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Hydro-geomorphic Approach for Delineation of Site-Specific Rainwater Harvesting Structures in Chennai Basin, Tamilnadu

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Abstract

Regions with immense variation in the rainfall and unforeseeable droughts or floods often affect people with severe water scarcity and insecure livelihoods. Many parts of India are affected by acute water shortage mainly due to the lack of sufficient mechanisms to harvest the rainwater that flows away as runoff. Rainwater harvesting (RWH) act as an effective tool to prevail over the disparity between water demand and supply by augmenting the groundwater and surface water supply under the climate change conditions. RWH systems enhance the sustainability of water supplies by recycling and reducing the runoff discharges thus maintaining the quality of water. In the semi-arid and arid regions, identification of suitable sites for rainwater harvesting of the major steps taken to enhance the availability of water and productivity of the land. Chennai is one among the water-scarce regions in India deprived of freshwater resources along with the deterioration in the surface and sub-surface water quality. Currently, Chennai city does not receive the annual rainfall due to climate change variability. The study was conducted to demarcate favorable locations for RWH structures in the Chennai basin, Tamil Nadu using GIS to provide sustainable solutions to minimize the impacts on water scarcity. The optimum sites of rainwater harvesting were identified by the weighted overlay analysis in ArcGIS 10.7.1 software. Hydraulic structures such as farm ponds, percolation tanks, subsurface dykes, check dams and recharge pits were proposed for the augmentation of surface and groundwater resources in the Chennai basin. It has been concluded that remote sensing and GIS offer a wonderful tool for implementing rainwater harvesting technologies on a wider scale.

Keywords

Hydro-geomorphology, Water Scarcity, RWH, Hydraulic Structure, Chennai Basin, RS/GIS

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1. Introduction

Water, one of the fundamental resource that is present both on the surface and subsurface strata of the earth is a primary requirement for domestic, agricultural, industrial purposes along with other numerous applications. Rapid industrialization and urbanization have led to the population growth which has increased the pressure on hydro- geomorphologic system affecting recharge mechanisms and quality as well as the quantity of surface and groundwater resources [1]. Currently, it is estimated that nearly one-fifth of the global population is affected from water scarcity and a quarter of population across the world face lack of adequate technology to reacquire fresh water from ponds and rivers [2]. As per the predictions, if appropriate adaptive measures are not taken to retrieve the hydrological resources, 52% of the world's population would be suffering from acute water scarcity by the year 2050 [3].

Rainwater harvesting is considered as of vital importance in the current scenario to meet the inadequacies in the water supply. The database of the World Overview of Conservation Approaches and Technologies (WOCAT) defined RWH as the collection and management of floodwater or rainwater runoff

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to increase water availability for domestic and agricultural use as well as ecosystem sustenance. The primary objective of RWH is to capture the rainwater falling in a specific region for local usage or transferring it to another region. Artificial recharge techniques and RWH improve the groundwater availability and increase the subsurface water levels, improves both the surface and sub-surface storage of water, and enhance the water quality in aquifers [4]. It acts as an effective tool to prevail over the disparity between water demand and supply by augmenting the groundwater and surface water supply under the climate change conditions. Rainwater harvesting has proved to be one of the most sustainable and affordable intervention in the regions where the cost of development of ground and surface water resources are high. Identification of potential sites for RWH is one among the most significant factors that govern the success of rainwater harvesting systems [5]. Various hydraulic structural measures like recharge shafts, farm ponds, nala bunds, percolation tanks, check dams etc. for rainwater harvesting has been identified by many researchers [6-11] to minimize the rate of runoff, augment the aquifer recharge and conserve the surface and groundwater for domestic and agricultural needs.

The application of remote sensing and GIS technologies have been widely used in identifying the optimum sites for water harvesting. GIS is a tool used for the collection, storage, and analysis of non-spatial and spatial data [12]. The spatial analysis property in GIS is found effectively useful in regions with compact data and distinctive areas. Challenges of missing data that are necessary for the identification of RWH structures can be solved by remote sensing and GIS. Several researchers [1, 9, 11, 13-16] have applied the method of remote sensing and GIS to delineate potential sites for water harvesting.

The primary objective of this study is to present an effective and robust methodology for estimating favorable sites for various RWH structures using remote sensing and GIS applications. Chennai is one among the water-scarce regions in India deprived of freshwater resources along with the deterioration in the surface and sub-surface water quality. Currently, Chennai city does not receive the annual rainfall due to climate change variability. This paper presents a GIS-based method to assess the suitability of various hydro-structures such as recharge pits, sub-surface dikes, percolation tanks, check dams, and farm ponds that combines various attributes to improve the water availability for Chennai basin, Tamil Nadu.

2. Literature Review

Several methodologies have been adopted by many researchers for identifying the locations suitable for rainwater harvesting. Remote sensing and GIS were regarded as the preliminary step for the delineation of water harvesting structures [17-21]. A new set of procedures incorporating hydrological modelling, multicriteria analysis etc. were developed based on the technological advancement in the remote sensing, GIS, and computer applications [5]. The analysis of the rainfall-runoff relationship and the simulation of runoff within a watershed were made possible by incorporating the hydrological modelling in GIS [5]. One among the most widely used techniques to estimate the runoff from minor catchments is the Soil Conservation Service (SCS) method which consider the relationship between land use and hydrologic soil group [9, 18, 22-23]. SCS-CN method were incorporated in several hydrological models like KINEROS, TOPMODEL, SWAT and WMS and integrated with remote sensing and GIS to improve the precision required for the delineation of low cost RWH zones [1, 9, 22, 24].

Thornthwaite and Mather (TM) model [25] estimate the water balance equation to determine the water balance regime of a specified region, with the aid of remote sensing and GIS to delineate the runoff potential zones and sites favorable for rainwater harvesting [26]. The outflow, inflow and change in water storage of an area are computed by using the water balance equation. Application of Multi-criteria analysis (MCA) in the GIS environment identify the sites by combining different criteria based on the set of decision rules [17, 27-29]. Weighted overlay process (WOP) is a widely used MCA, that combines data from various themes, assigns suitable weights to each thematic layer and finally aggregate the weighted cell values [30]. Several studies integrated MCA with hydrologic modelling in GIS to identify suitable RWH sites. The analytical hierarchy process (AHP) is a multi-criterion decision tool that renders structured methodology for analyzing and organizing complex data [5, 19, 31].

The site selected for rainwater harvesting mainly depends on various factors [17]. Biophysical and socioeconomic factors were considered for the site suitability analysis in various research studies. Land use, slope, rainfall, soil texture, drainage networks were included in the biophysical criteria [18, 20]. Cost, distance to roads, distance to streams, distance to settlements etc. are some of the socio-economic factors which were integrated along with biophysical factors in the identification of suitable locations for water harvesting structures since 21st century [5, 21, 23, 30].

Several criterions are adopted for the delineation of potential sites for RWH structures [32]. Integrated Mission for Sustainable Development (IMSD), Food and Agricultural Organization of United Nation (FAO) and Indian National Committee on Hydrology (INCOH) are some of the commonly used guidelines followed for the identification of water harvesting sites. The IMSD developed initial set of guidelines that incorporated only the biophysical criteria [4, 7, 9, 22, 26, 33-34]. The criteria’s defined in the IMSD were found to be more flexible in comparison with the other guidelines. The guidelines proposed by FAO [35] were inclusive of both biophysical and socio-economic criteria, thus providing a more comprehensive approach in the identification of suitable rainwater harvesting sites [5, 22, 36-37]. It considers a wide range of parameters pertinent to RWH and includes various socioeconomic factors related to local farmers [17]. Collaborated criteria for the identification of potential sites for RWH are given in Table 1.

Table 1. Consolidated Criteria from IMSD and FAO Guidelines.

Structure	Rainfall (mm)	Permeability	Slope (%)	Soil Type
Check Dams	< 1000	Low	< 15	Sandy clay loam
Farm Ponds	> 200	Low	< 5	Sandy clay loam and Silty
Percolation Tank	< 1000	Medium	< 10	Silt loam, Clay loam
Subsurface Dyke	-	High	0–3	-
Recharge Pits	-	-	< 5	-

Table 1. Continued.

Structure	LULC	Catchment Area (ha)	Order Stream	Runoff Potential
Check Dams	Barren, shrub, & scrub land	> 25	1-4	Medium / high
Farm Ponds	Cultivated and Shrub land	>2	1	Medium / high
Percolation Tank	Barren or scrub land	25-40	1-4	Medium / low
Subsurface Dyke	-	> 5	1-4	Medium / high
Recharge Pits	-	<1	1	-

A summary of various literature reviews considering the proposed structures and key findings are illustrated in Table 2.

Table 2. Proposed Structures and Key Findings from Various Research Works.

S. No.	Proposed Structure	Key Findings	References
1	Check dams Recharge pits	Criteria: geology, geomorphology, lineaments, topography, land use, and groundwater recharge. Identified sites contains - weathered and fractured basalt, pediment, presence of lineaments, gentle slope.	[28]
2	Check dams Farm ponds Nala bunds Percolation tanks	Guidelines: IMSD, INCOH Biophysical criteria: drainage network, land cover, soil texture, geology, and run-off potential Socio-economic criteria: proximity to utility points Runoff potential determined by Thornthwaite and Mather (TM) model [25]	[33]
3	Check dams Percolation tanks	Criteria: drainage density, slope, land use, lineament, and water table level fluctuation data Identified 14 check dams in 2nd and 3rd order streams and 9 percolation tanks in 5th and 6th order streams	[6]
4	Check dams Recharge pits Contour bunds Contour trenches	Guidelines: IMSD, INCOH Criteria: geomorphology, lineaments, land use, road, and drainage Method: Weighted aggregation method Identified sites with poor, moderate, good, and excellent sites for water harvesting	[34]
5	Check dams Percolation tanks Subsurface dykes	Guidelines: IMSD, FAO Criteria: drainage, lithology, soils, slope, rainfall, and land use Methodology: AHP Determined the water balance of watersheds	[15]
6	Check dams Farm ponds	Guidelines: IMSD, INCOH Criteria: slope, soil texture, run-off potential, and land use Check dams were identified in regions with medium slope, moderate runoff, and low permeability	[7]
7	Farm ponds	Methodology: Boolean Techniques and Weighted Linear Combination (WLC) Criteria (WLC): rainfall, slope, soil (clay%), distance to roads and urban centers Criteria (Boolean): distance to international border, wadis, roads, faults, wells, and farms Boolean criteria have significant importance than WLC	[38]
8	Check dams Farm ponds Nala bunds Percolation tanks	Guidelines: IMSD (1995), INCOH Criteria: drainage order, land use, slope, and soil Identified structures along the streams (2nd and 3rd order) and adjacent to the cultivable and settlement area	[4]
9	Farm ponds	Criteria: topography, soil, land cover, distance from rural settlements Identified run-off potential by SCS-CN model Identified farm ponds in agricultural fields	[39]
10	Check dams	Methodology: MCDM with AHP Criteria: drainage density, geology, geomorphology, slope, and aquifer transmissivity Favourable sites obtained by overlapping artificial recharge zone, drainage, and lineament map Identified 23 suitable and 17 moderately suitable favourable recharge sites	[37]
11	Check dams Farm ponds Percolation tanks	Methodology: MCDA with Boolean Logic Approaches Criteria: water demand, groundwater fluctuation, and post monsoon water level	[16]
12	Check dams Farm ponds	Methodology: AHP Identified suitable zones for groundwater recharge Criteria: geomorphology, slope, drainage density, road density, rock type, lineament, weathered zone	[1]

S. No.	Proposed Structure	Key Findings	References
		thickness, groundwater level fluctuations, and groundwater level	
13	Check dams Percolation tanks Rooftop rainwater harvesting	Criteria: drainage density, stream order, runoff potential, and geomorphology Check dams were identified in the 2nd order streams Percolation tanks were identified in the 3rd order streams	[10]
14	Check dams	Criteria: land use land cover, soil texture, geology, drainage network / stream order, topography / slope, natural vegetation, soil erosion, morphometric analysis-based compound parameters, and sediment yield index. Based on the analysis, it is found that a total of 10 micro-watersheds fall under very high and high category, in which 33 check dams were proposed specifically on 3rd, 4th and 5th order streams.	[11]

3. About the Study Area

Chennai, the capital of Tamil Nadu is situated on the coromandel coast of Bay of Bengal. It is one among the largest educational, social, and cultural centre in southern India. As per the Indian census of 2011, Chennai is regarded as the fourth most populous urban agglomeration and sixth largest city in the country. The Chennai metropolitan area (CMA), which is constituted by the Chennai city along with adjoining areas is the 36th largest urbanized area by population in the world. Chennai covers an area of 426 Km^2 with a population of 7.1 million in 2011 (Census of India, 2011), and 11.2 million in 2021 (https://worldpopulationreview.com/world-cities/chennai-population). The average elevation of CMA is 6.7 m amsl, while the peak point resides at 60 m. The water table of Chennai is found at a depth of 2 m in 8 month of the year. Chennai has a tropical wet and dry climatic conditions. An immense variation in the seasonal temperature is prevented as the city is located along the coast on the thermal equator. During the end of May to early June, the city experiences extreme temperatures around 35-40°C, being the hottest part of the year. A minimal temperature of 19-25°C is observed during the month of January, being the coolest part of the year. The average annual rainfall is about 140 cm. The main rainy season for Chennai is northeast monsoon with 663 mm of rainfall (56% of the annual rain). During the southwest monsoon, 436.2 mm (37% the annual rainfall) of rainfall is observed. In summer and winter, seasonal rainfall amounts are 74.2 and 19.2 mm, respectively.

Chennai basin has an area of 6118 Km^2 spread over in four districts namely Chennai, Kancheepuram, Tiruvallur and Vellore. The river groups of Chennai basin are situated in the northern region of Tamil Nadu and is located between Latitudes 12° 35' 05" N to 13° 35' 49" N and Longitudes 79° 09' 07" E to 80° 21' 37" E (Figure 1). Chennai basin group of rivers are Araniar, Kosasthalaiyar, Cooum and Adayar and small minor stream on the south region. The basin comprises 8 sub-basins, namely Adayar, Araniar, Cooum, Gammadion, Kosasthalaiyar, Kovalam, Nagari, and Nandhiyar [40].

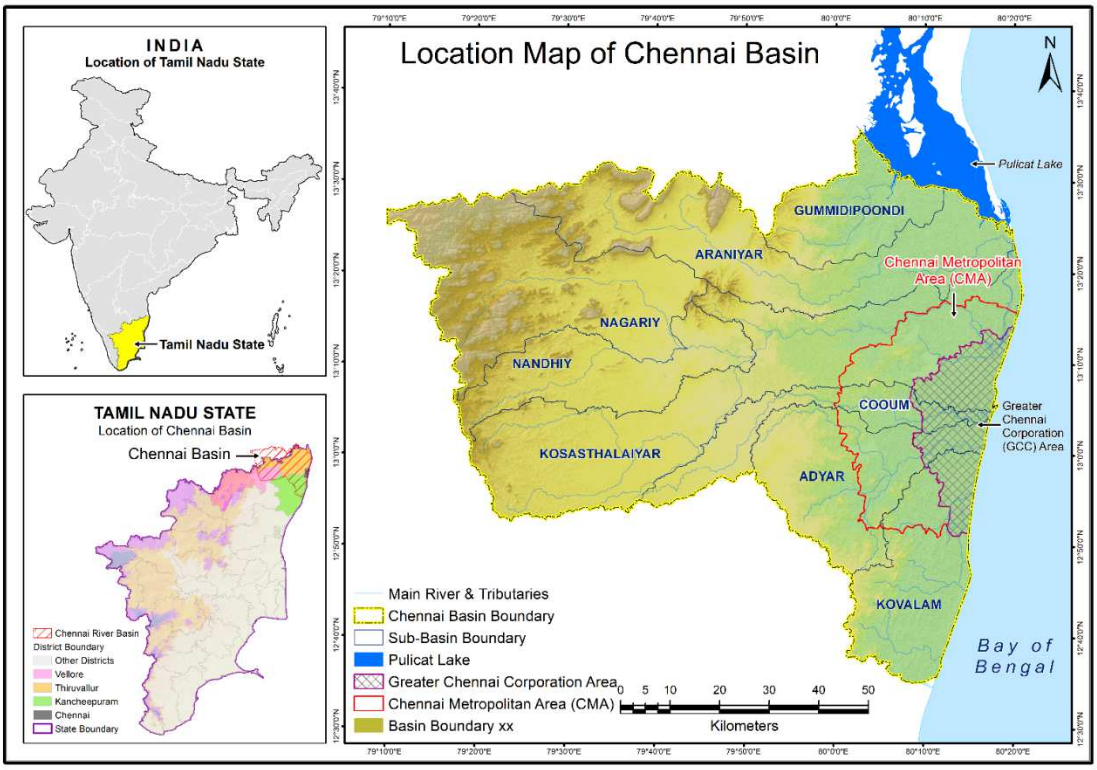

Figure 1. Location Map of Chennai Basin.

In Tamil Nadu, 73% of groundwater and 98% of surface water resources have been depleted. The climate of Chennai has been changing drastically over the past few years. Chennai has experienced extreme rainfall in 1903, 1943, 1978, 1985, 2005, and 2015. In Nov-Dec 2015, torrential rain disrupted life in Chennai and many other parts of Tamil Nadu. Chennai and the adjoining areas are frequently affected by cyclonic storms which originate in the Bay of Bengal. The changes in the land use pattern in Chennai due to urbanization has resulted in the frequent occurrence of floods. The loss in interconnectivity and marshland has resulted mainly due to the unsystematic growth in the northwestern direction. As the development increased, all the green cover has been reduced to non-vegetative surfaces which resulted in the low infiltration capacity and high surface run-off. In the agricultural areas of Chennai region, the waterlogging condition occurs due to the steady rise in the groundwater table due to inadequate drainage capacity of the area. The quality of surface water in Chennai is very poor and the groundwater quality is degraded due to saltwater intrusion. Groundwater exploitation is another issue prevalent in the region. These factors have led to a severe drinking water crisis and the region of Chennai faces extreme scarcity in freshwater resources. Hence for the sustainable urban development it is required to cope up with these challenges for the efficient water use and management.

4. Data Used and Their Sources

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. Data used, and their sources are given in Table 3.

Table 3. Data Used and Sources.

S. No.	GIS Data Layer	Data Sources
1.	Satellite Remote Sensing Data	Landsat-8 OLI (G, R & NIR & PAN merge) data with 15 m spatial resolution, Acquisition date: March 15th, 2021. Source: U.S. Geological Survey (USGS), Earth Explorer. http://earthexplorer.usgs.gov
2.	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
3.	Drainage Network and Drainage Density	Drainage network and drainage density has been generated in GIS environment using ALOS PALSAR (DEM) data and ArcHydro tool in ESRI ArcGIS 10.7.1 software.
4.	Slope Map	Topography, slope, relief maps have been created using Spatial Analyst Extension in ArcGIS 10.7.1, and ALOS PALSAR (DEM) data with 12.5 m spatial resolution.
5.	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 2021. These data layers have been updated with best available Google Earth satellite imagery. These data layers are also verified through limited field check.
6.	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 OLI and PAN sharpened satellite remote sensing data.
7.	Geological Map	Geological quadrangle map has been downloaded from Geological Survey of India (GSI) website and updated through Landsat-8 OLI and PAN sharpened satellite imagery, and Survey of India (SoI) Toposheets at 1: 50,000 scales with limited field check. Source: http://www.portal.gsi.gov.in
8.	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 and PAN sharpened satellite imagery, ALOS PALSAR (DEM) data, and other ancillary data i.e. topographical map, lithological map.
9.	Rainfall Data	Rainfall data from year 2011 to year 2021 have been collected from Indian Meteorological Department. Source: http://dsp.imdpune.gov.in
10.	Groundwater Data	Depth to Water Level (DTWL) data has been downloaded from Central Ground Water Board (CGWB) for selected district of Tamil Nadu and Andhra Pradesh state of year 2020. Source: https://indiawris.gov.in/wris/#/groundWater

5. Materials and Methodology

Data collection, developing geodatabase for different thematic layers, assignment of weights and weighted overlay analysis have been used in a systematic approach. Spatial database for various themes such as slope, annual average rainfall, lineament density, contour lines, drainage density, geology, geomorphology, and groundwater potential have been prepared by using ArcGIS 10.7.1 software. These data have been obtained from satellite images, field surveys, topographical maps as well as collateral data. All the obtained data had been converted to digital format and referenced geographically to UTM-WGS 84 projection and coordinate system. The topography, contours and drainage networks of the basin were obtained using the ALOS PALSAR DEM data (12.5 m spatial resolution) with the aid of ArcGIS 10.7.1 software. Geomorphological landforms and lineament characteristics of the study area were delineated in the map format by georeferencing and digitizing the satellite images.

The line density tool in the spatial analyst feature of the ArcGIS 10.7.1 software was used to develop the spatial characteristics of lineament density and drainage density demarcated from the lineament and drainage network layers respectively. The data of monthly average annual rainfall from 31 rain-gauge stations obtained from the IMD (Indian Meteorological Department) and PWD (Public Works Department, TN) has used to identify the spatial distribution of average annual rainfall. The projected available groundwater potential of the Chennai basin of the year 2020 has been collected from CWC and PWD, TN. LULC map of Chennai basin has been digitized on Landsat-8 OLI and PAN sharpened satellite imagery (15 m spatial resolution) by using ArcGIS 10.7.1 software.

Weighted Overlay Analysis Method

Weighted overlay analysis is one among the most effective methodologies for multi-criterion decision approaches. In weighted Overlay Analysis (WOA), the various thematic layers to identify the favourable zones to delineate RWH structure can be integrated to a single map in GIS environment using SAT as it is an effective tool for multi-criteria decision making. These thematic layers were converted to raster format with high accuracy followed by reclassification with assigned suitable weights as per the method followed by [8, 28, 41]. The weights 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 are 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 was assigned to individual features in the thematic layers based on the influence of each layer for groundwater potential.

Thematic layers were assigned separate values for weight regarding the influence of groundwater and surface water potential in the Chennai basin (Table 4) The ranks assigned for each individual features based on their influence is also depicted in the above table. Considering the groundwater recharge, lineament density and geology were assigned the highest weight of 20%, drainage density was assigned 15%, similarly, slope, groundwater potential, land use were assigned a value of 10%. Whereas the factors which have a lesser influence on groundwater potential such as rainfall geomorphology, soil were assigned a value of 5%. For surface storage potential, drainage density and LULC were assigned the highest value of 20%, followed by 15% weight each on slope and rainfall, 10% weight on geomorphology, and lastly, geology, lineament density, groundwater potential and soil were accounted for only about 5% weight.

Table 4. Assigned Weights and Ranks for the Overlay Analysis.

Theme	Assigned Weights (%) (GW Recharge)	Assigned Weights (%) (SW Storage)	Features	Ranks for GW Recharge	Ranks for SW Storage
Slope Classes	10	15	Less than 10%	5	5
			10-15%	4	4
			15-20%	3	3
			20-25%	2	2
			> 25%	1	1
Geology	20	5	Pebble gravel	2	2
			Sandstone	1	1
			Laterite	3	3
			Biotite Hornblend Gneiss	5	5
			Charnokite	3	3
			Coastal Alluvium	5	5
			Epidote Hornblend gneiss	2	2
			Fluvial alluvium	4	4
Rainfall	5	15	Low	3	3
			Medium	4	4
			High	5	5
Lineament Density	20	5	Low	5	5
			High	2	2
Drainage Density (Km/Km^2)	15	20	Poor	3	3
			Medium	4	4
			Excellent	5	5
Groundwater Potential	10	5	Low	3	3
			Medium	4	4
			High	5	5
Geomorphology	5	10	Water bodies	5	5
			Valley fills	2	2
			Upland tertiary	1	1
			Upland	1	1
			Structural hill	1	1

Theme	Assigned Weights (%) (GW Recharge)	Assigned Weights (%) (SW Storage)	Features	Ranks for GW Recharge	Ranks for SW Storage
			River island	3	3
			Quartz gravel tertiary		
			Paleo deltaic plain	2	2
			Pediment	4	4
			Old river course	5	5
			Low land	3	3
			Laterite cap tertiary	3	3
			Dyke ridge		
			Flood plain	2	2
			Buried pediment shallow	1	1
			Buried pediment deep	2	2
			Buried pediment medium	3	3
			Built up land	1	1
			Alluvial plain	2	2
			Clay	2	5
Soil Type	5	5	Sand	5	2
			Rocky	1	1
			Urban	1	1
			Rural	2	2
			Mining	1	1
			Fallow land	3	3
			Crop land	5	5
Land Use and Land Cover (LULC)	10	20	Water bodies	4	4
			River/stream/canals	4	4
			Coastal wetland	3	3
			Barren Rocky	1	1
			Forest plantation	2	2
			Scrub forest	2	2

6. Analysis of Bio-Physical Criteria

6.1. Slope Analysis

Digital elevation model (DEM) provides a wide range of information on the hydrological and geomorphic properties of an area such as slope, steam order, drainage network, flow accumulation etc. [1]. ALOS PALSAR DEM data with 12.5 spatial resolution has been downloaded from Alaska Satellite Facility and processed to extract the terrain information for Chennai basin (Figure 2-A). The terrain in the study area has an elevation profile ranging from 0 m to 939 m above mean sea level.

The runoff and infiltration of an area are directly controlled by the slope of that area. Slope map for the study area generated from the Chennai basin filled DEM, ranges from 0-30% as shown in Figure 2-B. Slope is reclassified into six categories as per IMSD guidelines [42] as given in Table 5. (i) nearly level (0–5%), (ii) gentle (5-10%), (iii) moderately gentle (10-15%), (iv) steep (15-20%), (v) moderately steep (20-25%) (vi) very steep (>25%). Nearly level and gentle categories of slope classes are found to be more favourable for RWH with a spatial extent of 39.75% and 12.32% respectively. Moderately gentle slope category covers 22% of the study area. 10.69% of the area belongs to steep slope class and is found in minor patches over the region. Moderately steep and very steep classifications of the slope are the least suitable for RWH with an area of coverage of about 8.49% and 6.7% respectively.

Table 5. Slope Classes of Chennai Basin.

Percentage Slope (%)	Description	Percentage Area (%)	Significance
0-5	Nearly level	39.75	Low surface runoff
5-10	Gentle	12.32	Low surface runoff
10-15	Moderately gentle	22	Medium surface runoff
15-20	Steep	10.69	Medium surface runoff
20-25	Moderately steep	8.49	High surface runoff
>25%	Very steep	6.7	High surface runoff

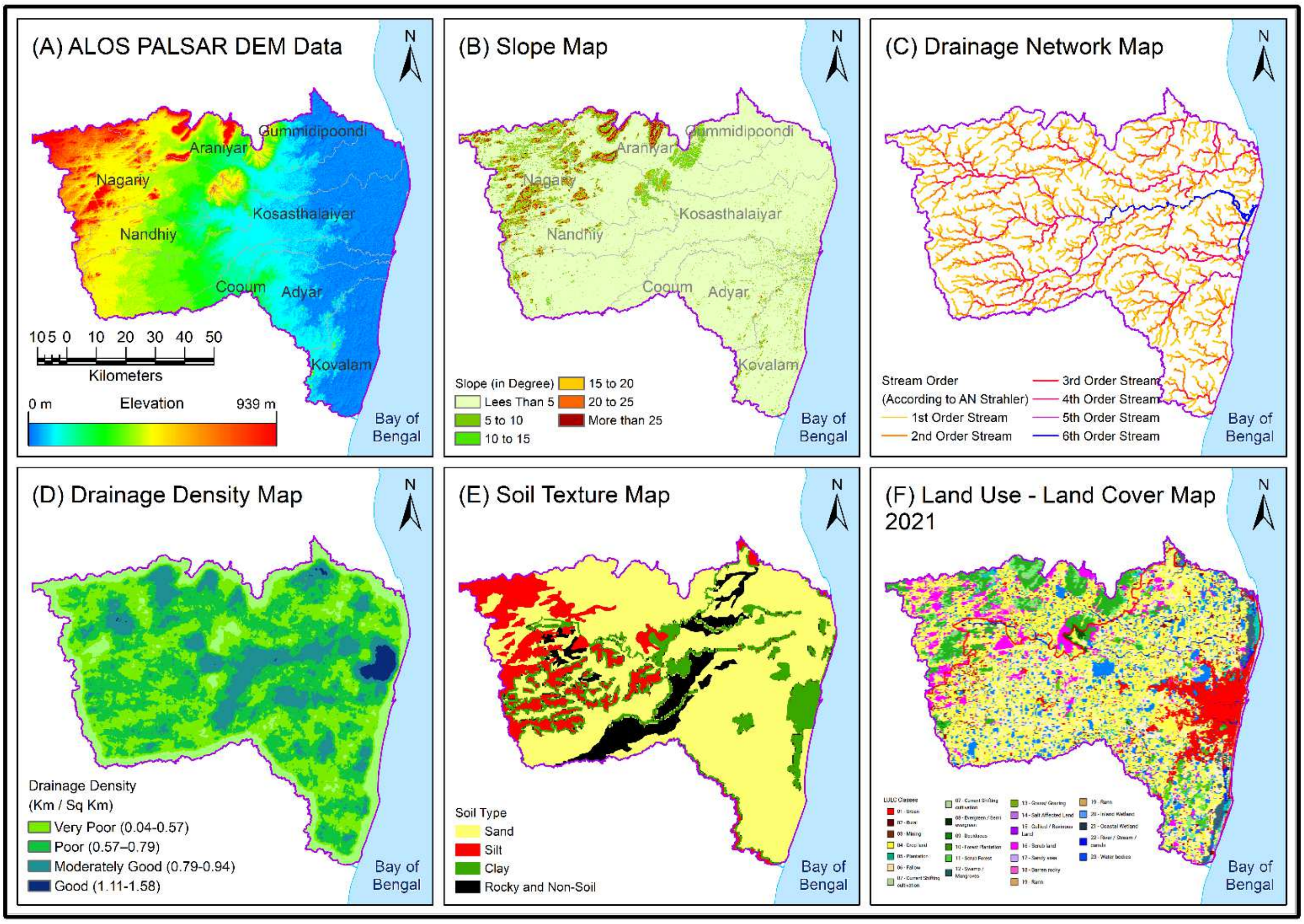

Figure 2. Chennai Basin Maps of (A) ALOS PALSAR DEM Data, (B) Slope, (C) Drainage Network, (D) Drainage Density, (E) Soil Type, and (F) LULC of Year 2021.

6.2. Drainage Analysis

Drainage pattern represents both the characteristics of subsurface and surface strata. Dense areas of the Chennai basin region are the most suitable for the RWH structures. The order of a stream is related to the connection of tributaries. Stream order represents the hierarchical connection amongst stream segments. It also enables to categorize the drainage basins depending on their size. Determination of steam order in an area plays a crucial role in the identification of potential sites for RWH structures. Streams with lower order permit high infiltration and permeability. Drainage order in the study area is of 6th order. Nearly 50.5% of the drainage network is found to be first order. Second and third order streams contribute to 25.57% and 12.62% of drainage respectively. 5.88% of the drainage network in the study area is contributed by fourth order streams. While the fifth and sixth order streams are of 4.14% and 1.32% of the drainage respectively. The Drainage network map is shown in Figure 2-C.

The study area has a drainage density within the range of 0.04 to 1.58 Km / Km^2 (Figure 2-D). Based on this, the micro-watershed of the basin is mainly classified into four groups: (i) very poor (0.04-0.57 Km / Km^2), (ii) poor (0.57–0.79 Km / Km^2), (iii) moderately good (0.79-0.94 Km / Km^2), and (iv) good (1.11-1.58 Km / Km^2). Regions with lower surface drainage density are highly recommended for rainwater harvesting. Poor and moderately good classes of drainage density are prevalent in Chennai basin. Hence it is mostly preferred for RWH.

6.3. Soil Texture Analysis

The soil is one among the most influencing parameters that determine the potential locations for water harvesting. The texture and permeability of soil are the governing factors for surface water storage and aquifer recharge. The soil group of the study area is divided into four groups namely (i) sand (ii) silt (iii) clay (iv) rocky and non-soil (Figure 2-E). In Chennai basin, the most widely seen soil type is sand. It covers the major portion of the area. Clay is found along the coastal reaches of the area. Patches of silt are spread across the North West part of the basin and the rest of the region is occupied by rocky and non-soil.

6.4. LULC Analysis

The LULC pattern of an area plays a crucial role in determining the potentiality of water harvesting structures. It is the component that controls the excess rainfall and evapotranspiration [15]. LULC map of year 2021 has been prepared by using Landsat-8 OLI satellite imagery from USGS for Chennai basin using unsupervised classification of Image Analysis in GIS. LULC classes namely urban, rural, mining, fallow land, cropland, water bodies, river / streams, forest, and barren rocky region were identified in Chennai basin and shown in Figure 2-F.

6.5. Geology of the Area

Chennai basin constitutes 60% of sedimentary formation and 40% of hard rock formations. It is predominant with Charnokite, Alluvium, Laterite, Sandstone, Biotite Hornblend Gneiss, Epidote Hornblend Gneiss and Gravel. The south-eastern and west side of the basin is comprised of hard rock formations. West side of the basin is occupied by Epidote Hornblend Gneiss and Biotite Hornblend Gneiss whereas Charnokite resides in north-eastern and south-eastern sides. Fewer deposits of Sandstone constitute the middle and western parts of the basin. Eastern and central region are occupied by the Alluvium Deposits. Few patches of laterite as well as gravel were seen along the north and eastern region of the basin. Geological setting of the study area is shown in Figure 3-A.

6.6. Geomorphology of the Area

Geomorphology is an important parameter that determines the run-off, rate of infiltration, drainage pattern and steam flow of an area. The geomorphic features observed in the Chennai basin were pediments, structural hills, alluvial plains, old river course, buried pediment, dike ridge, paleo deltaic plain, flood plain, valley fills, water bodies, upland tertiary, low land etc. Denudational as well as fluvial were identified based on the rock types, geological formations, structural and relief details of the study area. Denudational landforms were further classified into different geomorphic units namely buried pediment deep, pediment, structural hill, bazada, residual hill, buried pediment shallow and buried pediment moderate. The west and southeastern part of Chennai basin is mainly covered by denudational landform. Among these geomorphic units buried pediment moderate and buried pediment deep are having moderate to good groundwater potential zones in this basin area. The fluvial landforms are further classified into 15 geomorphic units such as flood plain, gullies, alluvial plain, old river course, buried channel, river island, paleo deltaic plain, valley fill, tertiary upland, quartz gravel tertiary, laterite cap tertiary, laterite tertiary, laterite gravel tertiary, Gondwana upland and Gondwana lowland. Valley fill, alluvial plain, buried channel and flood plain belongs to the fluvial geomorphic unit that enhances the groundwater potentiality of the area (Figure 3-B).

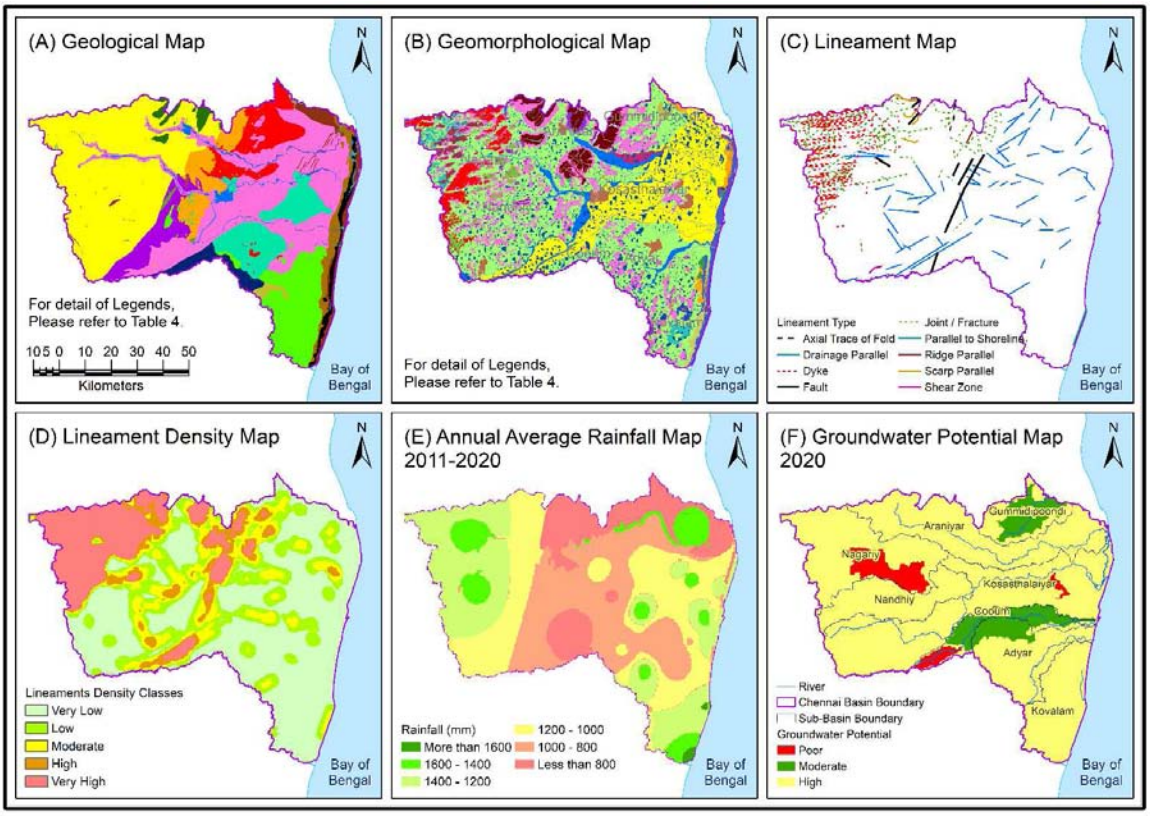

Figure 3. Chennai Basin Maps of (A) Geology, (B) Geomorphology, (C) Lineaments, (D) Lineament Density, (E) Annual Average Rainfall (2011-2020), and (F) Groundwater Potential Zone of Year 2020.

6.7. Lineament Analysis

Lineaments are weak planes that act as conduits for the movement of groundwater in various directions along the subsurface. The lineament intersections provide the potential groundwater zones [43]. Lineament map was prepared by using Landsat-8 OLI satellite imagery of year 2021 (Figure 3-C). The lineament characteristics of Chennai basin were found to be in north-east and south-Western directions. Lineaments and intersection zones indicate the presence of deeper fractures in the regions suitable for groundwater recharge. Lineament density for the Chennai basin is shown in Figure 3-D.

6.8. Average Annual Rainfall

The variations in the intensity of rainfall control the subsurface and surface hydrological resources of an area. It has also a direct influence on the parameters such as infiltration rate, run-off, and stream flow. Chennai basin resides in the tropical monsoon region and is divided into the monsoon period and non-monsoon period depending on the hydrometeorological features of the basin. Monsoon period which spans from Jun-to-Dec is again divided into southwest monsoon period (Jun-Sep) and northeast monsoon period (Oct-Dec) whereas non-monsoon period which spans from Jan-to-May is further divided into winter period (Jan-Feb) and summer period (Mar-May). With the intense rainfall that happens during the monsoon period, surface water storage and groundwater recharge of the basin region is improved. The average annual rainfall in the Chennai basin ranges from 841.76 mm to 1,590.54 mm (Figure 3-E).

6.9. Available Groundwater Resource

The available projected groundwater potential for the Chennai basin of year 2020 is shown in Figure 3-F. The region was reclassified into low, moderate, and high zones based on the groundwater potential.

7. Result and Discussion

7.1. Weighted Overlay Analysis

Artificial recharge zone map and surface water storage map is derived by assigning suitable weights to thematic layers using weighted overlay analysis in a GIS environment. The characteristics of recharge zone were identified by classifying the region of artificial recharge into four different zones namely poor (<1%), moderate (24.78%), good (73.4%) and excellent (1.73%) zones (Figure 4-A). Similarly, the surface storage characteristics of the basin were derived by classifying the surface storage zone map into three zones namely good (27.58%), moderate (71.85%) and excellent (<1%) (Figure 4-B).

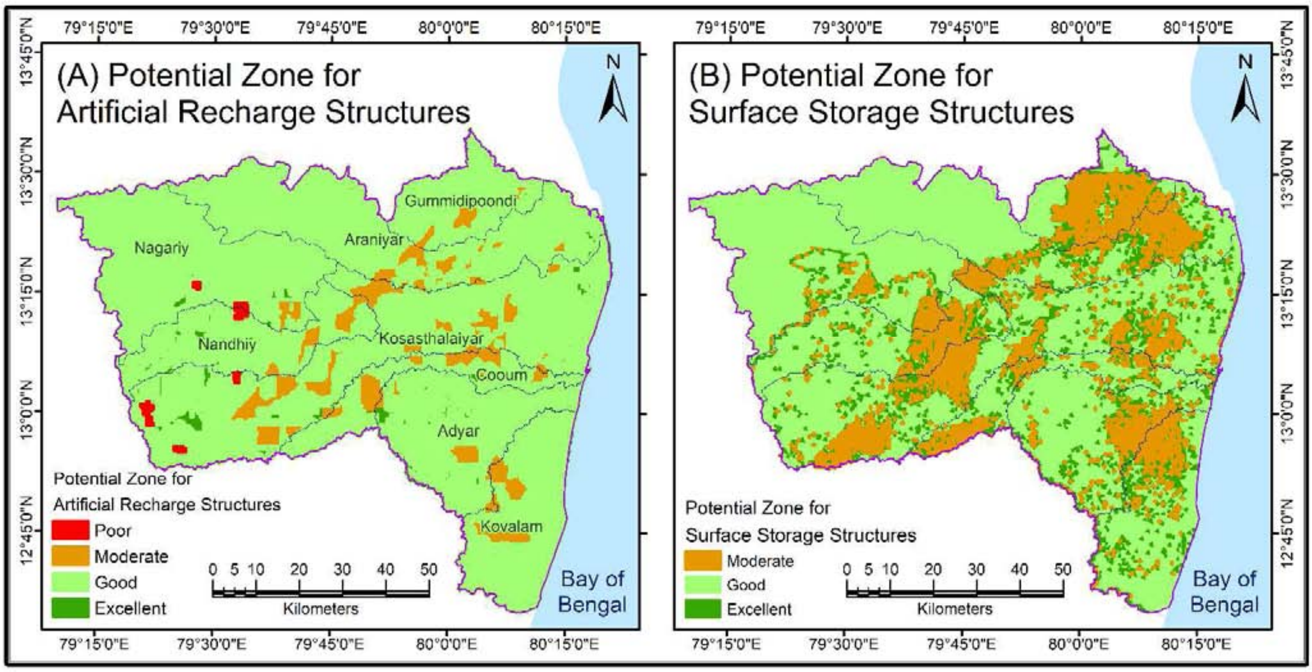

Figure 4. Potential Zone for Artificial Recharge Structures and Surface Storage Structures.

7.2. Proposed Rainwater Harvesting Structures

Potential zones for rainwater harvesting structures were delineated by weighted overlay analysis and by prioritizing the areas near to community settlement by using google earth. 92 structures were proposed in the Chennai basin (Figure 5).

Check Dams are the most prevalent structures identified in the

(1-4) order streams with a slope less of 15%. 12 check dams were proposed within the basin region to augment the surface water supply and to enhance the subsurface infiltration. The feasibility of check dams lies in the alluvial formations and hard rock terrains. The thickness of weathered formation and permeability of bed determine the groundwater recharge within the sites selected for check dams [10].

Farm Ponds are made by excavating pits in regions of low permeability, flat topography and are identified near to agricultural areas [15]. 32 sites were identified for the farm ponds in the 1st order stream with a slope of less than 5%, to enhance the water potential in the agricultural areas of the Chennai basin.

Percolation Tanks were identified across the (1-4) order streams in the regions with less than 10% slope. 19 favourable sites for percolation tanks were demarcated in various parts of the basin.

Recharge Pits / Recharge Shafts are identified in the water divide areas, alluvial terrains, and plateaus for the direct recharge of aquifer where the availability of water is perennial. 14 favourable sites for recharge pits were located in the Chennai basin in regions with a slope of less than 5% to augment the groundwater supply.

Subsurface Dikes are the groundwater recharge structures identified in the areas with a slope of less than 5% across 15 potential sites to recharge the subsurface water resources.

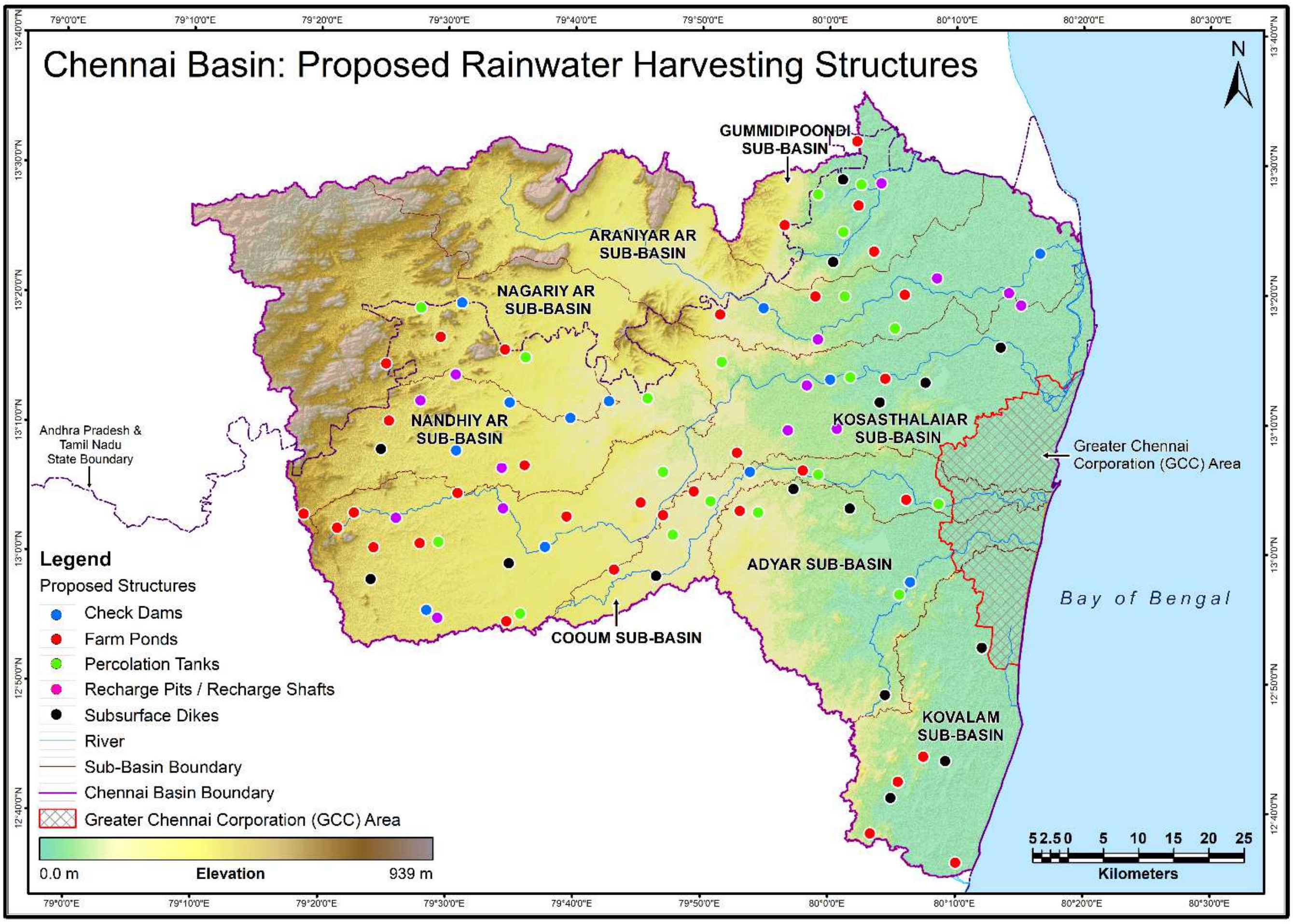

Figure 5. Proposed Rainwater Harvesting Structures in Chennai Basin.

8. Conclusion

Chennai is one among the water-scarce regions in India deprived of freshwater resources along with the deterioration in the surface and sub-surface water quality. Therefore, it is essential to cope up with these challenges for the efficient water use and management by proposing surface water storage and groundwater recharge structures to augment the water resource. Artificial recharge and RWH are adapted as one among the most effective technologies to conserve water and solve problems related to water scarcity by enhancing water supplies on a long-term base. Hence, they are recommended as the most significant adaptation measures for regional and global climatic changes. Estimation of rainwater harvesting potentiality and demarcation of appropriate locations for water harvesting structures possess a tough challenge to water managers and planners. Therefore, to tackle this situation, the present study focuses on a methodology for the identification of RWH sites / zones using remote sensing and GIS techniques. remote sensing and GIS technologies were used for the identification of potential sites for RWH structures.

From the present study, it was found that diverse information can be effectively integrated by the ArcGIS software to demarcate potential sites for RWH. A total of 92 structures were proposed in the Chennai basin including 12 check dams, 32 farm ponds, 19 percolation tanks, 14 recharge pits and 15 subsurface dykes. These structures will help in the storage of water for agricultural and domestic purposes, reduction of runoff velocity and helps in retaining the water for longer duration thereby increasing the recharge potential of the area. In a further study, water balance modelling of RWH structures were recommended. ArcGIS software is one of the cost-effective, time-saving, and flexible tools for intervening the potential for RWH in large areas. The final map that encloses the location of proposed hydro-structures will be usable to decision makers, planners, and hydrologists for easily identifying the suitable locations for harvesting the rainwater.

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