Chapter 14
Application of Remote Sensing and GIS in Floodwater Harvesting for Groundwater Development in the Upper Delta of Cauvery River Basin, Southern India

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Abstract People living in semiarid areas with inadequate rainfall are frequently affected by water scarcity. Upper delta region of Cauvery River Basin (CRB) in southern India was selected to search suitable areas for floodwater harvesting to induce artificial recharge that improves the groundwater level. The aim of this study is floodwater harvesting based on the technical design and identification of the appropriate locations for artificial recharge structures. Remote sensing and Geographic Information System (GIS) were used to produce the flood hazard map and recommend suitable areas for floodwater harvesting. Thematic layers were prepared and overlaid to determine the flood vulnerable zones and suitable recharge structures were identified based on the hazard map. Burrowing and flooding are the most favorable artificial recharge structures should be implemented in all parts of CRB, whereas battery wells near to the river banks should be built to improve the groundwater level. Hydrologists, decision-makers, and planners will use this appropriate map to quickly identify the locations with the greatest potential for flood water collection. This study concludes that geospatial technology becomes very effective for flood vulnerable zone mapping, floodwater harvesting, and suggesting management plans to improve groundwater level for sustainable development.

Keywords Floodwater · Harvesting · GIS · Semi-arid · Sustainable and development

14.1 Introduction

Drought is one of the periodically happened phenomena of the Indian agriculture system because water requirement has amplified manifold because of the increasing population, agricultural and commercial expansions (Belal et al. 2014). It affects not best the national food security however also the reasons for discomfort to human

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P. Kumar et al. (eds.), *Water Resources Management and Sustainability*,
Advances in Geographical and Environmental Sciences,
https://doi.org/10.1007/978-981-16-6573-8_14

existence and livestock. Drought is an insidious natural phenomenon that results from an anticipated (or) ordinary deficiency of precipitation so that when it is miles spread over a season or longer period, the amount of precipitation is insufficient to meet the needs of human activities and the environment (Wilhite and Buchanan Smith 2005; Hussain and Javadi 2016).

A qualitative and quantitative appraisal about droughts in the Indian state of Tamil Nadu were analyzed and identified in nine drought-prone districts such as Coimbatore, Pudukottai, Thirunelveli, Ramanathapuram, Madras, Madurai, Salem, Dharmapuri, North Arcot, and Thiruchirapalli (Nathan 1998). It has become the well-understood fact that the monsoon brings enough rainfall in catchment regions which leads to either flooding along river banks or simply let the turbulent water gush into the sea rapidly to avoid flooding and related problems. On the contrary, during the summer season, we suffer from a drought situation due to chronic water deficit because of the ever-increasing water demand for several purposes (Bariweni et al. 2012). While moving aloof from river flood to different water bodies by constructing small channel networks with artificial recharge structures that help for floodwater harvesting. Yet, another fact is also not a new one for this state that to divert major part of monsoon water to suitable areas where groundwater recharge can happen naturally or by artificial means or to store in periodically de-silted lakes, reservoirs, and tanks and strengthening of the river, lake, and canal bunds which was done promptly in the olden days by several kings. Nowadays, floodwater harvesting has been dealt with seriously as an essential practice to cope with today's water needs as well as to minimize groundwater abstraction along river bank sides and to improve the groundwater quality of the region by maintaining minimal flow in the river canals (Ramachandran et al. 2020; Sivakumar et al. 2016).

The use of Geospatial technology is rapidly developing among several international researchers in groundwater potential zones identification, managing the surface water resources, appropriate sites selection for artificial recharge systems and in groundwater recharge estimations (Chandra et al. 2019; Cabrera and Lee 2019; Bagyaraj et al. 2013; Scanlon et al. 2002). Geospatial technology is comprised of remotely sensed data with Geographic Information System (GIS) that is cost-effective and reliable (Selvam et al. 2015; Srivastava et al. 2012; Machiwal et al. 2011). Thus, a geospatial model study has been conducted in parts of upper Cauvery delta of Tiruchirappalli district, located in central Tamil Nadu to demonstrate how to harvest flood water to cater to the water requirements during summer and also to groundwater level depletion which leads to sustainable agriculture development.

14.1.1 Study Area

The upper delta of the Cauvery River Basin (CRB) is an active agriculture zone throughout the year. It has highly fertile soil and enough groundwater resources for its productivity. However, in the last two decades, gradual decrease of rainfall and groundwater levels were recorded in this region which will adversely affect

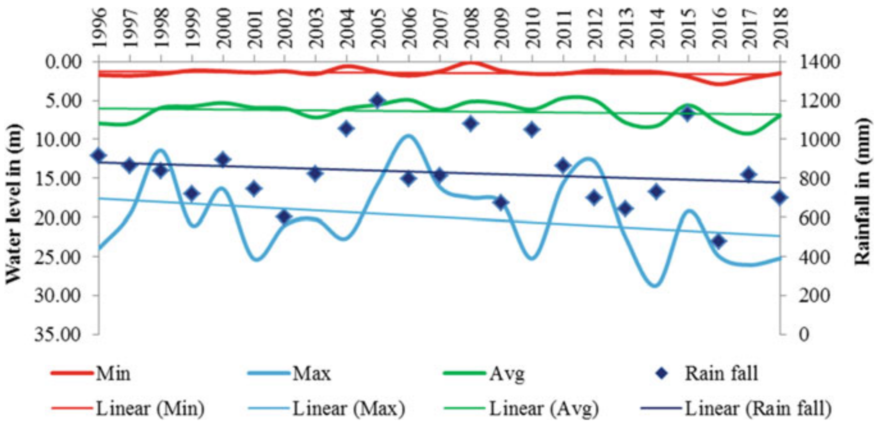


Fig. 14.1 Shown gradual decrease of rainfall and groundwater level. *Source* CGWD and IMD

agriculture productivity (Fig. 14.1). The study area has been buffered for 10 km on either side of the Cauvery River which is considered as an active area during the monsoon and is a linear strip along the river Cauvery covers approximately 1865 km^2 (Fig. 14.2). The area covers in 6 sheets of 1:50,000 scale Survey of India Toposheet (58 J/1, 5, 9, 13, 58 I/4, and 8), contained within the following Latitude N 10° 45′–11° 05′ and Longitude E 78° 10′–78° 55′. The study area climate is tropical with the lowest temperature of 20.6 °C and the highest temperature of noted as 37.2 °C. The total area of Tiruchirappalli District is about 5114 km^2 and its population as per Census

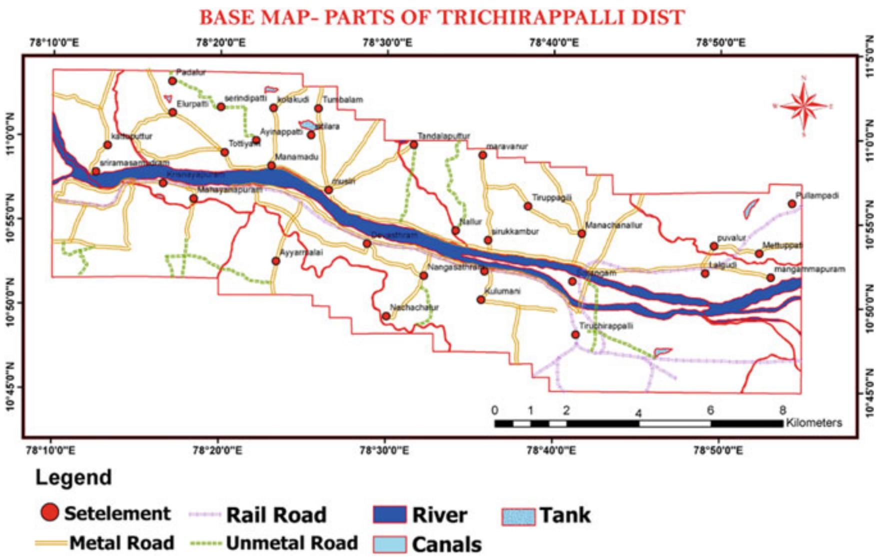


Fig. 14.2 Study area map

2011 is 2,722,290. In which 70% population engaged in agriculture actvities and it is the most predominant economic sector of the district. The area of net cropping land is 1412.82 km^2.

14.1.2 Material Method

The capability of geospatial technologies was applied to understand the issues present within the study area for mapping flood hazard zones, recommending appropriate techniques for floodwater harvesting, and to recommend acceptable remedial measures to attenuate flooding in Tiruchirapalli district. Survey of India Toposheets indexed 58 J/1, 5, 9, 13 and 58 I/4, 8 used as the bottom layers to prepare the avoidance map and relief map. The thematic layers of lithology, lineament, geomorphology, drainage, and land use/land cover were prepared from the satellite imagery IRS (Indian Remote Sensing) 1C LISS (Linear Imaging Self-Scanning Sensor)–III, Path–101, Row–65 (Sivakumar et al. 2017). The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data of DEM (Digital Elevation Model) information was set as base to prepare the relief map to spot the low-lying surfaces within the study area (Jayaprakash et al. 2016). To generate the flood plain map, MODIS (Moderate Resolution Imaging Spectroradiometer) information was used. In order to generate the final flood prone zone map in the GIS, both the flood plain map and the low-lying spot map are combined after the realm is categorized as extreme, moderate, and low flood zone (Fig. 14.3).

14.2 Flood Vulnerable Zone Mapping

14.2.1 One Meter Contour Map

The one-meter contour map was produced with the aid of and geographic ınformation system spatial analyst tools by using ASTER data and interpolated the contours for spot heights. All the 20 m interval contour's height details in the form of triangulation points, benchmarks, and spot heights are available in 1:50,000 scales Toposheets that were digitized separately (Sharma et al. 2009). Then the contour height was converted into point data and integrated with spot heights derived from the ASTER data. The Earth Explorer website (United States Geological Survey—USGS) from downloaded Advanced ASTER. The study area has been vectorized and integrated with the above point data of spot heights. From this final integrated point data, a one-meter contour map was generated to find out the low-lying area to delineate the possible flood vulnerable zones (Fig. 14.4a).

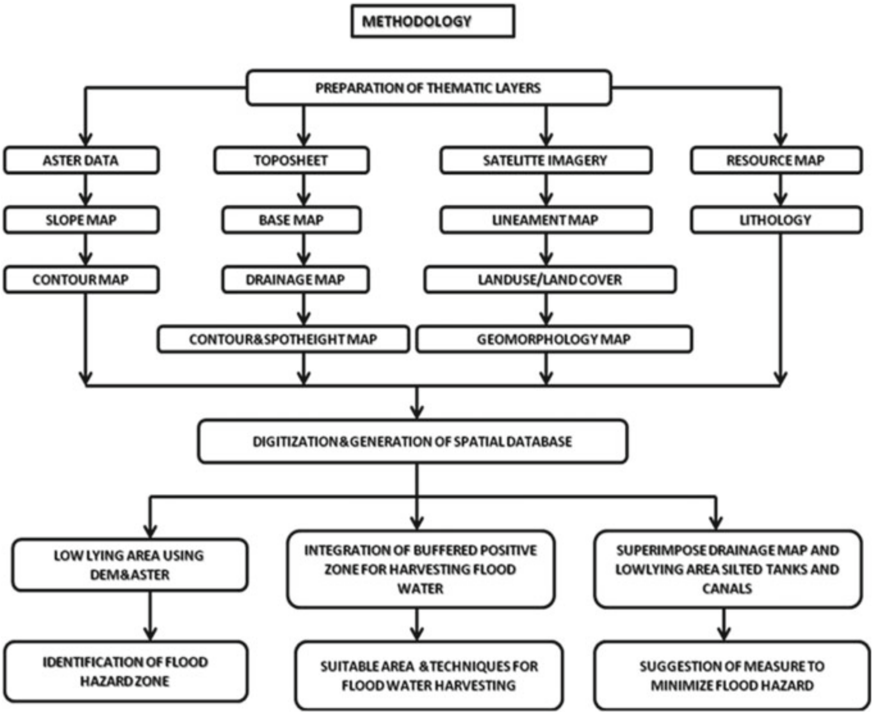


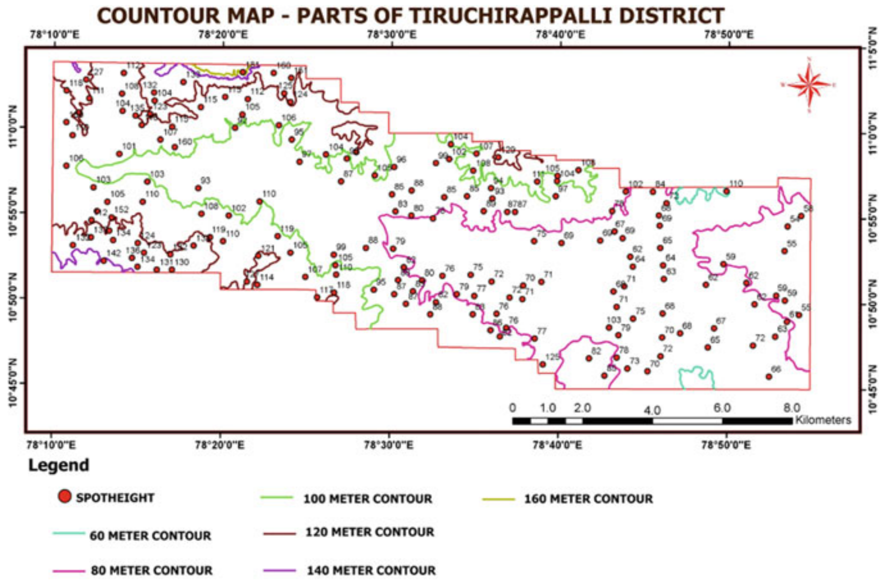
Fig. 14.3 Flow chart

14.2.2 Slope Map

The slope is a very vital aspect for flood water harvesting that if the slope is higher degree there is a risk for greater runoff and less infiltration and therefore automatically high erosion in the study region (Maina and Raude 2016). The slope map has been produced the usage of ASTER data and classified into 3 classes that are 0–3, 4–5, and 5–50°. The maximum part of the study region is located to be under the Very Shallow Sloping category. The slope map shows the following 3 different slope categories obtained (Fig. 14.4b).

14.2.3 Flood Vulnerable Zones

Using the one-meter contour map, all the low-lying areas concerning the local height of the river bed on either bank and every adjacent place have been digitized as flood vulnerable polygons. Thus, the GIS-based layout has been generated showing the flood vulnerable zones.



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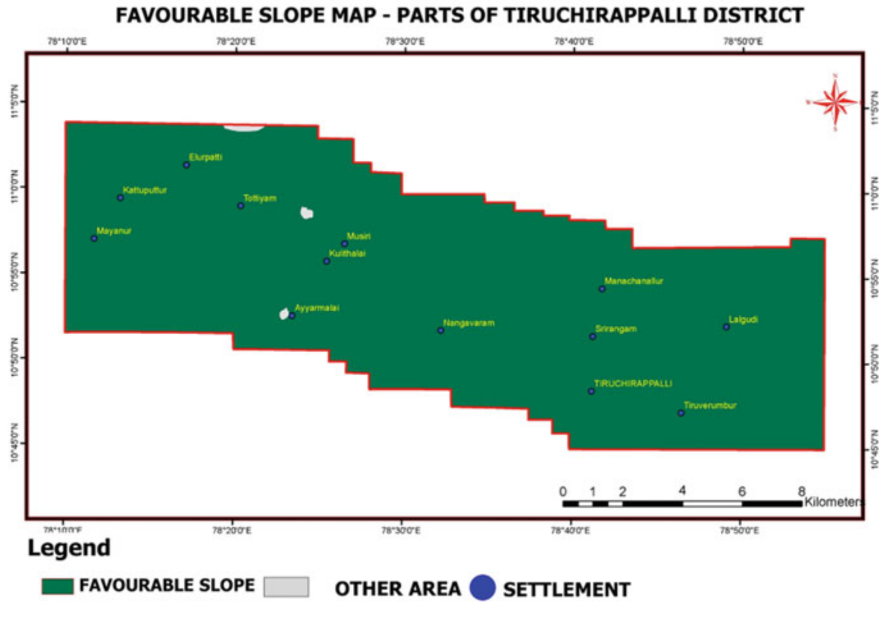


(b)

Fig. 14.4 **a** Contour map. **b** Favorable slope map of the study area

14.2.4 Validation of Flood Vulnerable Zone

The flood zones have been mapped for the past 9 years with 36 spectral bands with MODIS (Moderate Resolution Imaging Spectroradiometer) data ranging in wavelength from 0.4 to 14.4 μm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m, and 29 bands at 1 km). This flood map has been used to verify the commonality of flood polygons prepared in this present study. It is identified that though the web-published flood map is on a very small scale, there is a very good matching of polygons between them (Fig. 14.5a, b).

14.3 Floodwater Harvesting and Management—Data Base Generation

14.3.1 Lithology

The Lithology map was developed from the Tiruchirappalli district resource map produced by Geological Survey of India (GSI). The following are the geological age-wise different lithology classes that available in the present study area; Recent Alluvium, Pink Migmatites, Fissile Hornblende Gneiss, Granite, Garnet Granulite, Hornblende Biotite Gneiss, and Charnockites (Fig. 14.6a).

14.3.2 Lineament

Linear ground features such as fractures, joints, faults, litho contacts, and bedding are expressed together as lineamants. These linear structures influences on infiltraion, conductive and hydrostatic strain development on sloping ground surface (Nagarajan et al. 2010). 88% of the detected landslides have associated with proximity of major faults zones of about 250 m (Gökceoglu and Aksoy 1996). In order to create the lineamant map for the study area, IRS 1C, 1D LISS III satellite imagery was visually interpreted. Linear, rectilinear, and curvilinear characteristics originating in tectonics are derived from satellite data, and these lineaments usually display variations in satellite data in textural, soil tonal, relief, drainage, flower linearity, and curvilinear links. There are faults, joints, and limits between stratigraphic formations in geology. On satellite data, the lineaments are observed by deliberating various terrain characteristics such as drainage association, directly in-stream lines, valley, vegetation-tone variations are ordinary lineaments' geomorphic expressions. N–S, NE–SW, NW–SE, and E–W lineaments are defined in this analysis area (Fig. 14.6b).

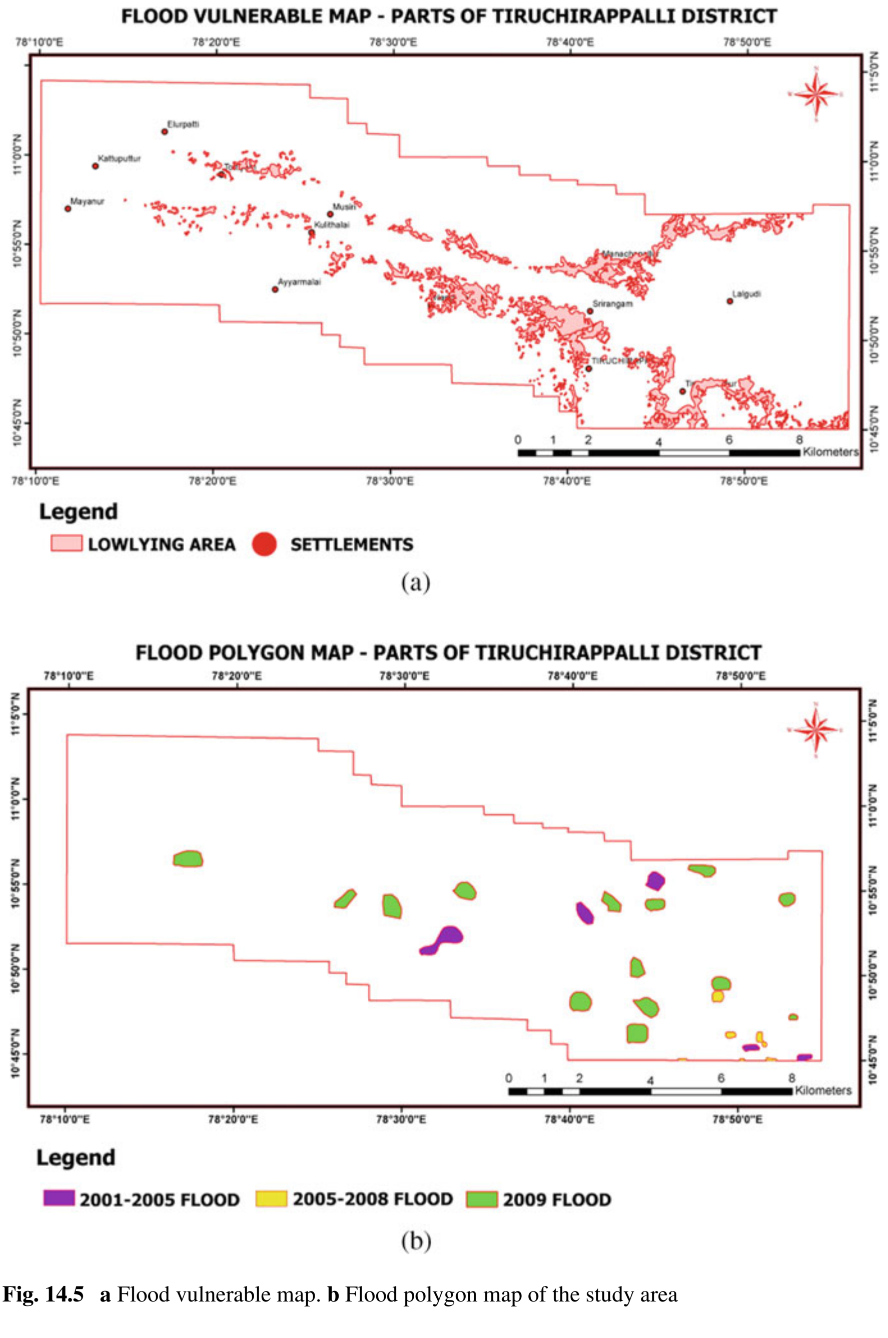
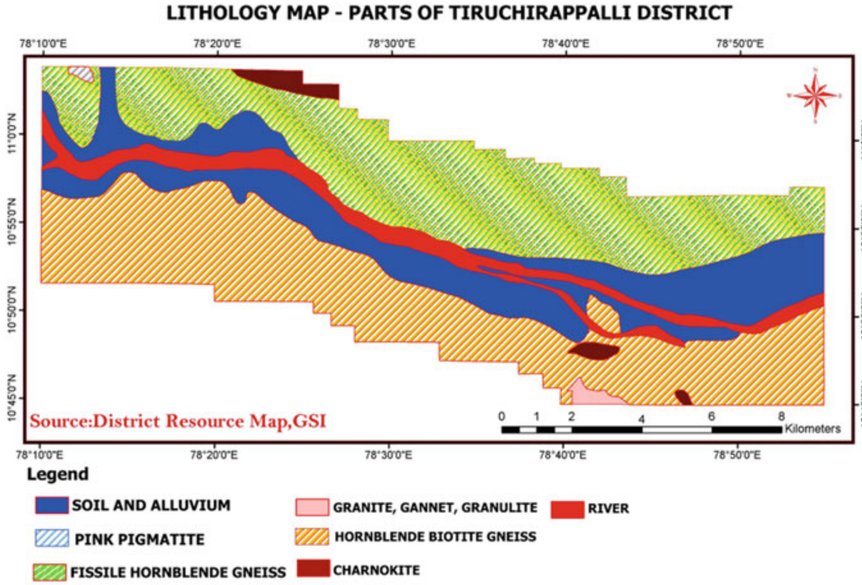


Fig. 14.5 **a** Flood vulnerable map. **b** Flood polygon map of the study area



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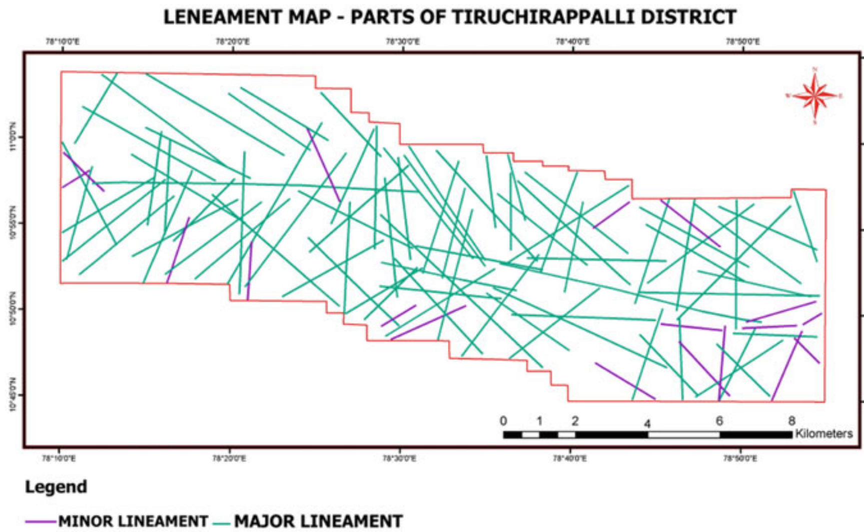


(b)

Fig. 14.6 **a** Lithology map. **b** Lineament map of the study area

14.3.3 Lineament Density and Intersection Density

The line map had a length of 140 m × 140 m and was superimposed over the grid map. For each grid, the total length of the lineaments and intersections was counted and tabulated. The line density and line intersection density contours were then mapped and the very low (0–0.67), low (0.68–1.32) medium (1.33–1.99) and high (2.0–2.66) very high (2.67–3.32) zones were demarcated (Fig. 14.7a, b).

14.3.4 Geomorphology Map

The Geomorphology is the scientific discipline in which the exterior expressions and architecture of the world where the earth's rocks are exposed or the earth's crust is exposed to weathering and erosion are studied. It is subjected to various external morphodynamics and morpho tectonic processes such as horizontal convergent and weathering process due to temperature variants, biotic interference, hydrological interference, the destructive and constructive processes, and the related interactive processes, the wind erosion, volcanic eruptions, geothermal processes, etc. Hence, the artwork of geomorphic mapping has simplest expanded for the closing six decades particularly the geomorphic mapping has gained terrific importance after the advent of modern remote sensing technology. Every landform has distinct physical properties and subsurface characteristics. In the existing study, a try made to prepare a detailed geomorphologic map on a 1:50,000 scale using IRS-1D data (Kongeswaran and Karikalan 2015, 2017; Karikalan and Kongeswaran 2015; Kongeswaran 2019). The photo recognition elements like tone, texture, shape, size, associated features, etc., have been utilized in delineating the following different landforms present in the study area such as Inselbergs, Residual Hill, Bajada, Rocky pediments, Shallow pediments, Moderate pediments, Deep pediments, Colluvial fill Gullies, Flood plain (younger), and Flood plain (older) (Fig. 14.8a).

14.3.5 Drainage Map

The drainage map was developed from the Survey of India (SOI) toposheet (58 J/1, 5, 9, 13, 58 I/4, 5) by digitizing possible rivers, streams, and tanks. Cauvery River, Kolidam River (Colleroon), Kudamurutti River, Vennar River were the major rivers flowing in the area. Cauvery river flows W–E direction then divided as Cauvery River and Kolidam river. Vennar river flows NW–SE direction and joins with Cauvery river. Most of the tanks are existing in the upper region of the study region and lower parts of the NW–SE area (Thirumalai et al. 2015) (Fig. 14.8b).

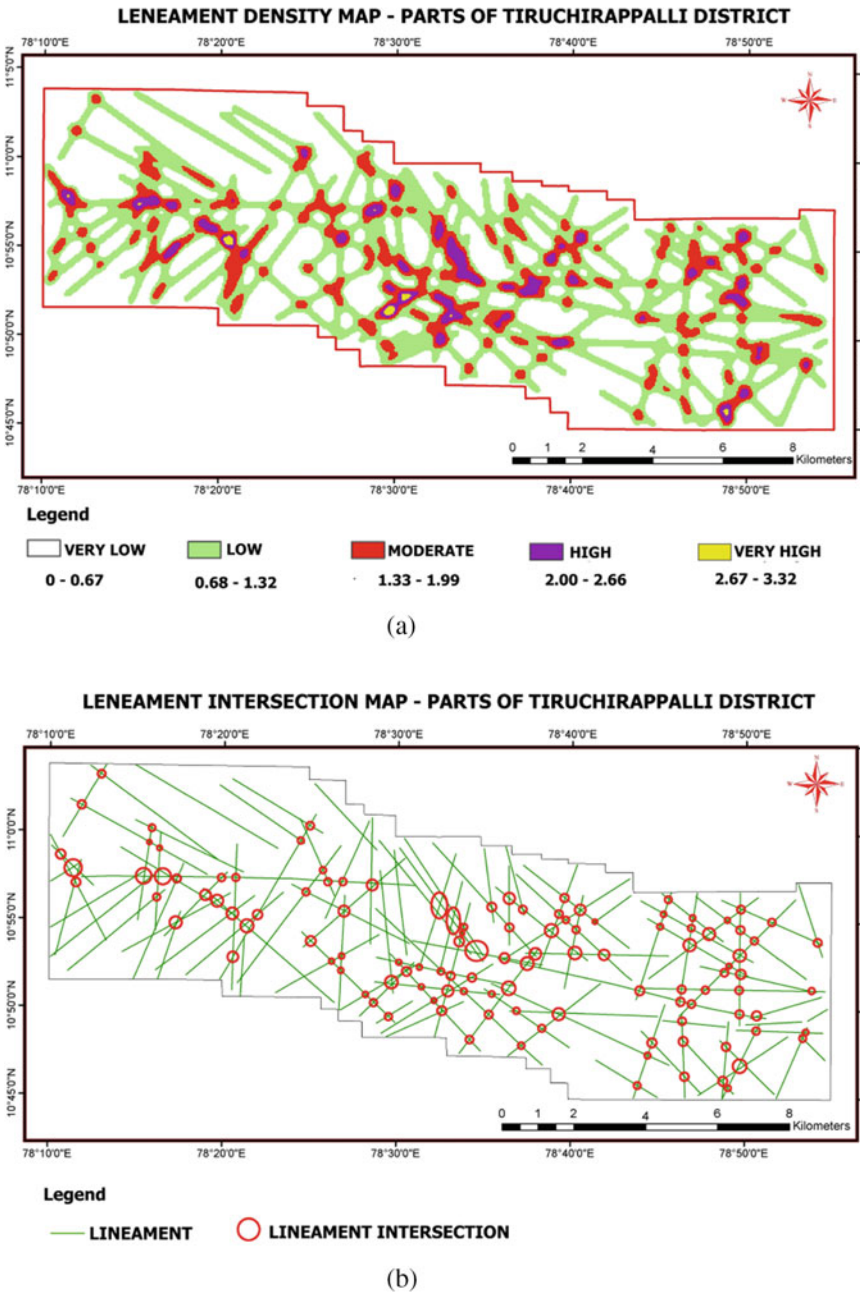
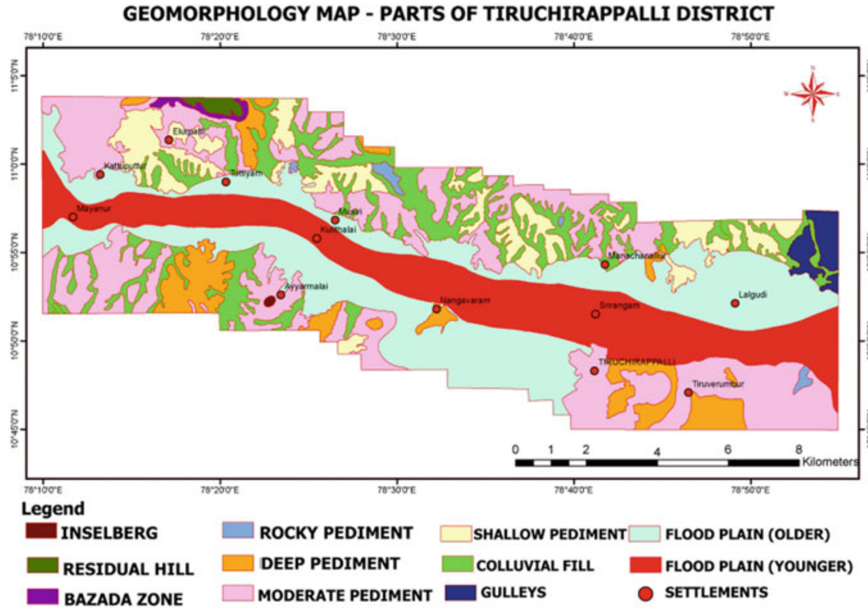


Fig. 14.7 **a** Lineament density map. **b** Lineament intersection map of the study area



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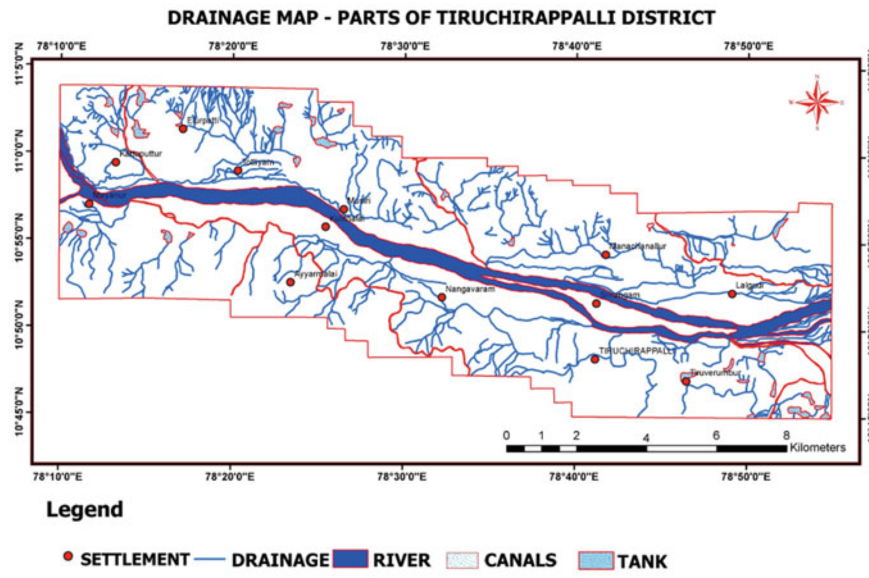

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Fig. 14.8 **a** Geomorphology map. **b** Drainage map of the study area

14.3.6 Drainage Density

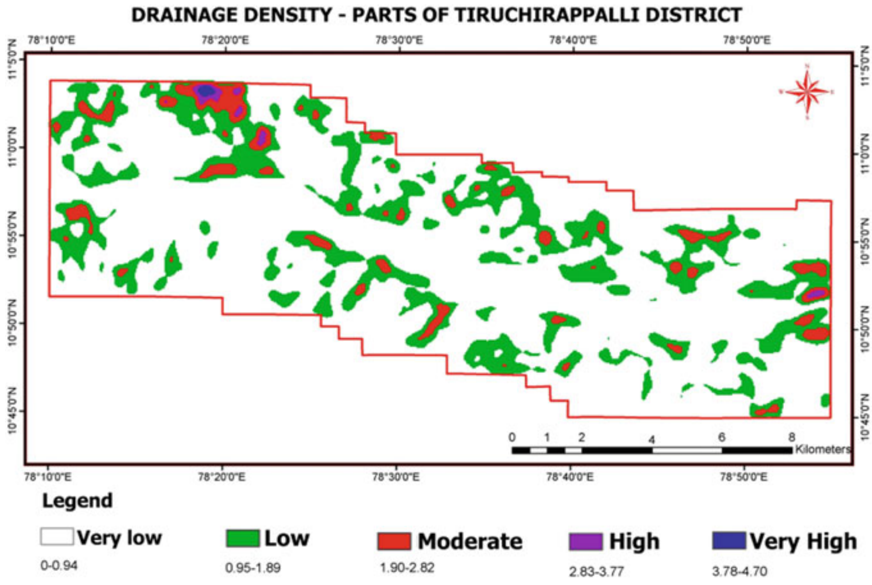
The entire study area was girded with the 1 m value of each. The drainage map was superimposed over the grid plotted in the corresponding grid center and contoured using Surfer software. As a drainage density diagram, these contours have been designated. The low, medium–high, and very high zones were demarcated after the anomalous values were removed and the image was generated in the ArcGIS environment (Fig. 14.9a).

14.3.7 Land Use/Land Cover Map

The Land use refers to the activities of man and different uses carried on land, land cover refers to natural vegetation, water sources, rock/soil, artificial cover, and other results attributable to land transformation. The classification of land use of the defined area using remotely sensed data may provide useful information on the interrelationship between land use and land cover. For the planners of various development activities, a systematic and detailed collection of land use/land cover map data is required. Since land use/land cover has a direct or indirect effect on soil erosion, the land use/land cover of the investigating area must be identified. Due to its synaptic view and temporal data capability, the role of remote sensing data in providing such information has been well defined (Kongeswaran and Karikalan 2016a, b, 2019; Venkata Ramireddy et al. 2015). The standard classification of land use/land cover defined by National Remote Sensing Agency (NRSA) is followed in the present research. The land use/land cover map was prepared using IRS 1-D imagery on a 1:50,000 scale. Settlements, Wet Crop, Dry Crop, Fallow Land and Plantations, Evergreen Green Thick, Land with Scrub, and Land without Scrub are the various land use and land cover groups of the study area (Fig. 14.9b).

14.3.8 Flood Water Harvesting and Management—Identification of Suitable Area to Divert Floodwater

The various thematic maps are prepared using Arc GIS 10.2 as a lithology map, geomorphology map, land use land cover map, slope map, and these separate thematic maps have been incorporated. From the integrated map it is dissolved into two categories that are 0 and 1, 0 is defined as an unfavorable area to divert the floodwater and 1 is defined as a favorable area to divert the floodwater. Likewise, the different thematic maps are integrated into different levels as mentioned below (Gnanachandrasamy et al. 2018).



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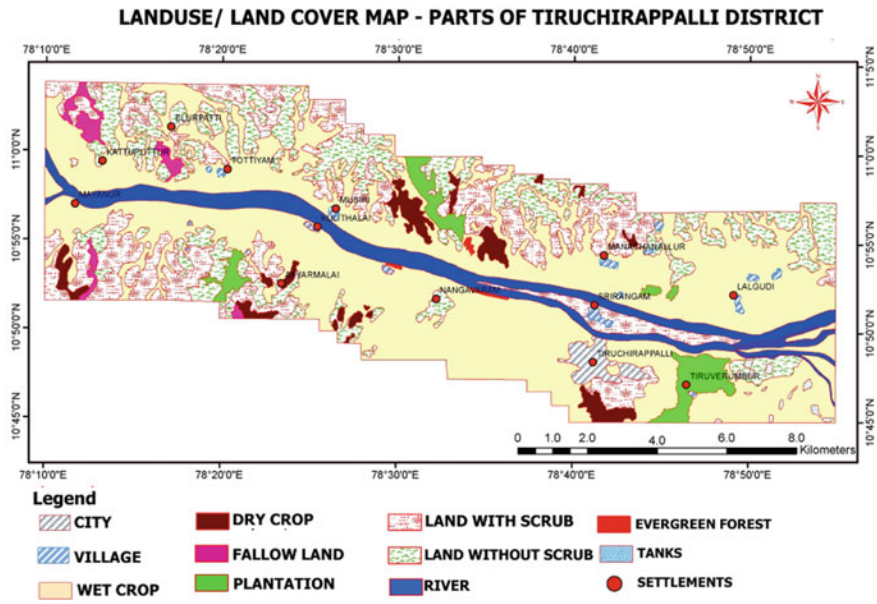


(b)

Fig. 14.9 **a** Drainage density map. **b** Land use/land cover map of the study area

14.3.9 Porous and Pervious Lithology

In this level I, the lithology map was dissolved into two categories by taking the features like weathered granitic rocks, soil, and alluvium, etc. are taken as favorable zones for diverting floodwater and remaining areas such as compact hard unaltered exposed rock as unfavorable zones. The dissolved output map is kept separately for further analysis (Musthafa et al. 2017).

14.3.10 Favorable Geomorphology and Level I Integration

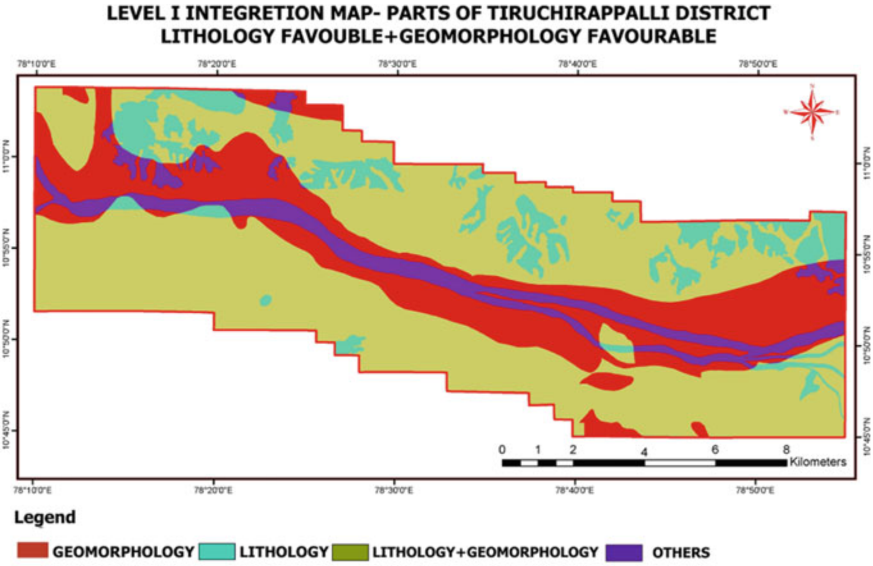
Geomorphology map was dissolved into two categories by taking the features like Deep pediment, moderate pediment, colluvial fill, flood plain (older, younger) are taken as favorable zones for diverting floodwater and remaining area such as shallow pediment, rocky pediment, gullies as unfavorable zones. The dissolved output map of geomorphology is combined with a Porous and pervious map (Fig. 14.10a). This map is also kept separately for further analysis.

14.3.11 Favorable Slope and Level II Integration

In this level III, the slope map was dissolved into two categories by taking features like 0–2 and 3–5° are taken as favorable zones for diverting floodwater and remaining areas such as 6–50° as unfavorable zones. With the dissolved output map of Slope, the level I output map is pooled. This map is also kept separately for further analysis (Fig. 14.10b).

14.3.12 Favorable Land Use Land Cover and Level III Integration

In this level IV, the Land use/Land cover map was dissolved into two categories by taking features like fallow land, scrubland, are taken as favorable zones for diverting floodwater and remaining cropland settlement area are as unfavorable zones. The dissolved output map of Landuse/Landcover is combined with a level II output map. This map is also kept separately for further analysis (Fig. 14.11a).



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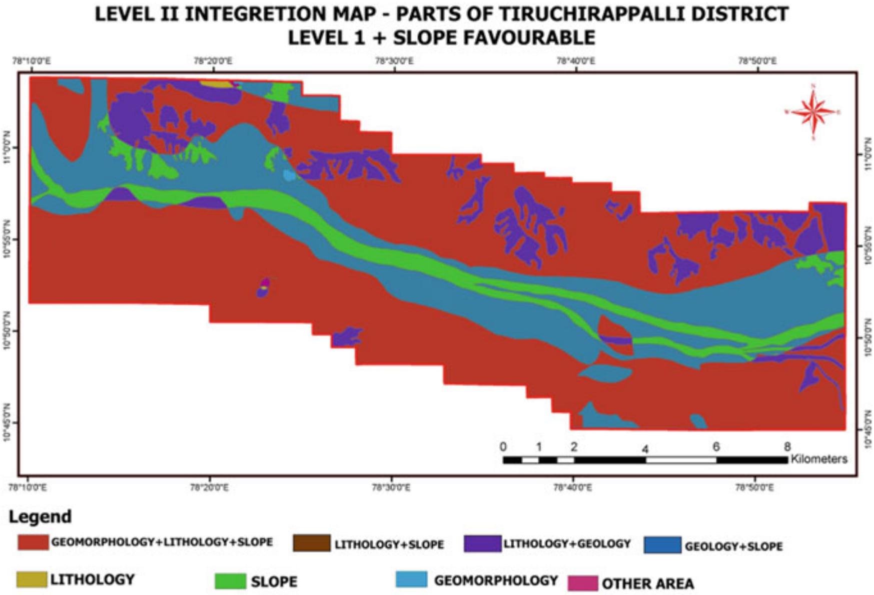

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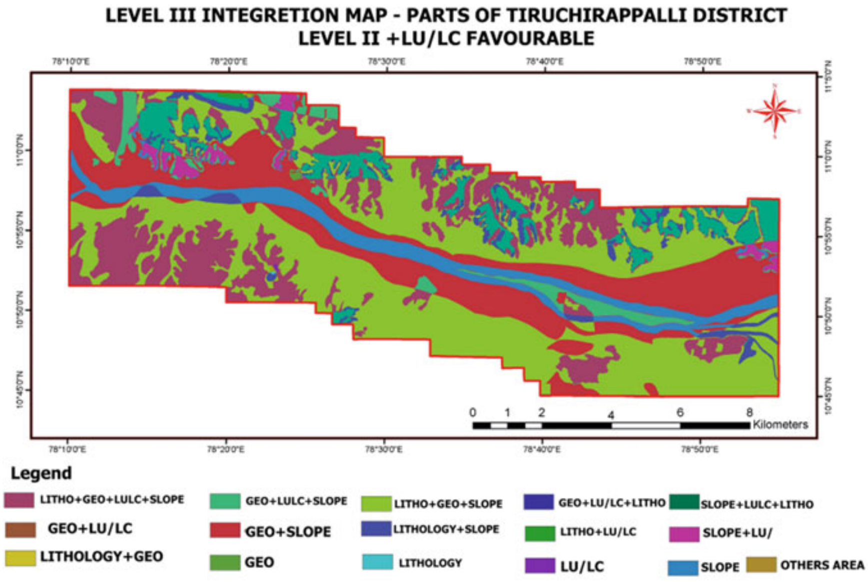
Fig. 14.10 **a** Level I integration map. **b** Level II integration map of the study area



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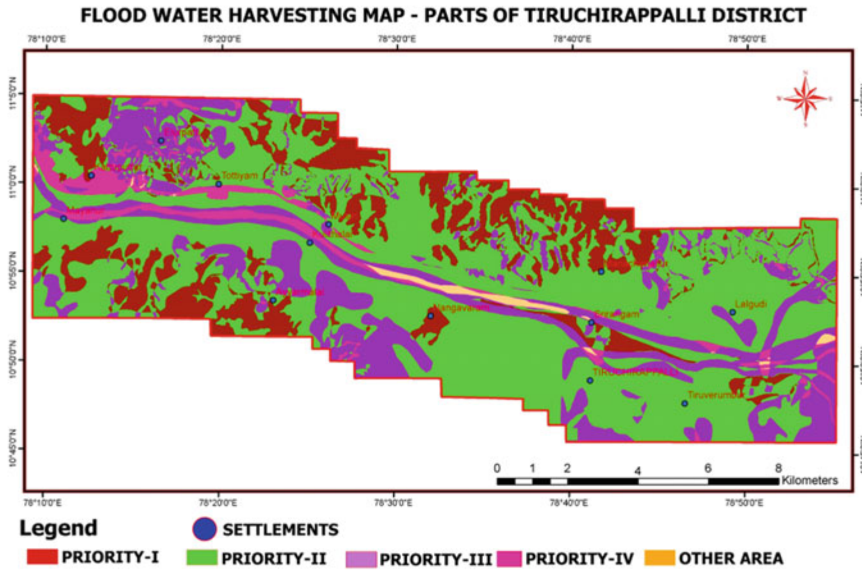

(b)

Fig. 14.11 **a** Level III integration map. **b** Flood water harvesting map of the study area

14.4 Flood Water Harvesting (Final Output)

Level III output map was divided into 5 categories and the final output map for the identification of suitable locations for floodwater harvesting was produced using the various thematic layers by GIS analysis with the results which are given in Fig. 14.11b as PRIORITY-I, PRIORITY-II, PRIORITY-III, and PRIORITY-IV, another AREA has been derived.

14.4.1 Pitting and Recharge Ponds

The drainage density map was dissolved into two categories by taking features high, very high, moderate density is taken as favorable zones for Pitting and Recharge Ponds and remaining areas such as low, very low (unfavorable) zones. With a dissolved output map, the finally integrated output map has been generated by a floodwater harvesting map (Anbazhagan and Manivel 2010). Finally found out the areas suitable for harvesting floodwater through the Pitting and Recharge Ponds technique. The final output map is classified as highly favorable, moderate favorable, and least favorable.

14.4.2 Burrowing and Flooding

The slope map was dissolved into two categories by taking features 0–2° as favorable zones for Furrowing and Flooding and the remaining area such as 3–5 and 6–50° as unfavorable zones and dissolved the output map accordingly. Then finally this map has been integrated with the floodwater harvesting map and found out the suitable areas for harvesting floodwater to improve the groundwater level through Furrowing and Flooding (Asare-Kyei et al. 2015). The final output map is classified as highly favorable, moderate favorable, and least favorable.

14.4.3 Battery Wells

The maps of lineament density and lineament intersection have been dissolved into two categories by taking features high, very high, moderate density as favorable zones because they are highly porous and previous zones and can receive and infiltrate maximum flood water very quickly. Hence, in these areas, several boreholes can be drilled. The remaining areas such as low, very low are considered as unfavorable zones and a dissolved output map is generated. Then finally the output map and floodwater harvesting map are integrated to find the favorable areas to harvest the flood water through the Battery Wells technique (Chowdhury and Nag 2017; Kumari

2018) (Fig. 14.12a). The final output map is classified and presented as highly favorable, moderate favorable, and least favorable zones for harvesting floodwater during monsoon using a Battery Wells technique.

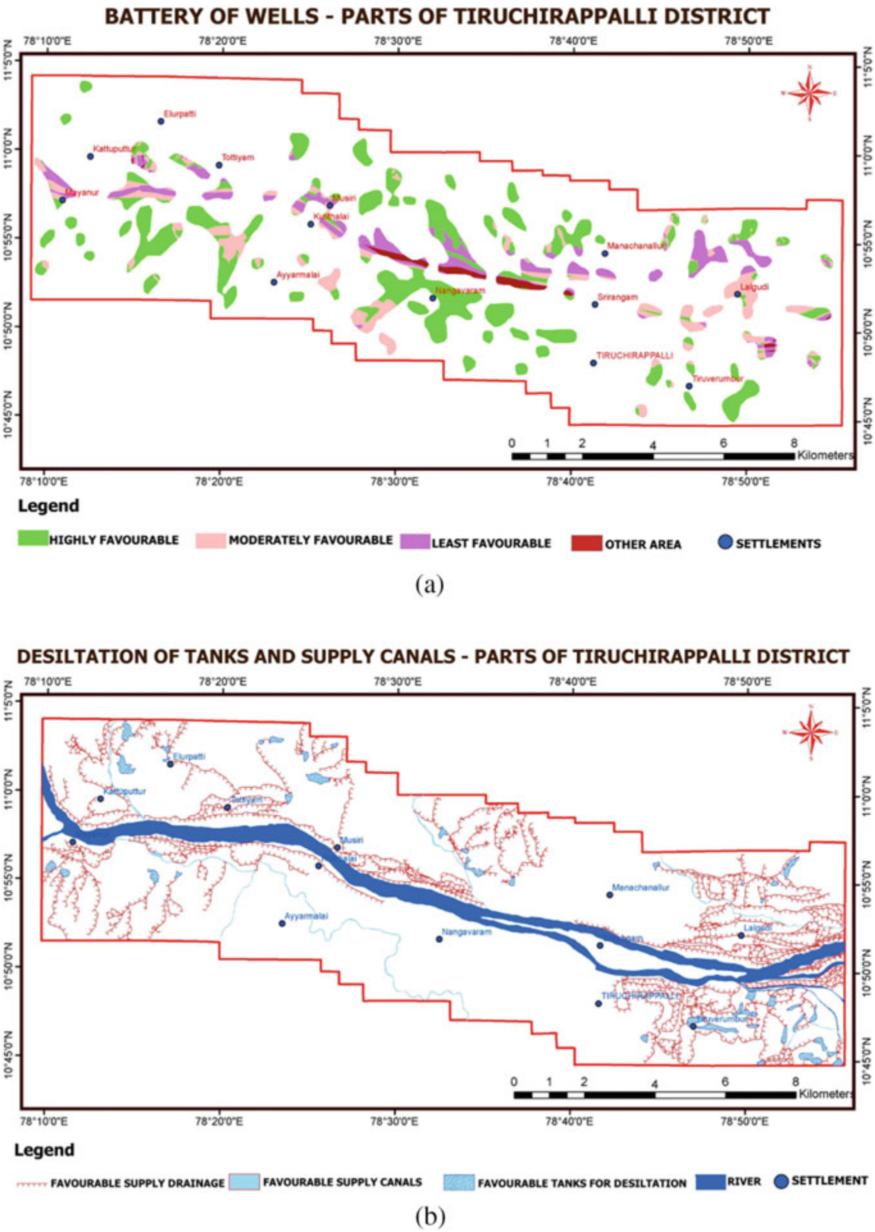

Fig. 14.12 **a** Battery wells. **b** Desiltation of tanks and supply canals maps for the study area

14.4.4 Desiltation of Tanks and Supply Canals

The drainage map was dissolved into two categories by taking the tanks and canals as favorable zones for desiltation of tanks and supply canals and remaining areas such as drainage are kept as unfavorable zones and a dissolved output map produced. Then finally this dissolved map has been integrated with the floodwater harvesting map to find out the Desiltation of Tanks and Supply Canals (Fig. 14.12b). The final output map is classified as highly favorable, moderate favorable, and least favorable zones for adopting the desiltation technique before the monsoon.

14.5 Results and Discussion

The various thematic maps were developed from GIS techniques. Among which the Geomorphology is a very important parameter for deciding zones for harvesting floodwater. Geomorphologically, the area has covered with Inselbergs, Residual hills, Colluvial fill, rocky sediment, shallow pediment, moderate pediment, deep pediment, older flood plain, younger flood plain, etc. Flood vulnerable zones are identified in the study area shows there are several such areas seen throughout the study area on either side of the river Cauvery. There are a lot of such polygons seen surrounding the Tiruchirappalli city and Tiruverumbur area and also on the north-east as an E–W strip north of Lalgudi area.

To preserve these areas from flooding, several canals have to be laid starting from the upstream side, aligned out of these low-lying areas toward the outreaches where there is actual water need. To harvest the flood water in the study region, suitable sites were identified by integrating various geo-parameters. The high priority zones are seen in little elevated and on either border sides of the study area for harvesting floodwater. These areas have to be connected by laying canals from the upstream areas in the western side of the river Cauvery for diverting floodwater, storing, and recharging the ground. A separate study can lead to identifying suitable alignment for constructing such canals. Then the suitable areas have been identified for implementing different floodwater harvesting techniques again using precise conditions existing in the study area. There are so many areas identified as highly suitable for harvesting floodwater through the Flooding and Furrowing technique in the study region. Similarly, several regions were found favorable for adopting the Battery Wells technique. Hence, the supply canals and tanks available in the study area have to be de-silted periodically before monsoon so that the floodwater can be easily diverted without any obstruction in the canals.

The map prepared was by using flood vulnerable maps and drainage maps. Overlay the flood vulnerable map and drainage map and finally find out to minimize the flood area. There is one big canal to drain the floodwater in the southern part of the study area, so these forms of canal construction help to mitigate the flood automatically in the future. Maps showing different techniques for recharging the groundwater in the

Table 14.1 Identification of suitable area to divert floodwater

Layers	Favorable zone	Unfavorable zone
Lithology	Soil, alluvium, and weathered gneiss	Compact hard unaltered exposed Charnockite rocks
Geomorphology	Deep pediment, moderate pediment, colluvial fill, flood plain (older, younger)	Shallow pediment, rocky pediment, gulley's
Slope	0–2 and 3–5°	6–50°
Land use/land cover	Fallow land, scrub land	Crop land settlement

Table 14.2 Flood water harvesting in favorable zone and unfavorable zone

Flood water harvesting technique	Thematic layer	Favorable zone	Unfavorable zone
Pitting and recharge ponds	Drainage density	High, very high, moderate density	Low, very low density
Burrowing and flooding	Slope map	0–2°	3–5 and 6–50°
Desiltation of tanks and supply canals	Drainage map	Tanks and canals	Drainage
Battery of wells	Lineament density	High, very high, moderate density	Low, very low density

priority areas lead to an idea that more canals need to be laid to bring the monsoonal flood water to these areas. Further studies are warranted to lay new canals that have to be constructed to divert the floodwater during monsoon to link the tanks, lakes, and reservoirs in nearby villages and to floodwater harvesting areas (Tables 14.1 and 14.2).

14.6 Conclusion

The current study has shown that satellite data is very useful in the preparation of various thematic maps such as Lineament, Geomorphology, Slope, Drainage, and Land use and Land Cover. Even with minor info, it provides fast and precise data for easy mapping on a GIS platform. All of the above different thematic maps were digitized, GIS data-based using ArcGIS 10.2, and analyzed using ENVI 4.5 digital image processing software. The GIS tool provides a variety of scenarios that are generated and studied before the finalizing of plans for implementation. From the analysis of thematic layers, the suitable intersection areas for flood water harvesting have been delineated and mapped. Further, suitable areas for adopting different floodwater harvesting cum recharge techniques are also be identified. High favorable zone for pitting and recharge ponds was found in the upstream direction of the river banks. All the parts of CRB are mostly favorable for burrowing and flooding whereas battery wells can be constructed very nearer to the river banks where the lineament density is more. Distillation of tanks with feeder canals is favorable in some parts upstream and downstream directions. This study concludes that remote sensing, digital image processing, and GIS becomes very effective technology for flood vulnerable zone mapping, floodwater harvesting, and suggesting management plans to improve the quantity as well as the quality of the groundwater. Further studies are warranted to delineate several suitable canal alignments for diverting flood water to water starving outer areas.

Acknowledgements This work was supported by Department of Geology, Faculty of Science, Alagappa University, Karaikudi, Tamil Nadu, India. This article has been written with the financial support of RUSA—Phase 2.0 grant sanctioned vide letter No. 24-51/2014-U, Policy (TNMulti-Gen), Department of Education, Government of India, Dated. 09.10.2018.

Conflicts of Interest No conflict of interest was declared by the authors.

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