharge pits, a sub-surface, and 2 farm ponds. Chittar with 1660.59 $Km^2$ includes 2 check dams, 7 percolation ponds, 5 sub-surface dykes, a farm pond, 2 anicuts, and 2 contour farming. The Gadananadhi sub-basin of 437.94 $Km^2$ comprise of 2 check dams, a recharge pits, sub-surface dykes, farm ponds, and a contour farming. Upper Tamiraparani sub-basin with 520 $Km^2$ have a check dam, percolation pond, sub-surface dyke, anicut, and a contour farm bund. Pachaiyar with 298.7 $Km^2$ has 2 check dams, a percolation tank, and a contour terracing. A small sub-basin Manimuthar with 189.12 $Km^2$ includes a check dam, a percolation tank, and a contour farm pond. 9 proposed check dams, 6 percolation tanks, 4 recharge pits, 5 sub-surface dykes, 5 farm ponds, and 2 anicuts are comprised in Lower Tamiraparani sub-basin. All structures for Kallar and Tamiraparani basin are presented in Figure 10.

## 6.3. Accuracy of Site Suitability

The accuracy of the suitable sites for all the proposed structure in Kallar and Tamiraparani basin showed 65-88.8% correctness. This fairly accurate result gives a good guidance for the selection of suitable site. For example:

Total number of proposed percolation tank site in Tamiraparani basin = 15

No of tanks coinciding with the existing tank site = 12

Accuracy of site selection = [12 / 15] * 100 = 80%

# 7. Conclusion

In Thoothukudi district, flood and drought-like situation prevails due to climatic changes in return affects the annual rainfall, runoff, and recharge potential. This problem can be overcome by proposing surface water storage and groundwater recharge structures to augment the water resource. In this study, a new set of consolidated and comprehensive criteria from IMSD, FAO, and INCOH were evolved to delineate water conservation structures. Various thematic layers including slope, drainage network, drainage density, geology, geomorphology, lineament, lineament density, projected GW resources and soil texture map have been generated and weighted overlaid for delineating potential site and structures zones.

In Kallar basin, 58 structures were proposed including 9 check dams, 11 percolation tanks, 13 recharge pits, 9 sub-surface dykes, 10 farm ponds, and 5 anicuts. Similarly, in Tamiraparani basin, a total of 77 structures were planned, counting 19 check dams, 12 percolation tanks, 10 recharge pits, 13 sub-surface dykes, 9 farm ponds, 5 anicuts, and 6 contour farming bund. The accuracy check of the site suitability for all the proposed structure showed 65-89% correctness.

This study best exemplifies the assimilation of RS and GIS with the aid of GoogleEarth through visual interpretation in water resource development by the suitable proposal of water conservation structures. The future study comprises of water balance modelling (WBM) of these water conservation structures using MIKE Hydro-Basin software.

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