IDENTIFICATION OF SUITABLE AREAS FOR WATER HARVESTING USING GIS AND WATERSHED MANAGEMENT FOR CROPS IN TIPPASANDIRAM WATERSHED OF CAUVERY BASIN

Thesis submitted in part fulfilment of the requirement for the Degree of

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SOIL AND WATER CONSERVATION ENGINEERING

to the Tamil Nadu Agricultural University, Coimbatore.

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CERTIFICATE

This is to certify that the thesis entitled **"IDENTIFICATION OF SUITABLE AREAS FOR WATER HARVESTING USING GIS AND WATERSHED MANAGEMENT FOR CROPS IN TIPPASANDIRAM WATERSHED OF CAUVERY BASIN"** submitted in part fulfilment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY (SOIL AND WATER CONSERVATION ENGINEERING),** faculty of Agricultural Engineering to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **A.SELVAKUMAR** under my supervision and guidance and that no part of thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and the work has not been published in part or full in any scientific or popular journal or magazine.

Place: Coimbatore

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Date: (**A.Selva Kumar)**

ABSTRACT

IDENTIFICATION OF SUITABLE AREAS FOR WATER HARVESTING USING GIS AND WATERSHED MANAGEMENT FOR CROPS IN TIPPASANDIRAM WATERSHED OF CAUVERY BASIN

By

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Rain Water Harvesting technologies have a high potential of contributing towards eradicating poverty and hunger, provision of safe drinking water and sanitation, ensuring environmental sustainability, promoting gender equity and women empowerment. It is one way of improving the living conditions of millions of people, particularly those living in the dry areas. Water scarcity especially for domestic and agricultural purposes compromises the role of women in food production. Hence, provision of water by promoting rainwater harvesting and management technologies reduces the burden for rural women thus increasing their productivity.

Keeping this fact in mind, this study was carried out in Tippasandiram watershed of Cauvery basin at Krishnagiri district of Tamil Nadu. The study will help the Government and Non Government Organizations (NGOs) to implement the suggested development measures in the different potential zones for rain water harvesting. Also it will help the farming community to construct the site specific water harvesting structures at favourable zones in order to store the surface water for supplemental use, thereby irrigation frequency will be increased to facilitate maximum yield.

Toposheets of the study area obtained from SOI on 1: 50,000 scale, soil map and land use map were scanned, georeferenced and digitized to get final thematic maps. Contour map was prepared from toposheets. All the contours present in the toposheets were digitized and rasterization was done to get digital elevation model. Slope map (in per cent) was derived from digital elevation model. Reclassification was carried out to reclassify the slope map into four

classes namely, low, less moderate, moderate and high. All the thematic maps were converted into raster format.

Ranking was given to criteria according to their response to water harvesting process for surface storage. In case of soil, highest ranking was given to clay and lowest ranking was given to sandy loam and loamy sand. In case of topography, highest ranking was given to low slope (0-1per cent) and lowest ranking was given to high slope (> 5 per cent). In case of land use/land cover, highest ranking was given to water body followed by fallow land and lowest ranking was given to land with scrub, forest land and settlements. Weightage is the term coined for assigning the value (out of 100) to a particular theme according to its importance to the study. Considering the soil, slope and land use of the study area, highest weightage was given to soil followed by slope and lowest weightage was given to land use / land cover.

After assigning suitable ranking and weightage to the various parameters, weighted overlay analysis was carried out to identify the suitable sites for water harvesting. After weighted overlay analysis, final result map was obtained from which suitable sites for water harvesting were identified. There are four zones found for water harvesting process which are most favourable zone, favourable zone, moderately favourable zone and poorly favourable zone having an aerial extent of 0.72, 318.82, 618.34 and 169.12 ha respectively. Weighted overlay map shows that most of the study area falls under moderately favourable zone. Water harvesting bundhis were suggested for most favourable zone. Farm ponds were suggested for favourable zone and check dams were suggested for moderately favourable zone. No recommendation of water harvesting structures suggested in the poorly favourable zone of the study area due to its poor storage conditions. A horticultural crop, Mango with drip irrigation system was suggested.

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LIST OF SYMBOLS AND ABBREVATIONS

%	-	Per cent
>	-	More than
AED	-	Agricultural Engineering Department
AHP	-	Analytical Hierarchy Process
CEC	-	Cation Exchange Capacity
cm	-	Centimeter
DEM	-	Digital Elevation Model
EC	-	Electrical Conductivity
ESP	-	Exchangeable Sodium Percentage
ESRI	-	Environmental System Research Institute
GCS	-	Geographic Coordinate System
GIS	-	Geographic Information System
ha	-	hectare
IDA	-	Immediate Downstream Area
IMSD	-	Integrated Mission for Sustainable Development
INCOH	-	Indian National Committee on Hydrology
IRS	-	Institute of Remote Sensing
Km^2	-	Square kilometer
Km^3	-	Cubic kilometer
lit	-	liter
m	-	Meter
m^3	-	Cubic meter

mcft	-	million cubic feet
MCM	-	Million Cubic Meter
mm	-	Millimeter
NCWI	-	Normalized Cumulative Weighted Index
NGOs	-	Non Government Organizations
PCS	-	Project Coordinate System
RVP	-	River Valley project
RS	-	Remote Sensing
SAT	-	Semi Arid Tropics
SOI	-	Survey Of India
SYI	-	Sediment Yield Index
TNAU	-	Tamil Nadu Agricultural University
USDA	-	United States Department of Agriculture
WLC	-	Weighted Linear Combination
WMS	-	Watershed Modeling System
WSA	-	Water spread Area
WRO	-	Water Resource Organization

CHAPTER I

INTRODUCTION

Water is the elixir of life, a precious gift of nature to mankind and millions of other species living on the earth. It is fast becoming a scare commodity in most part of the world. Water resources comprising of surface water (river and lakes), groundwater and coastal waters, support all living things including human beings.

1.1 World Water Resources

It is estimated that in the world the available water is sufficient even if the population is increased to 25 billion (i.e. 4 times of the present population), provided it is spatially distributed uniformly. In India, it is estimated that the available water resources can a feed a population of 1650 million.

The total water present in the earth is about 1.41 billion km^3 of which 97.5 per cent is brackish and only 2.5 per cent is fresh water. Out of 2.5 per cent, 2.175 per cent is in ice caps and in glaciers and the balance of 0.325 per cent only is available fresh water. It means if the total water on the earth is 100 litres, usable water is only 0.325 litres. Of this usable water, 30 per cent is stored as groundwater. According to Serageldin (former vice president, World Bank) 22 of the world's countries currently have renewable water supply less than 1000 m^3/capita/year which is classified as a scarce condition. Further the World Bank estimates that by the year 2025, one person in three i.e.3.25 billion people in 52 countries will live in conditions of water shortage.

Table 1.1 Per capita water availability in some selected countries.

Country	m^3/person/year
World	7,000
USSR	20,000
USA	10,000
China	2,500
Israel	450
India (Tamil Nadu)	2,200 (800)

Source: Water management for sustainable Agriculture, 2008.

1.2 Indian Scenario

India is one of the most well endowed countries with an annual average rainfall of 119.4 cm and has about four per cent of world's fresh water. Although India occupies only 3.29 million km^2 geographical area, which forms 2.4 per cent of the world's land area, it supports over 15 per cent of the world's population. Thus, India supports about $1/6^{th}$ of world population, $1/50^{th}$ of world's land and 1/25th of world's water resources. India also has a livestock population of 500 million, which is about 2 per cent of the world's total livestock population. More than half of these are cattle, forming the back bone of Indian agriculture. The total utilizable water resources of the country are assessed as 1086 km^3.

Table 1.2 Water Resources of India and Tamil Nadu

Source	India	Tamil Nadu
Total Rain	400 M ha m	12 M ha m
Surface Water	187 M ha m	2.42 M ha m
Ground Water	43 M ha m	2.24 M ha m

Source: Water management for sustainable Agriculture, 2008.

1.3 Water Resource of Tamil Nadu

The annual average rainfall of Tamil Nadu is about 925 mm compared to India's average of 1194 mm. The total rainfall over Tamil Nadu is about 12 M ha m per year. The immediate loss after rainfall, like evaporation, interception etc. may be in the order of 40 to 50 percent. A part of rain water flows as runoff in the rivers/streams and accumulates in the tanks, while the other part percolates into the ground as soil moisture and groundwater etc.

1.3.1 Surface Water

The surface water availability in Tamil Nadu has not been consistent over the past several years due to uncertain rainfall events. According to the Irrigation Commission in 1972, the annual surface flow in all the rivers of Tamil Nadu was estimated as 3.18 M ha m. Subsequently, Kumarasamy (1974) estimated the utilizable run off in all the rivers of Tamil Nadu as 2.49 M ha m. Subsequently, in 1998, the Water Resource Organization (WRO) of the government of Tamil Nadu estimated the total surface water potential of the river basins of Tamil Nadu, except Cauvery basin, at 75 percent dependability, as 1.31 M ha m. According to the 1974 estimate the utilizable runoff water in Cauvery was about 1.02 M ha m. Combing the WRO estimate of 1998 and the 1974 estimate for Cauvery, total utilizable surface water quantity in Tamil Nadu was at the figure of 2.33 M ha m. It should be noted that of this amount, more than 95 percent has already been utilized for various purposes.

1.4 Water Harvesting Technology

In scientific terms, water harvesting refers to collection and storage of rainwater and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage and all other hydrological studies and engineering inventions, aimed at conservation and efficient utilization of the limited water endowment of physiographic unit such as a watershed. Rain is the primary source of water for all. There are two main techniques of rainwater harvesting:

a) Storage of rainwater on surface for future use.

b) Recharge to groundwater.

Directly collected rainwater can be stored for direct use or can be recharged into the groundwater. All the secondary sources of water like rivers, lakes and groundwater are entirely dependent on rain as a primary source.

In India, water harvesting technology is as old as civilization since it is the art and science of survival. Historical records show the ancient practices of surface runoff water harvesting for irrigation in the southern states of semi arid tropics (SAT) representing red soils. Tank based water conservation and irrigation have existed since Vedic times. Numerous tanks constructed for water harvesting in the olden days especially in the south and north western parts of the country. Small ponds called 'Oorunis' to collect and store water in each village for drinking purposes can be seen in most of the southern districts in Tamil Nadu. In addition Temple tanks/ponds were also constructed in all the big temples for the drinking, cultural and religious functions. Further farmers used to construct storage ponds in the lower portion of their land to be used for animals and growing trees.

The objective of water harvesting in India differs between urban and rural areas. In urban areas, emphasis is put on increasing groundwater recharge and managing storm water. On the other hand, in rural areas securing water is more crucial. There the aim is to provide water for drinking and farming, especially for life-saving irrigation, and then to increase groundwater recharge.

1.5 Need for Water Harvesting

Water becomes a scarce commodity and it is considered as a liquid gold in this part of the country. The demand of water is also increasing day by day not only for agriculture, but also for household and industrial purposes. It is estimated that water need for drinking and other municipal uses will be increased from 3.3 M ha m in 2020 to 7.00 M ha m in 2025. Similarly the demand of water for industries will be increased by 4 fold i.e. from 3.0 M ha m to 12.00 M ha m during this period. At the same time more area should be brought under irrigation to feed the escalating population of the country, which needs more water. But in fact for the future generation, even a litre will not be available more than the present situation.

Surface water sources fail to meet the rising demands of water supply in urban areas. Groundwater reserves are being tapped and over-exploited resulting into decline in groundwater levels and deterioration of groundwater quality. This precarious situation needs to be rectified by immediately recharging the depleted aquifers.

Hence, the need for implementation of measures to ensure that rain falling over a region is tapped as fully as possible through water harvesting, either by recharging it into the groundwater aquifers or storing it for direct use.

1.6 Role of GIS in identification of water harvesting sites

GIS in combination with Remote Sensing is found effective in preparing and maintaining database and carrying out analysis related to natural resources management. GIS can be very useful in integrating, modeling and visualizing different types of data. Repetitive tasks like data feeding, updating, processing, querying, analysis, generation of thematic maps and statistics are some of the important areas where GIS plays a major role. GIS combined with remote sensing has applications in site selection for agricultural development, water harvesting structure, waste land and mapping, soil resources mapping, groundwater potential mapping, geological and mineral exploration and in various fields of environmental impacts of water resources and management issues. The work aimed at exploring the usage of such a dynamic and efficient tool in the selection of locations for water harvesting structures in Tippasandiram watershed of Cauvery basin at Krishnagiri district.

1.7 Need for the study

As already mentioned, rainfall is the major sources of water in Tippasandiram watershed and gets an average annual rainfall of 813 mm. Major part of this water simply runs off without usage.

Currently, majority of the area is unirrigated and there are few efforts to store the rain water. If the rainwater is harvested it will help in growing crops more than once in a year. Thus an attempt has been made to select suitable water harvesting sites for storing the rainwater.

1.8 Objectives

Comprehensive watershed development programme has been implemented in all the parts of our country to augment the groundwater recharge and to improve the surface resources since the seventh plan. Now it is necessary to improve the surface water resources on the regional basis so that rural areas can be improved. Having this concept, a study to identify the sites suitable for rain water harvesting was proposed. For this study Tippasandiram watershed of Cauvery basin at Krishnagiri district was selected. River Valley Project Works for Tippasandiram watershed were carried out by Government of Tamil Nadu, Agricultural Engineering Department, Krishnagiri. The study will help the Government Organizations and Non Government Organizations (NGOs) to implement the suggested development measures in different zones for rain water harvesting. Also it will help the farming community to construct the site specific water harvesting structures at favourable zones in order to improve the surface water level of the watershed thereby irrigation frequency will be increased to facilitate maximum yield.

Keeping this in view, an attempt was made to select suitable sites for rain water harvesting in Tippasandiram watershed of Cauvery basin at Krishnagiri region of Tamil Nadu (Fig 1.1) using GIS with following objectives.

i) To select suitable water harvesting structures in the identified area of the watershed.

ii) To study the impact of the existing water harvesting structures.

iii) To study the existing land use pattern and suggest suitable horticulture crops.

iv) To suggest suitable advanced irrigation methods for the selected

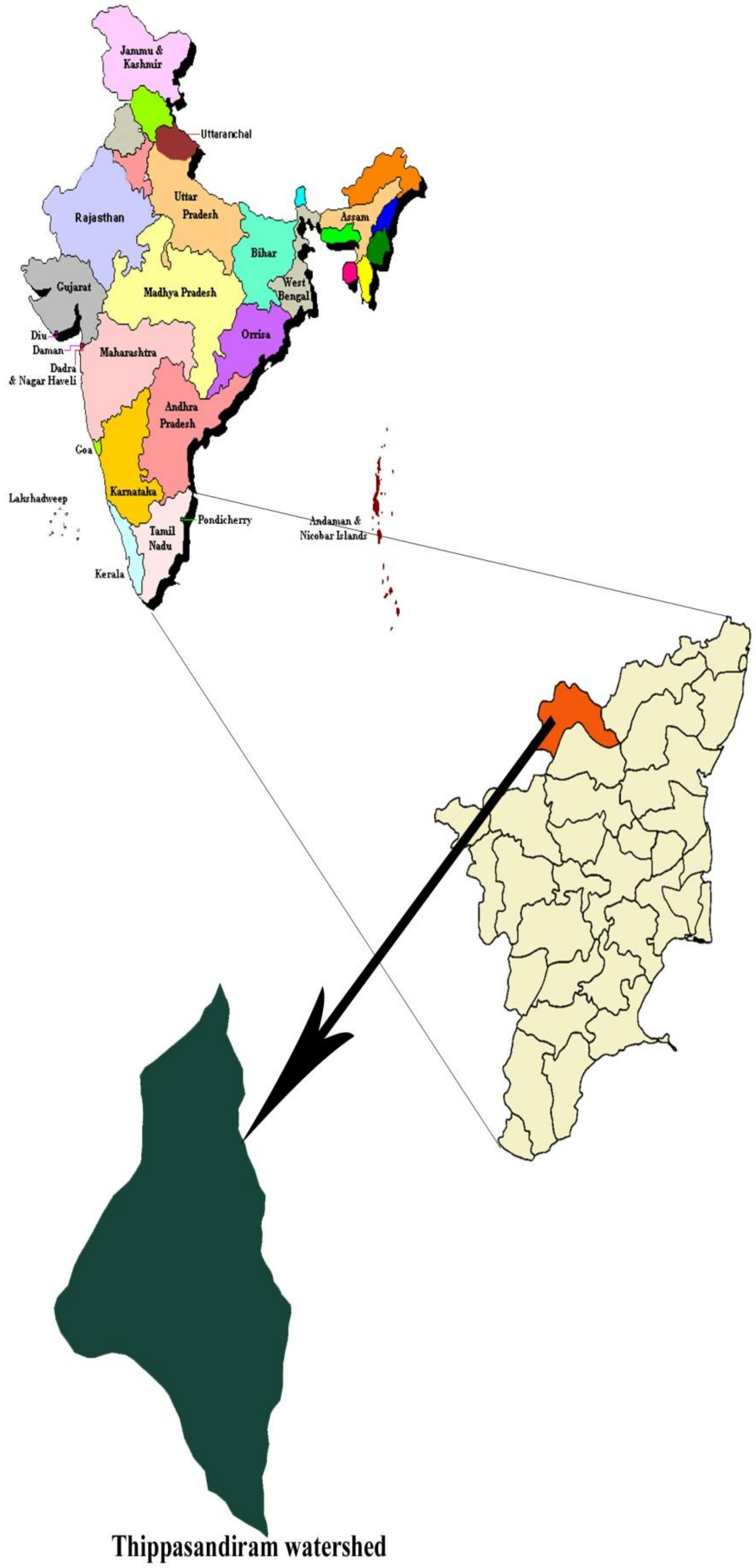

Fig.1.1 State map of India, District map of Tamil Nadu and Study Area

CHAPTER II

REVIEW OF LITERATURE

Over exploitation of available water reserves has lent us to the precarious situation of mining of water “the liquid gold”, if not an exaggeration. Prevailing situation of prolonged drought has now forced us to renew the ideas related to rain water harvesting. The collection and storage of rain water produced as runoff from an area treated to increase runoff. ‘Rain Water Harvesting’ is itself a very broad term. It can be sliced into different sub-components such as Rain Water Harvesting and Micro-catchment Water Harvesting etc.

The comprehensive literature pertaining to the Rain Water Harvesting studies, experiments carried out elsewhere in the world has been reviewed in this chapter in the following subheadings.

1. Remote Sensing and Geographic Information System for Water Harvesting Sites
2. Rain Water Harvesting
3. Micro-catchment Water Harvesting
4. GIS for watershed Management

2.1 Remote Sensing and Geographic Information System for Water Harvesting Sites

Padmavathy *et al*. (1993) made their study using GIS to select suitable sites for check dams for harvesting rain water in Alur taluk of Hassan district, Karnataka. Surface water harvesting was given priority and a suitable methodology had been developed for selecting sites for constructing check dams. Various thematic maps of the study area on 1:50,000 scale were used as input and analysed using ARC/INFO GIS package. Second and third order streams were selected and superimposed over lineament (fracture) map to avoid such segments of streams which are controlled by fractures to avoid weak zone/ seepages. Suitable sites were selected depending on contour and slope. Probable Water spread Area (WSA) and Immediate Downstream Area (IDA) were drawn. These polygons were intersected with different thematic maps to find out the suitability. Before intersecting, appropriate weightages (least suitable to most suitable in the scale of 1 to 5) were assigned to different classes of thematic maps keeping in mind that worst area only gets submerged in case of WSA while in the case of the IDA, weightages were assigned keeping in view of the requirement of water. Normalized Cumulative Weighted Index (NCWI) was developed to find out the suitability of the sites from the view point of natural resources. All the seven sites selected were found quite reasonable based on the NCWI values. The beneficiary villagers were identified. Field check had been carried out and it was observed that the sites were quite suitable.

Vorhauer and Hamlett (1996) produced maps showing the locations of suitable pond sites using GIS. Based on these maps, the watershed of each site was determined and the potential runoff to the pond was predicted using the Natural Resources Conservation Service Curve Number Method. Spreadsheet calculations were used for performing a water balance. Potential pond sites were selected for further consideration based on a slope of 8% or less, soil suitable for aquifer-fed ponds, and land areas not used for homesteads, croplands, utilities, roads, or streams. Using water balance calculations for 10 years of simulated climate data, the potential amount of water harvested at each site was determined. Using water harvesting potential, location, and negative impacts of a pond at a specific site as criteria, nine sites were ranked as most desirable.

Prinz *et al.* (1998) did their research work at the ICARDA, Aleppo, Syria with an aim of developing a methodology for the application of remotely data and GIS for identifying appropriate sites and methods of water harvesting in dry areas of West Asia and North Africa. The image processing software ERDAS IMAGINE and GIS software ARC/INFO were used to process the images and to establish a geo-information system comprising digital data sets of satellite imagery, topography, soil, vegetation, hydrology and meteorology. Using these tools, it was possible to identify areas generally suitable for water harvesting and to determine water harvesting techniques for those sites. The developed methodology was also applicable in other regions with similar conditions.

Ramprasad *et al.* (2000) used Arcview, a powerful desktop GIS to make an attempt for the identification of potential water harvesting sites which can fulfil both the drinking and irrigation needs of the population living in the Sadiyagad watershed. The GIS and Remote Sensing techniques provided the base information on the land –cover and land use maps, the pattern and placement of villages, forest, agriculture land and road network. Using an elevation contour map prepared in ArcInfo (version3.4); a Digital Elevation Model was prepared in ArcView (version 3.0) on a desktop computer system. From the DEM model, models for flow direction, flow accumulation, stream channels and finally Unique Basins to split the whole watershed into 9 basins were developed. Spring criteria and stream criteria maps were developed using the land use and infrastructure maps to reach final target of finding the suitable sites for the construction of storage tanks. 40 sites were identified for harvesting runoff water for the purpose of irrigation and other domestic uses. Out of these, 21 sites were within 100 m from the road and easily accessible; finally it was concluded that about 50 km^2 area can be irrigated within ½ km distance from these potential sources in the Sadiyagad watershed.

Wan Yusofl *et al*. (2000) developed a criteria to locate reservoirs in Langkawi Island, Malaysia taking into consideration all relevant factors including; topography, geology, hydrology, location in relation to both abstraction and supply points, land use/cover types and settlements. A satellite imagery and digitised geological and elevation maps were analysed and used to generate the necessary data layers to satisfy various conditions within the established criteria. Then, IDRISI, a raster based GIS was employed to implement the criteria using two different methods to combine the information layers. First, the Boolean method and second, the Weighted Linear Combination (WLC) method which grouped the layers and graded them according to their perceive importance. The Boolean method produced five reservoir sites located at the northern, southern and eastern part of the Island. Whilst, the WLC method produced five sites located mainly towards the central area of the Island. Comparing these outcomes with a field based study with a similar objective on the Island, which identified six suitable reservoir sites, showed that two of the sites located using the Boolean method and four of the sites identified using the WLC method have corresponded well with the field-based study sites. Their study indicated that the developed criteria for locating reservoirs were sensitive to the physical, environmental and economical settings on the Langkawi Island.

Rajashree *et al.* (2002) used a decision support system "WARIS" for identification of suitable sites for water harvesting structures in upper Betwa watershed of Betwa basin, which covers 1385.61 sq.km area. Theme layers such as land use/ land cover, soil, slope, hydrogeomorphology etc which affect the identification of suitable sites were generated in Arc/INFO environment. The themes were then integrated to generate a composite coverage. A buffer of 1 km around second and third order drainage was constructed. Suitable weights were given to all the categories in each theme. The cumulative weighted values were calculated for each polygon of the composite theme map falling within buffer area. Three suitability zones namely, most suitable, more suitable and suitable were generated from cumulative weighted value. Lineament map was also superimposed over the suitability zones. Various water harvesting structures like contour bund, anicuts, farm ponds etc were suggested in the area. WARIS has provided a guided flexible approach for identification of suitable sites making it versatile for any type of terrain.

Durga Rao and Bhaumik.(2003) availed a user friendly Spatial Expert Support System (SESS) for identifying suitable sites for water harvesting structures such as check dams, farm ponds, and groundwater recharge tanks. The developed system had been used to identify potential sites for water harvesting in the Song watershed, India. Basic input layers required for this study such as a digital elevation model, landuse, soils, drainage, geology, and buffer map for utility points were generated in a geographic information system (GIS). Technical guidelines suggested by the Integrated Mission for Sustainable Development (IMSD), and the Indian National Committee on Hydrology (INCOH), had been used as decision rules in the knowledge base shell of the developed SESS. Monthly water balance had been estimated using remote sensing and GIS techniques to augment the proposed water harvesting structures. The knowledge base can suitably be modified as and when required on the basis of other expert knowledge if found more judicious in this present context.

Ninad Bhodhankar (2003) used a commercially available software Surfer for his study. Contours were digitized, on screen, from the scanned base map. These data were then interpolated to obtain intermediate contour lines. Using the contour data, a wireframe map was generated to visualize the topography and ground slope variation in three-dimension. Vectors were emplaced over contour and wireframe maps to evaluate the gradient variation in topography. The vector map aided in emphasizing the correlation of ground slope and surface water flow for the topographic analysis of landform for the siting of surface water harvesting structures. Vector maps could be guiding tool for the construction of surface water runoff structures/traps for augmentation of artificial recharge. It was concluded that this was a very fast and reliable method to evaluate the utility of the proposed structure to be used for surface water harvesting before actual construction, and it could be of a help to evaluate the suitability of the structure for its maximum utilization.

Paritosh Gupta *et al*. (2003) used GIS for watershed delineation for the proposed and existing irrigation schemes for some districts of the state of Jharkhand, India. The types of schemes were check dams, Ahar, Ponds etc. In order to carry out watershed analysis of various irrigation schemes, ArcHydro tools were used. ArcHydro is a geo spatial and temporal data model for water resources that operates within ArcGIS. ArcHydro has an associated set of tools that populate the attributes of the features in the data framework, interconnect features in different data layers, and support watershed analysis. Watershed areas of all the irrigation schemes were calculated and saved as polygon feature classes using ArcHydro tools.

Sreedhar Reddy and Deva Pradap. (2003) adopted an integrated remote sensing and GIS based methodology for identifying the suitable sites for artificial recharge structures and water harvesting structures in the chosen study area located in the Jangaon and the Lingala Ghanpur mandals of Warangal District, Andhra Pradesh, India. IRS p6 (Resourcesat-I) – LISS III Precision geocoded FCC data on 1:50,000 scale and field observation data were used for extracting thematic information such as geomorphology, geological structures, soil, land use/land cover, well locations, drainage pattern etc. of the area. Slope map and flow accumulation maps were prepared using Survey of India toposheets on 1:50,000 scale. Soil erosion map of the study area was prepared using universal soil loss equation (USLE). The various thematic layers and field observation data were integrated into GIS and various spatial and non spatial queries were performed. The suitable sites of installation of artificial recharge structures and water harvesting structures were identified.

Jabr and El-Awar. (2004) developed a methodology for siting water harvesting reservoirs and applied in a 300 km^2 area of Israel-Lebanon characterized by low and erratic precipitation to improve the agriculture potential. This involved development and application of a three-step Hydro-Spatial Analytical Hierarchy Process (AHP). First ArcGIS was used to produce pertinent spatial coverages. In the second step, Watershed Modeling System (WMS) was used to simulate the runoff in the watersheds. Finally, in the third step, a decision hierarchical structure using the AHP was developed and implemented to rank various potential reservoir sites according to their suitability expressed in terms of a Reservoir Suitability Index. As a practical outcome of this study, a water harvesting reservoir was actually excavated at the outlet of the highest ranking watershed.

Nooka Ratnam *et al.* (2005) used Sediment Yield Index (SYI) model and results of morphometric analysis had been used to prioritize watersheds and to locate sites for check dam positioning in Yarafeni watershed in Midnapur district, West Bengal. Various thematic maps such as land use/land cover, slope, drainage, soil etc. were prepared from IRS I D LISS Ill digital data, SOl toposheets of 1:50,000 scale and other reference maps. Morphometric parameters such as Bifurcation ratio (Rb), Drainage density (Dd), Texture ratio (T), Length of overland flow (Lo), stream frequency (F.), compactness coefficient (Co), circularity ratio (Pc), elongation ratio (Er), shape factor (Bs) and form factor (Rf) were computed. Automated demarcation of prioritization of micro-watersheds was done by using GIS overlaying technique by assigning weight factors to all the identified features in each thematic map and ranks were assigned to the morphometric parameters. Five categories of priority viz., very high, high, medium, low and very low, were given to all the watersheds in both the methods. Sixty-two micro-watersheds using SYI method and twenty-three micro watersheds using morphometric had been prioritized as very high priority. Final priority map was prepared by considering the commonly occurred very high-prioritized micro-watersheds in both SYI model and morphometric analysis. Twenty-four suitable sites were identified for check dam construction in 21 highly prioritized watersheds. It was proved that integrated study of SYI model and morphometric analysis yielded good result in prioritization of watersheds.

Santasmita Das and Paul (2006) found that the choice of site for small hydro in the inaccessible tracts of Himalayan region was a difficult task by the conventional methods. They made an attempt to use GIS and Remote Sensing technology to arrive at various alternative sites available in the study area and finally to select the most technically suitable site. The Soil Conservation Service (SCS) Curve Number (CN) method had been utilized to identify the monthly average runoff of the site. The distributed curve number technique had been used in this work.

Narendra *et al*. (2006) studied the morphometry of Meghadrigedda watershed, Visakhapatnam using GIS for the construction of check dams. The morphometric parameters such as linear aspects and aerial aspects of six sub-watersheds of the watershed were determined and computed. The drainage pattern was mainly dendritic type. The six sub-watersheds were elongated in shape. Twelve recharge pits were located to excavate silted water tanks. To improve the ground water levels, thirteen suitable sites were identified for the construction of check dams in the Meghadrigedda watershed.

De winnaar *et al.* (2007) found the representation of spatial variations in landscape characteristics such as soil, land use, rainfall and slope information to be an important step in identifying potential runoff harvesting sites. In their study, Geographic information systems (GIS) was used as an integrating tool to store, analyse and manage spatial information and when linked to hydrological response models, provided a rational means to facilitate decision making by providing catchment level identification, planning and assessment of runoff harvesting sites as illustrated by a case study at the Potshini catchment, a small sub-catchment in the Thukela River basin, South Africa. Through the linked GIS, potential runoff harvesting sites were identified relative to areas that concentrate runoff and where the stored water will be appropriately distributed. Based on GIS analysis, it was found that 17% percent of the Potshini catchment area had a high potential for generating surface runoff, whereas an analysis of all factors which influenced the location of such systems, shown that 18% is highly suitable for runoff harvesting. In their study paper, output from the integrated GIS modelling system was presented using suitability maps. It was concluded that providing an accurate spatial representation of the runoff generation potential within a catchment is an important step in developing a strategic runoff harvesting plan for any catchment.

Mbilinyi *et al.* (2007) used a geographic information system (GIS)-based decision support system (DSS) that uses remote sensing (RS). The input into the DSS included maps of rainfall, slope, soil texture, soil depth, drainage and land use/cover and the output maps were showing potential sites of water storage systems, stone terraces, bench terraces and borders. The Model Builder in the Arc View GIS was used as a platform for the DSS. Two sites in the Makanya watershed, in Kilimanjaro Region, Tanzania, were used for testing and validation of the DSS. The results reflected specific suitability levels of parameters and weight of factors; for example, near streams (drainage) with slope ranges from moderately steep to steep (10^0- 30^0) are potential sites for water harvesting locations whereas moderately undulating to steep slopes (5^0- 30^0) with unstable soils are potential sites for stone terraces. Moderately undulating slopes (5^0-10^0) with clay, silt clay and sandy clay soils are potential sites for bench terrace and gently undulating slopes (2^0- 5^0) with clay, silt clay and sandy clay soils were potential sites for borders. The results from testing and validation of the developed DSS indicated that the tool can be used reliably to predict potential sites for RWH technologies in semi-arid areas.

Most of predicted RWH technologies during testing were found within very highly and highly suitable locations (41.4% and 40%, respectively) also in validation 36.9% of RWH technologies were found within the moderately suitable followed by very highly suitable and highly suitable both with 23.6%. Despite the good results, it was recommended that more work had to be carried out to refine the model and to include other pertinent ancillary data like socio-economic factors to increase its usefulness.

Ahmedou ould cherif Ahmed *et al.* (2007) chose the Adrar region of Northern Mauritania covering the main watersheds of Atar district(Wadi Seguelli) and Aoujeft district (wadi Labiodh) with an aim of identifying suitable sites for water harvesting (WH) in the arid zone of Northern Mauritania (oasis area) using Landsat imagery and GIS technology. The combinations of different thematic layers prepared from remote sensing images and ancillary data, such as land cover, geology, slope, drainage, geomorphology and lineament using weighted overlay technique permitted an effective way for monitoring and planning natural resources. The suitability analysis results reflected the limitations of suitable areas, which were concentrated at the wadi's beds along the valley zone with 1.4% of excellent to high suitability.

Sekar and Randhir (2007) developed a spatially explicit method to evaluate costs of harvesting and potential benefits in water harvesting in the Taunton River Watershed in Eastern Massachusetts, USA. A spatial analysis was used to assess surface storage and groundwater recharge potentials in developed and undeveloped regions of the watershed. Distributed parameters used in the analysis were runoff coefficients, land use, soil properties, precipitation, aquifer and land price. Prioritization maps were developed to characterize conjunctive harvesting potential that was based on benefits and costs. The results demonstrated that a spatially variable harvesting strategy could be used to minimize runoff loss and to augment water supplies. The potential harvest areas were clustered in specific locations that satisfy feasibility and economic criteria. In some sub-watersheds, potential harvest locations were dispersed. A spatially variable approach that incorporated economic criteria to hydrologic assessment could be used to enhance efficiency related to water harvest and supply management. Given the increasing demand for clean water, a distributed and conjunctive harvesting strategy could be effective in several urbanizing watersheds. The model had potential for further extension into complex situations of biophysical and socioeconomic conditions at watershed level.

Wifag Hassan Mahmoud *et al.* (2007) focused on investigating the potential of floodwater harvesting from four ephemeral seasonal streams (wadis) in Seleit Area in the north of Khartoum State in Sudan. The area was subjected to severe flash floods that resulted in huge damages in lives and properties. The study was aimed to estimate the potential runoff of the rainstorm events that could be impounded in some sites along the wadi course to prevent downstream population from the flash floods threats. And from the other hand, to site some locations that could be suitable to endure new environments for effective use of the floods water by practicing some kinds of irrigated agriculture or rangeland enhancement, as an example. GIS and Remote Sensing were used as assisting tools in calculating the watershed areas of the wadis and in assessing the potential sites for water harvesting systems.

Mohamad Bakir and Zhang Xingnan. (2008) made an attempt to describe the state of Rainwater Harvesting (RWH) techniques and the contributions of GIS and Remote Sensing (RS) technologies for RWH in the Syrian Desert (AL-Badia). Images of the Indian satellite with ground resolution of 5 m^2 were used to identify tents of herds during the grazing seasons. The image processing software ERDAS IMAGINE and GIS software ARC/INFO were used to process the images and to establish a geo-information system comprising digital data sets of satellite imagery, topography, soil, vegetation, hydrology, and meteorology. This information was used to study the watershed network in the Syrian Desert (AL-Badia) and to identify areas generally suitable for water harvesting in order to determine water harvesting techniques for those sites.

Rida Al-Adamat (2008) used GIS techniques to select the optimum sites for water harvesting ponds within the basalt aquifer/Ne Jordon. Buffering, Union and arithmetic operations in GIS were all used in analysing the data based on different socio-economic and physical criteria. The outcomes of the GIS analysis resulted in selecting 72 suitable sites within the study area. These sites could be used as a guideline to the decision makers in Jordan when they decided to establish a water harvesting pond in the area. This would save time and money which could be directed to the construction of the actual water harvesting ponds.

Ramakrishnan et *al.* (2008) studied site suitability for check dams, percolation ponds, and subsurface dykes as an integral part of watershed management using remote sensing and GIS tools. Thematic layers such as land use/land cover, lithology, soils, slope, rainfall and drainage were generated using LISS-III, PAN (IRS-1D), Landsat Thematic Mapper (TM) and collateral data. Runoff potential for different combinations of land use and hydraulic soil groups was computed and classified into three classes. A potential site suitability map for water harvesting/recharging structures was derived following an analytical hierarchy process. The analytically derived potential site suitability map was validated in the field. The accuracy of prediction was estimated on the basis of proximity between derived and field validated sites. In 75% of cases, the sites derived for check dam, percolation pond and subsurface dyke were accurate.

2.2 GIS for Watershed Management

Bhuwneshwar Prasad *et al.* (1997) prioritized the sub watersheds of Trijuga river watershed in eastern Nepal by considering their degradation condition and land sensitivity. Universal soil loss equation in conjunction with Remote Sensing and GIS had been utilized for estimating soil loss and land cover change. Two time series data, that are aerial photographs of year 1978 and Landsat TM data that of year 1991, were used to make the analysis of soil loss and land cover change. The rate of forest degradation of the study area was 0.57 per cent per year, which was too high while considering the sustainability, along with 0.42 mm/yr increment in soil erosion rate between 1978 to1991. The new concept of conservation prioritization had been proposed by considering sub watershed degradation speed, sensitivity index and present rate of soil erosion. Based on conservation prioritization, sub watershed conservation activities were proposed.

Khan *et al.* (2001) made their study in an integral part of Guhiya basin (with an area of 1614 km^2) for priority watershed delineation with the objective of selecting watersheds to undertake soil and water conservation measures using remote sensing and Geographical Information System (GIS) techniques. Using the terrain information derived from geocoded satellite data and 1:50,000 topographic maps, 68 watersheds were assessed on the basis of their erosivity and sediment-yield index values. Thematic maps of landform, land use and land cover, and slope were digitised using ARC/INFO. On the basis of sediment yield index values the watersheds were grouped into very high, high, moderate and low priorities. They concluded that high priority watersheds with very high SYI value ('150) required immediate attention for soil and water conservation whereas, low priority watershed having good vegetative cover and low SYI value (50) might not need immediate attention for such treatments.

Chrysoulakis *et al.*(2003) analyzed high spatial resolution stereo imagery from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), onboard terra satellite in combination with Global Positioning System(GPS) data and field observations, using GIS techniques to examine the potential of high spatial resolution multi-spectral remote sensing to support, watershed management. Terrain elevation data were derived by applying photogrammetric processes to overlapping ASTER stereo pairs for the region of Heraklion. Crete, whereas land cover data were derived by applying supervised classification techniques on ASTER multispectral imagery. Supervised classification techniques were applied for land cover production using ASTER multispectral imagery and filed observations at predefined application sites. The determination of training areas required in the supervised classification scheme was based on these observations. Finally, GIS methods were applied to estimate watershed characterization parameters for the study area offering the advantages of spatial data handling capabilities and automatic extraction of thematic information. The drainage pattern which was derived, provided a generally representative depiction of the watershed. The output pixel spacing of 15 m of the produced DEM as well as the high spatial resolution of ASTER imagery found to be quite satisfactory for the watershed characterization of the study area, indicating the high potential of ASTER multispectral imagery and filed observations at supervised classification scheme was based on these observations. Finally, GIS methods were applied to estimate watershed characterization parameters for the study area offering the advantage of spatial data handling capabilities and automatic extraction of thematic information. The drainage pattern, which was derived, provided a generally representative depiction of the watershed. The output pixel spacing of 15 m of the produced DEM as well as the high spatial resolution of ASTER imagery found to be quite satisfactory to the watershed characterization of the study area, indicating the high potential of ASTER multispectral imagery to support watershed management. It was therefore expected, the proposed method to provide valuable information for hydrological research and modelling in Greece.

Dao Huy Giap *et al.* (2003) conducted a study in Dai Tu district of Thai Nguyen province during November 2001 – January 2003 to assess the aquaculture development potential for watershed ponds by integrating socioeconomic and environmental data into GIS database, detecting land use change, and identifying and estimating potential areas for aquaculture development in watershed ponds. The socio-economic and environmental data were collected using pre-test questionnaires and field measurements. Three SPOT multi-spectral band satellite images were used to detect land use change during three periods of 1994- 1998, 1994-2002, and 1998-2002. For land suitability evaluation, the suitability ratings were established according to FAO classification in terms of suitability of land for defined uses. Aquaculture production and economic returns from interviewed farmers were used to verify the results and comparisons among different land suitability levels. The study had predicted that about 4.7% (2,725 ha) of the total land area of 57,618 ha in Dai Tu district were suitable sites for watershed pond construction, compared to the existing 404-ha watershed ponds and demonstrated the usefulness of integration of remote sensing, GIS and attribute data to select suitable sites for the development of watershed ponds, and the importance to be a useful tool for planners to develop strategic plans for aquaculture development.

Sunday Tim and Sumant Mallavaram (2003) defended the Geographic Information Systems (GIS) technology in the aspects of watershed management, from assessing watershed conditions through modelling impacts of human activities on water quality and to visualizing impacts of alternative management scenarios and added that GIS application in watershed management has changed from operational support (e.g., inventory management and descriptive mapping) to prescriptive modelling and tactical or strategic decision support system.

Singh and Prakash. (2003) did their research study in Mirzapur district of Utter Pradesh, India to evaluate the groundwater potentiality of Ojhala subwatershed. Hydrogeomorphological and lineament maps had been prepared using IRS 1C LISS- III data by visual interpretation. Topographic information had been collected form SOI toposheet. Surface electrical resistivity surveys were conducted at 68 sites to get subsurface lithological information, identification of horizontal and vertical disposition of aquifer system and for pin pointing of suitable drilling sites. Criteria for GIS analysis had been defined on the basis of ground water conditions and appropriate weightage had been assigned to each information layer according to relative contribution towards the desired output. The ground water potential zone map generated through this model was verified with the yield data to ascertain the validity of the model developed. The verification showed that the ground water potential zones demarcated through the model were in agreement with the bore well yield data. Since the present approach was built with logical conditions and reasoning, this approach could be successfully used elsewhere with appropriate modifications. Thus, the study had clearly demonstrated the capabilities of remote sensing, geoelectrical and GIS technique in demarcation of the different ground water potential zones.

Gosain and Sandhya Rao. (2004) suggested the use of GIS-based modelling framework for local-level planning, incorporating the sustainability aspects of watershed development. They took a study in Bijapur district, Karnataka to demonstrate the implementation of these new technologies for watershed prioritization.

Roy and Rao. (2007) suggested the use of Remote Sensing and GIS for evaluation of the physical attributes of water and land resources and a unique opportunity towards comprehensive monitoring of water resources dynamics in the country.

Lizama Rivas and Koleva-Lizama (2008) used GIS-based tools such as the Automated Geospatial Watershed Assessment - Soil and Water Assessment Tool (AGWA - SWAT) to illustrate the effects of land use practices on runoff, and to support watershed-wide land use management decisions in Vrana River - Bulgaria. Their paper illustrated how the AGWA tool represents a powerful and flexible tool for managing resources and understanding and predicting complex and changing systems. By integrating spatial data and distributed modelling in natural resources management, AGWA allows stakeholders and decision makers to assess the relative impacts of several alternative sets of options and thus provides an important tool to make better informed choices for an improved future. AGWA automates the process of converting commonly available GIS data to input parameter files for the SWAT hydrologic model. Input parameters for this model were obtained using AGWA in conjunction with available topographic, soil and land cover data.

Srinivasa vittala *et al.* (2008) took one of the watersheds of North Pennar basin, covering an area of 570 km^2 and lies between latitude 13°55′–14°17′N and longitude 77°05′–77°25′E in Pavagada area, Tumkur District, Karnataka and a small portion in Ananthpur District, Andhra Pradesh, India, forming a part of the hard rock terrain for their study. The drainage network showed dendritic to sub-dendritic pattern and was non-perennial in nature. Poor soil cover, sparse vegetation, erratic rainfall and lack of soil moisture characterized the area for most part of the year. Recurring drought coupled with increase in groundwater exploitation resulted in decline the groundwater level. The entire study area had been divided into nine sub-watersheds, namely Byadanur, Devadabetta, Talamaradahalli, Gowdatimmanahalli, Naliganahalli, Nagalamadike, Maddalenahalli, Paluvalli tank and Dalavayihalli, ranging in geographical area from 49 to 75 km^2. It had been taken up for prioritization based on available natural resources derived from satellite images and socio-economic conditions, including drainage density, slope, water yield capacity, groundwater prospects, soil, wasteland, irrigated area, forest cover and data on agricultural labourers, SC/ST population and rainfall. On the basis of priority and weightage assigned to each thematic map, the sub watersheds had been grouped into three categories: high, medium and low priority. The prioritization results revealed that Nagalamadike, Maddalenahalli and Dalavayihalli sub-watersheds rank highest on the basis of weightage and were considered as high priority. These sub-watersheds might be taken up with development and management plans to conserve natural resources on sustainable basis with immediate effect, which would ultimately lead to soil and water conservation.

2.3 Rain Water Harvesting

Though the rainfall received in the arid and semi arid regions of our subcontinent in scanty and erratic, high intense showers resulting into sizable runoff are seldom. It provides ample scope for surface rainwater harvesting. Local people have developed various water harvesting systems. ‘Rainwater harvesting’ structures known as ‘tanks’ constructed by putting small earthen bunds across ephemeral stream has been an age old traditional practice in India. A statistics on tank irrigation released during our independence era reveals that there were about half a million tanks under use for irrigating about 4.5 M ha over the country.

Bruins *et al.* (1986) suggested that rainwater harvesting agriculture is a specialized form of rainfed farming that has a significant potential to increase food production in arid zones. Runoff farming and rain water harvesting agriculture are considered synonymous terms. There are indications that runoff rainwater was already used for farming during the Neolithic age. Remnants of ancient rainwater harvesting agricultural systems have been found in many dry regions of Asia, Africa and America. Today rain is still the cheapest and often only available source of water for agriculture purposes, but not always reliable. In many dry regions there is no alternative to a better and more effective use of rain to increase food production. Hyper-arid zones are usually too dry for runoff farming, five major types of runoff farming are distinguished arranged in order of generally increasing geomorphic scale: (1) micro- catchment system; (2) terraced wadi system; (3) hill side conduit system; (4) liman system; and (5) diversion system. This introduction and use of runoff farming in arid zones of African countries was reported. As arid regions are characterized by large yearly fluctuations in the amount of runoff producing rainfall, droughts have to be taken into account in proper runoff farming management. Forming reserve buffer stockpiles of water and food during the good years for drought periods are considered essential in this respect.

Frasier (1987) suggested that water harvested or runoff – farming techniques are technically feasible methods of supplying water for animals, households and growing plants. Some water harvesting systems had been outstanding successes, others total failures. Despite use of proper materials and design, many systems have failed because social and economic factors were not adequately integrated into the systems. There will be a higher probability of system failure when funds are available for construction at no obligation to the user unless there is a clear understanding of who is responsible for maintenance.

A successful water harvesting system must be;

a) Technically sound, properly designed and maintained;
b) Socially acceptable to the water user and his method of operation;
c) Economically feasible in both initial cost and maintenance at the user level.

Grewal *et al.* (1989) stated excess monsoon rainwater was harvested from 10 contiguous forest watersheds and used for supplemental irrigation in the foothills of North India in an operational Research Project. The performance of 1 typical reservoir was studied for 10 years (1978-87) with particular reference to the management of agricultural droughts. Rainwater was harvested from a 9.2 ha forest watershed by constructing a 12 m high earthen dam to store to store 55, 600 cubic metre of water and to provide supplemental irrigation to 20 ha in 9 out of 20 crop seasons studied. Winter wheat was grown on areas of 18.5, 16.7 and 10.9 ha using 27.960, 24,980 and 16,400 m^3 of water in 2 irrigations applied during the severe droughts of 1979-80, 1984-85 and 1987-88. The project cost was recovered from the production benefits of 1 severe drought. It was calculated that 33,000, 35,900 and 23,900 m^3 of water available during the most critical droughts of 1979-80, 1984 and 1987-88 had the potential to save crops on 44.0, 47.9 and 31.9 ha with 1 irrigation and on of supplemental irrigation were discussed. The project had been extended to more than 80 locations in the foothill regions.

Subbaiah (1991) suggested a linear programming technique was formulated and applied to a typical alkali area under reclamation in the western Yamuna canal in Haryana, India storage of rainwater in the field of rice in alkali soils was the most cost effective way of managing rainwater followed by fallow alkali land storage and artificial recharge. Storage of rainwater in aquifers through induced recharge was preferable to storage above ground in farm ponds. Runoff volume up to 80% could be profitably stored in various rainwater management components.

Mahoo *et al.* (1994) proposed a physically based model of Rainwater Harvesting (RWH) for semi arid areas of Tanzania. RWH is defined as the collection of runoff as sheet flow from a catchment area into an adjacent cropped area without storage other than in the cropped area. The model was formulated to: (i) design the most appropriate system given site characteristics by optimizing predicted crop yield; and(ii) act as a tool for technology transfer both from research to the farmer and from location to location. Experimental work was undertaken in 3 of Tanzania's major agro-climatic zones. Runoff was measured directly from 50 and 100 m^2 catchments on bare soil, bare compacted soil, natural vegetation and a low-management crop. Soil moisture, infiltration rates and bulk density were monitored throughout the growing seasons. The model was composed of 4 sub-units a climate generator; a soil water storage model; a crop model and a catchment area rainfall runoff model. To facilitate the model's intended use in areas where few or no data are available, it represents the important hydrological processes using physical parameters that are readily available or can be easily measured or estimated, using runoff data from Morgoro, the relationship between rainfall, surface treatment, soil moisture and runoff were examined. An attempt was made at validating the runoff model by comparing predictions form 'blind' simulations with observed runoff. The problems inherent in validating a model, which is physically based, and therefore not liberated for a particular situation, were examined.

Singh *et al*. (1994) stated that water management in arid and semi arid area includes water harvesting and runoff management, storing rainwater for protective irrigation, reducing evaporation losses by using bentonite and silt to increase soil moisture retention capacity. These areas receiving an annual rainfall ranging from 100-400 mm. Problems in the management of irrigation water include an inadequate source of groundwater supply, high evaporation, high rate of percolation in soils, low water use efficiencies, saline irrigation waters and drainage requirements. Selection of the appropriate irrigation techniques for the area was discussed.

Todd and Vittori (1997) showed that collecting rainwater is not only water conserving, it is also energy conserving, since the energy input required to operate a centralised water system designed to treat and pump water is by passed. Rooftop water harvesting also lessen local erosion and flooding caused by runoff from impervious cover such as pavement and roof as some rain is instead captured and stored.

Ghosh (1999) quoted that k. Raheja Group's Towers was constructed with rain water harvesting systems. A trench along the boundary wall recharges the ground water; and a simple man Ramani, who lines in korattur, water starved area that still gets its potable stock from Ambattur municipality. He has constructed rainwater harvesting system 16 years ago. The terrace has been resurfaced to generate a mild slope to direct rainwater to feeder which runs the water into a tank. He has used alum to sink the floating sediment and dust particles and has two sets of pipes one leading to the soak pit and then to the well, the other available on the first floor with a link to the kitchen. The only thing modern is the monobloc pump set and water purifier installed for drinking water. He does not depend on municipal water supply at all. If properly planned, the whole system will cost just Rs.6,000/-.

Hatibu and Mahoo (1999) reviewed major techniques of RWH for crop production namely, In-situ, Internal (Micro) and External (Macro) catchment RWH and gave specific examples of RWH techniques being practised in Dodoma Region and their extent of usage in the region. They concluded that there was a significant use of water conservation and harvesting for crop production by farmers in Dodoma region and added that where water harvesting has been adopted for crop production, there was a clear evidence of increased farmers' income and poverty reduction.

Majed Abu-Zreig *et al*. (2000) carried out field experiments in Northern Jordan to harvest rainfall and store it deeper in the soil profile with the intention of reducing the effect of evaporation and increasing water availability for plants during the growing season. The experiment consisted of digging experimental trenches 80 cm deep, 5 m long and 1 m wide across the land slope between two rows of olive trees. The trenches were filled up to the original soil level using local deposits of fractured rock and river sand with large infiltration rate. These filled trenches, called sand ditches, were expected to collect rainfall, intercept runoff, and store water in the surrounding soil at greater depths to be used by plants for longer periods of time. It can be a very efficient method since it increases water infiltration and prevents evaporation during the growing season. The efficiency of sand ditches in storing water was assessed by monitoring soil moisture conditions and depth of infiltration in the sand ditch area, a 35 m^2 area located between four olive trees, and at a control area without a sand ditch, using an auger hole. The amount of water stored in the soil was calculated at each time interval and compared with total rainfall. Experimental results indicated that sand ditches increased both the percentage of rainfall stored in the soil matrix and the infiltration depth of water during the two consecutive winter seasons.

At one of the experimental areas, the infiltration depth and water content in the sand ditch area were 100 cm and 28%, respectively compared to only 68 m and 19% in the control area. During the same period, the calculated ratio of depth of water stored in the sand ditch area to rainfall was 73% compared to only 45% in the control area.

Xiao-Yan Li (2003) gave a successful example of rainwater harvesting program launched by the Gansu provincial government in china to assist each rural households to build about 100 m^2 of concrete catchment, two concrete storage tanks and irrigate one mu (1/15 ha) of cropland for the production of high market value cash crops. Statistics showed that in the whole country rainwater-harvesting practice had solved drinking water problem of about 23.80 million rural residents and 17.30 million livestock. Rainwater harvesting also had improved agricultural production. And 236,400 ha farmland was irrigated using supplemental water from runoff collection in Gansu Province and 1.51 million ha in the whole country.

Theib Oweis *et al*. (2004) addressed the potential role of supplemental irrigation and water harvesting for improved water productivity in the dry areas of West Asia and North Africa. They reported two success stories for microcatchment Water Harvesting Agriculture in Syrian badia using countour bunds and ridges and Jordan using runoff basins. In Syria, bunds were planted with Atriplex shrubs. An adjacent field was planted also with shrubs without constructing the water harvesting bunds. Rainfall in 1997 on the project area was 174 mm annual. Planted shrubs with no bunds had less than 10% survival rate, while those grew under micro-catchments had over 90% survival rate. The three following years were very dry with annual rainfall of less than 50 mm. Most of the surviving shrubs without bunds dried out during the 1^{st} drought year. The shrubs supported with water harvesting bunds survived three consecutive drought years and are still growing vigorously. In Jordon, runoff basins of 25 to 75 m^2 were constructed on deep soils and almonds and olives trees were planted in the winter season. Polymers were added to the tree pit in order to increase the water storage capacity of the soil so enough runoff was kept for the long dry summer. Planted trees survived the harsh climatic conditions and grew well only because of providing the water harvesting system. The production was so good that farmers in the area started adopting the technology. They stressed to plan the location, the design and the crop to be selected for a successful development.

2.4 Micro catchment Water Harvesting

Sharma *et al*. (1986) stated that the micro-catchments having different combinations of slopes, slope lengths and contributing areas, aimed at generating runoff supplements of 0 to 400 mm, were studied to determine their runoff yield, soil moisture storage, growth, yield, and long term runoff behaviour under hot air conditions in India. Runoff and soil moisture storage increase significantly with increasing slope, and decreasing slope length and controlling area; the highest being at 10 percent slope, 5.12m slope length and 31.5m^2 per tree contributing area. Similar trends were observed for growth parameters, yield of jujube (ziziphus mauritiana) Juju yield was a function of the available soil moisture storage. Over a period of seven years the threshold rainfall reduced half and runoff efficiency doubled due to the formation of a nearly impervious soil crust over the micro-catchment surface.

Oron *et al.* (1987) studied the micro-catchment water harvesting system and developed a method for predicting the volume of runoff from a flat terrain micro – catchment subject to rainfall of uniform intensity, and various initial conditions for the upper soil layer. The model was derived from the kinematic overland flow equations and used manning's equations as an approximation of the momentum equations. The modified Green – Ampt equation was adopted for water intake rate in crust soils. In areas where crop water requirement problem can at least be partially solved by the use on non-conventional water sources, the model will be of application to the design of systems for the water harvesting of runoff in micro – catchments.

Gainey (1988) proposed various micro-water harvesting techniques (micro catchment, semi-circular hoops and trapezoidal bunds) have been established in the Turkana district of the North West Kenya. Larger schemes require much outside input, especially of food or cash to pay for labour. Problems of cultural acceptability and future replicability remain, and any successful technique must take into account the requirements of the people for whom it is build.

Gielen (1990) gave the design and methods for micro – basins which was dug out in April – May, before tree planting in June. The micro basins retain the limited and irregular rainfall so that the trees are able to establish a root system that can survive the ensuring dry season.

Bithu (1994) studied the benefits of Micro – Catchment Water Harvesting (MCWH) and soil trap techniques in the loessial soils of the western Thar desert, Rajasthan, India. Under the MCWH system overall surface runoff is reduced by increasing infiltration rates. Root zone soil analysis was conducted from the bare loessial soils and from the sand plains with MCWH. Root soil moisture was greater under the MCWH system salinity was less compared with the bare soil, crop yield increased by 40 – 50 percent under the MCWH system were more remunerative than the conventional (canal) irrigated agriculture in the region.

Boers (1994) described a design procedure for a water- harvesting system in micro catchments that can be used in developing countries. The procedure was based on sheet-flow-runoff models and a soil water balance model, which together predict the water balance of the root zone below the basin area of a micro – catchment. It was illustrated by a prediction of the water supply to wind breaks in Nigeria. It was concluded that, in arid and semi arid zones, runoff from small areas such as micro – catchments is an important potential source of water for the establishment, development and growth of trees.

Renner *et al.* (1995) proposed that the micro catchment water harvesting could act as an important technique for sustainable agriculture in developing countries if important socioeconomic elements are incorporated into its design. The paper discussed some of these socioeconomic design elements, including evaluation and monitoring of the economic benefit and social acceptability of the water harvesting project, local participation, involvement of women, and appropriate technology.

Suleman et al. (1995) stated that micro – catchments 4 – 5m long with 7 – 15 percent at slopes increased soil moisture by 59, 63 and 80 percent at depth of 0 – 15 , 15 – 30 and 30 – 45 cm, respectively, soil moisture increased in late summer and in late winter when precipitation is greatest. Rill erosion increased with micro – catchment length and gradients, with erosion volumes of 14.9 – 29.3 litres from areas of 120 and 150 m^2.

Oweis *et al.* (1996) conducted experiments on the performance of a small runoff – basin water harvesting system. It was evaluated under a typical Mediterranean arid environment in Jordan. Rainfall, runoff, catchment area, soil water storage and crop evapotranspiration were analysed as elements of one system. There micro – catchment areas (25, 50 and 75m^2) and three surface treatment methods (natural, plastic cover, and compaction) were used. Runoff efficiency of the system varied from more than 85 percent as low as 7 percent depending on the size of the catchment and the root zone capacity. The required ratio of the catchment area to the cultivated area was strong capacity and the rate of consumptive use as well as rainfall – runoff characteristics.

Kayombo *et al*. (2004) carried out a study between 1992 and 1996 in a semi-arid zone of Mwanga District of Kilimanjaro Region,Tanzania, to assess the performance of maize grown in micro-catchment systems with Catchment to Basin Area Ratio (CBAR) varying from 0:1 to 4:1 Maize var. TMV1 was used as a test crop. Grain was harvested in five out of six experimental seasons (viz. *Masika* 1993, 1994 and 1995, and *Vuli* 1994/95 and 1995/96). The results showed that micro-catchment rainwater harvesting (RWH) farming is feasible during *Vuli*. The yield benefits due to RWH were found to be 120-152% and significant at P = 0.05. An increase of CBAR resulted in higher yields. The CBAR used in this study were, however, rather low.

Xiao-Yan Li *et al.* (2005) conducted a study to explore the possibility of using microcatchment water harvesting Tamarix ramosissima, a semi arid loess region of China during the period between 2001 and 2003. The experiment involved four different size micro catchments (5, 15, 30 and 50 m2) and the control (0 m2) with six replications to supply runoff water for one tree. Micro catchment water harvesting treatments significantly improved the growth of the T. ramosissima because more water was made available to the tree. Runoff volume increased with increasing catchment size, following a positive linear function; and runoff percentage decreased with increasing catchment size, following a negative exponential function. Considering catchment/planted area ratio and soil moisture storage characteristics, catchment/planted area ratios of 38.2 and 19.1 may be most appropriate for growing T. ramosissima using micro catchment water harvesting in the study area.

Akhtar Ali *et al.* (2007) studied the potential of micro-catchment water harvesting (MCWH) to conserve soil-water and establish shrubs on a degraded land in an arid environment. A research site was developed on 100 ha in Syrian rangelands having an average annual rainfall 117 mm. Contour ridges with 6 and 12 m spacing were built by using mechanized implements and 10,000 shrubs were planted with direct seeding and seedling methods. Rainfall, soil-water and shrub survival and growth parameters were measured. Results revealed that water at shrub location site was 1.2-4 times higher than the soil-water in micro-catchment area. Soil-water remained below wilting point during dry spells and increased after each runoff generating rainfall event. After 24-36 hours of rainfall, the soil-water was high in layers between 15 and 45 cm and low below 60 cm depth. Shrub survival rate was highest for *Atriplex halimus* (71%) followed by *Salsola vermiculata* (56%) and *Atriplex leucuclada* (31%). Efforts to raise shrubs by direct seeding method were not successful as only a few seeds germinated and none of them survived. Very low rainfall during second year (44 mm) contributed to low survival rate. In general, the shrub growth was slow but it was highest for *A. halimus* and lowest for *S. vermiculata*. The study showed that *A. halimus* due to its high survival and growth rate, is suitable for the environment.

CHAPTER III

MATERIALS AND METHODS

Details of the materials used and techniques adapted to conduct the study are discussed in this chapter.

3.1 Materials

3.1.1 Study Area

Krishnagiri district is situated in northwestern part of Tamil Nadu and forms border with Karnatka and Andhra Pradesh state. Cauvery and South Ponnaiyar are major rivers flowing through the district. Krishnagiri and Sathanur dams are constructed across the river Ponnaiyar.

3.1.1.1 Location

Tippasandiram watershed consists of Santhanappalli and Bevunatham revenue villages of Denkanikottai taluk in Krishnagiri district. The study area is located between 77˚50’ E to 77˚ 52’ E Longitude and 12˚28’ N to 12˚ 31’’ N latitude. Toposheets (No: 57 H /14 and 57 H/15) obtained from Survey of India (SOI) covers the locations of the above said villages. Fig.3.1. is the location map of Tippasandiram watershed of Krishnagiri district, Tamil Nadu.

3.1.1.2 Climate

The area has semi-arid climate with oppressively hot summer. The temperature of the area varies from minimum 23.60˚C to maximum 35.86˚C (AISLUS, Bangaluru). The average annual rainfall of the area is 813.20 mm (Denkanikottai Taluk office) and maximum rainfall occurs during the period of Northeast monsoon (October to December).

3.1.1.3 Soil

Soil is one of the important input variables in this study. The infiltration rate of the soil determines the type of water harvesting structure to be located. Also the surface runoff potential of the area depends on the soil texture. Hence digitized soil map (1:50,000 scale) of the study area was obtained from Remote Sensing and GIS Centre, Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore. There are three soil series found in the study area, which are Maripatti series, Tatikuppam series and Vadipatti series. The details of the soil series are furnished in Annexure.

Soil texture could be considered as a deciding factor when selecting a site for water harvesting process, especially if the purpose of this process is to preserve water for human, livestock and agricultural purposes. Keeping this fact in mind, soil map was reclassified on the basis of textural classes of the soil.

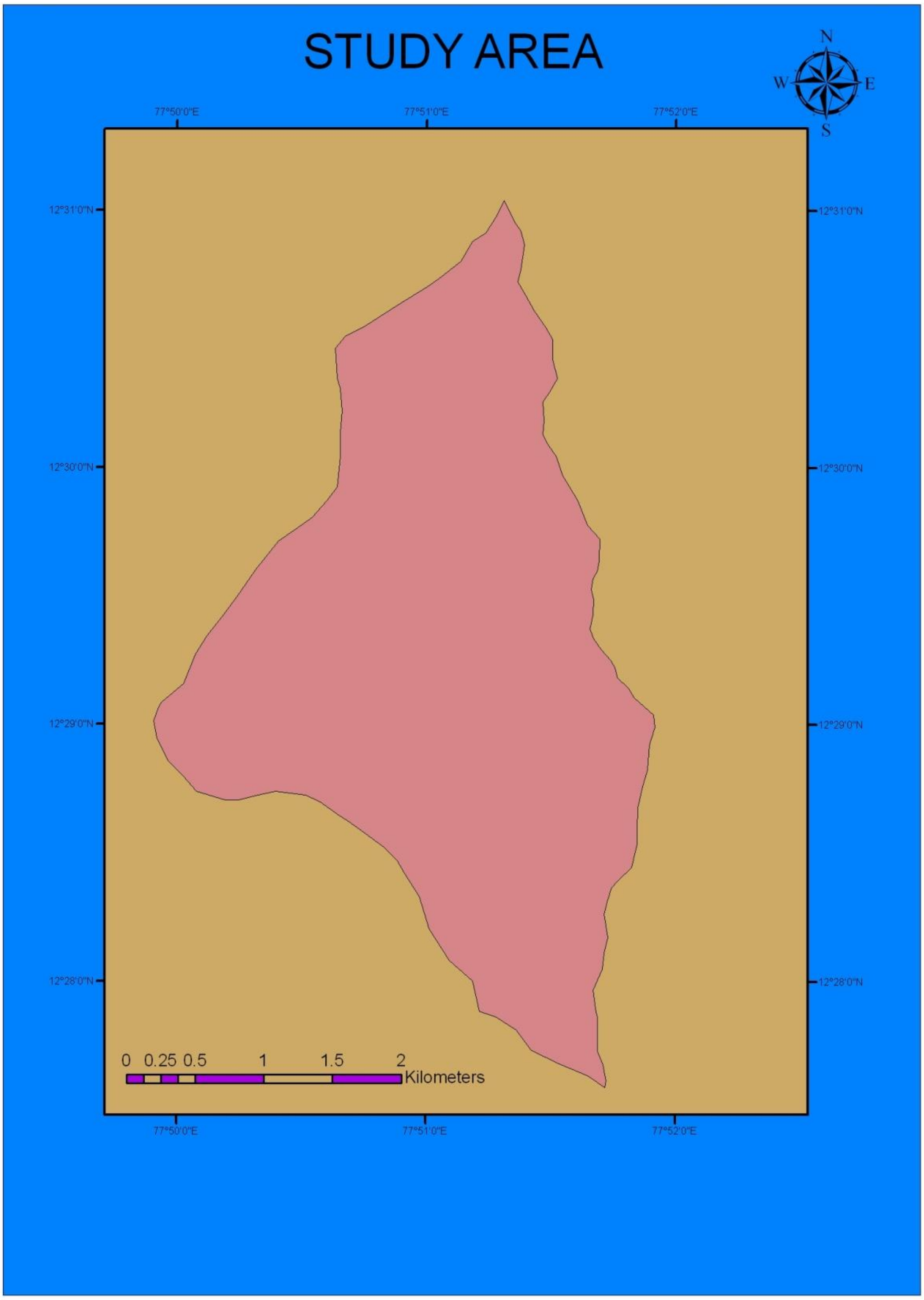

Fig. 3.1 Tippasandiram Watershed, Krishnagiri District, Tamil Nadu, India

Soil textural classes

Textural names are given to soil based upon the relative proportion of each of the three soil separates – sand, silt and clay. Soils that contain higher percentage of clay, are called clay (textural class), those with high silt content are silt (textural class), and those with high sand percentage are sand (textural classes).

Sand

The sand group includes all soils of which the sand separates make up 70 percent or more of the material by weight. Two specific classes are recognized. They are sand and loamy sand.

Loam

Loamy soil containing many sub-divisions and does not exhibit the dominant physical properties of any of these three soil separates. An ideal loam soil may be defined as a mixture of sand, silt and clay particles which exhibits light and heavy properties about equal proportion. It exhibit approximately equal properties of sand, silt and clay.

Clay

A clay soil must carry at least 35 percent of the clay separates and in most cases not less than 40 percent. For an example, sandy clay soil contains more sand than clay. Similarly silt clay soils contain more silt than that of the clay.

Based on these broad and fundamental groups, names of the different textural classes developed by U.S. Department of Agriculture (USDA) and U.S. Bureau of Soil are presented in table 3.1 and 3.2

Triangular textural diagram (Fig.3.2) shows the percentage of sand, silt and clay present in the basic soil textural classes. The relative percentage of sand in the soil decides the storage capacity of that soil. Soils that contain higher percentage of clay are most favourable for surface water storage purpose.

The detailed characteristics of each of the soil series are discussed in the Results and Discussion chapter.

Table 3.1 Textural class names developed by USDA

Common name	Texture	Basic soil textural class
Sandy soils	Coarse →	Sandy Loamy sands
Loamy soils	Moderately coarse →	Sandy loam Fine sandy loam
	Medium →	Very fine sandy loam Loam Silt loam Silt
	Moderately fine →	Clay loam Sandy clay loam Silt clay loam
Clay soils	Fine →	Sandy clay Silt clay clay

Table 3.2 Textural groups on the basis of sand, silt and clay separates

Sr.No	Textural group	Sand	Silt	Clay
1	Sand	80-100	0-20	0-20
2	Sandy loam	50-80	0-50	0-20
3	Loam	30-50	30-50	0-20
4	Silt loam	0-50	50-100	0-20
5	Sandy clay loam	50-80	0-30	20-30
6	Silt clay loam	0-30	50-80	20-30
7	Clay loam	20-50	20-50	20-30
8	Sandy clay	50-70	0-20	30-50
9	Silt clay	0-20	50-70	30-50
10	Clay	0-50	0-50	30-100

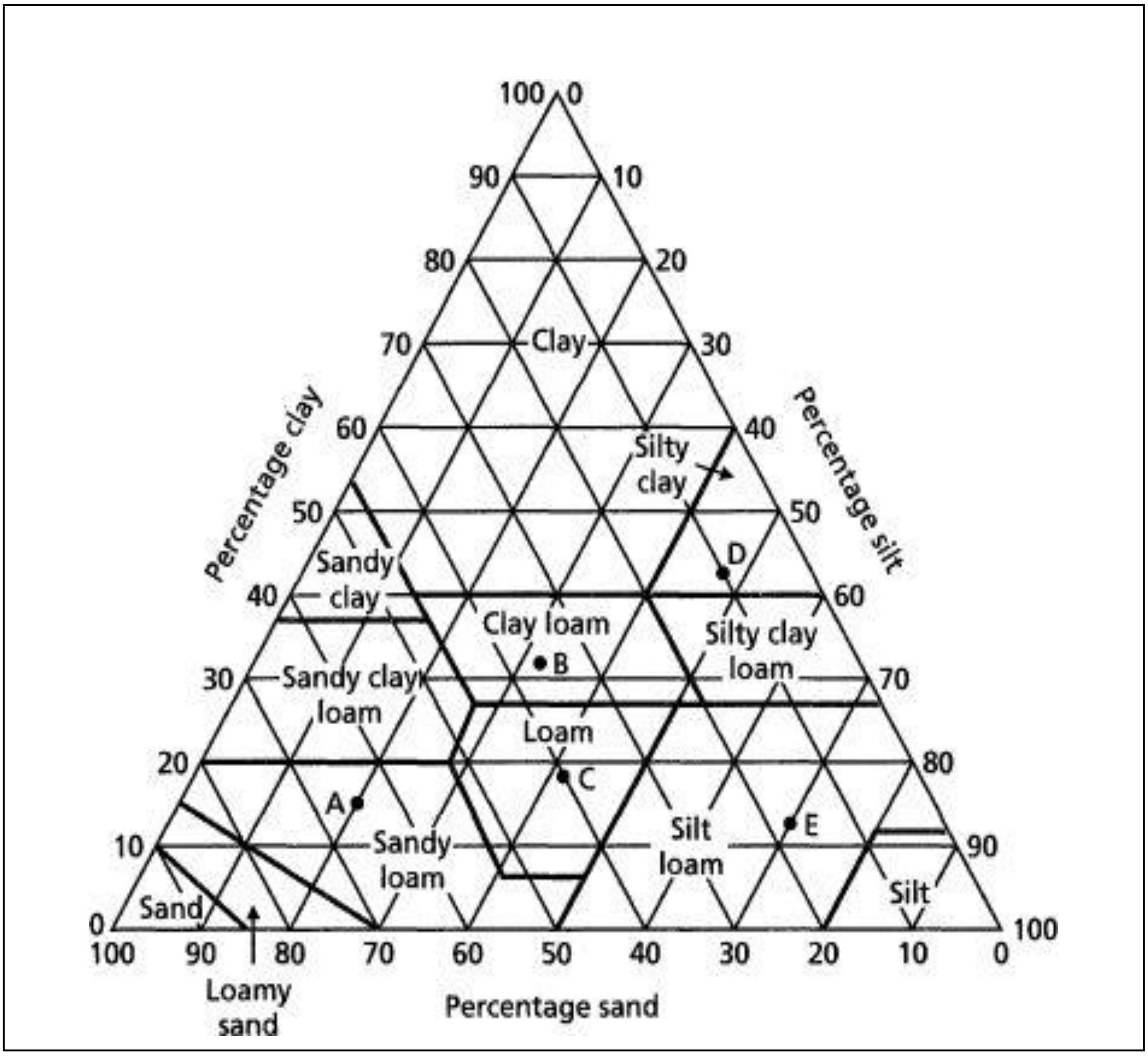

Fig. 3.2 Triangular textural diagram showing percentage of sand, silt and clay in the basic soil textural classes (USDA)

3.1.1.4 Land use/ Land cover

Land use/land cover map provides information on existing land use/ land cover pattern and their spatial distribution. Infiltration and runoff are greatly depending upon land use /land cover. Land use/land cover map of the study area was collected from Institute of Remote Sensing (IRS), Anna University, Chennai. It is well known that water harvesting is high in the water bodies and fallow lands compared to cultivable lands and settlements.

Of the total area of 1107ha, nearly 0.25 percentage of area contains a single water body and 32 percentage of area comes under fallow land in the present situation. The remaining area contains nearly 55 percentage is covered by agricultural lands, 8 percentage under forest and 4.75 percentage under other structures such as roads, buildings etc.

3.1.1.5 Topography

Topography mainly deals with surface slope of the study area. Slope of terrain is another important factor, which controls the infiltration rate. When the land slope increase the runoff also increases, and hence the areas of gentle slope are suitable for rain water harvesting. The slope also controls the distribution of vegetation, pattern of land use and feasibility of geotechnical construction for storage structures. Slope conditions in a watershed are depicted by slope map. The study area falls under undulating slope.

Digital Elevation Model (DEM) was prepared by interpreting contour map that was digitized from toposheets obtained from Survey of India. From the DEM, slope map was prepared in percentage, segregated into 4 classes and termed as low (0-1 %), less moderate(1-3%), moderate (3-5%) and high (>5).

3.1.2 Geographic Information System (GIS)

GIS is the system of hardware and software wherein geographically referenced spatial data and non-spatial data (attributes) can be captured for manipulation, analysis and modeling to solve management of decision making tasks. Some of the terminologies of GIS environment have been well explained below for better understanding of the procedure which was followed for the selection of suitable sites for water harvesting.

3.1.3 Software

The ArcGIS9 software acts as a tool, for water harvesting study, which was used for integration, manipulation and analysis of data.

ArcGIS

ArcGIS is the name of the group of geographic Information System (GIS) produced by Environmental System Research Institute (ESRI), U.S.A.

ArcGIS 9

For the present study ArcGIS 9 version was used. The ArcGIS 9.0 provides a geoprocessing environment that allows execution of traditional GIS processing tools such as clipping, overlay and spatial analysis.

Datasets

Datasets refer to the use of various data layers together in the analysis part. There are several parameters or factors that must match if data layers are to be used together.

Map projection

A basic system of co-ordinate which is used to describe the spatial distribution of element in a GIS environment.

Georeferencing

Georeferencing is the process of establishing a relationship between rasters (row, column) coordinate system, sometimes called image space, and a real world (x, y) coordinate system called map space.

Registration

Registration is the process of alignment of one image (unrectified) to another image (already rectified) of the same area and when it is done, any two pixels at the same location in both images are said to be ‘in register’ and represent two samples at the same point on the earth.

Digitization

The process of converting an image recorded originally on a photographic material into numerical format.

Thematic map

Thematic map is a map displaying selected kinds of information relating to specific themes, such as soil, Land use, population density and so on.

Rasterization

Rasterization is the process of converting an image of lines and polygon from vector representation to a gridded representation.

Digital Elevation Model (DEM)

A digital elevation model consists of an array of uniformly spaced elevation data. It is an image which stores the data that can be envisioned as heights on a surface.

Geographic Coordinate System (GCS)

GCS uses a three-dimensional spherical surface to define a location on the earth. A GCS includes an angular unit of measure, a prime meridian and a datum. A point is referenced by its longitude and latitude values. Longitude and latitude are angles measured from the earth's centre to a point on the earth's surface. The angles often are measured in degrees or in grads.

Projected Coordinate System (PCS)

A PCS is defined on a flat, two- dimensional surface. Unlike a GCS, a PCS has constant lengths, angles and areas across the two dimensions. A PCS is always based on a GCS that is based on a sphere or spheroid. In a projected coordinate system, locations are identified by x, y coordinate on a grid, with the origin at the grid.

Attribute data

Attribute data is one which specifies the characteristics of the location.

Overlay

Overlay is the process of stacking digital representation of various spatial data on the top of each other so that each position in the area covered can be analyzed in terms of these data.

3.2 Methodology

The flowchart of procedure for selection of suitable sites for water harvesting structures is given in Fig. 3.3.

3.2.1 Preparation of various thematic maps

For preparation of various thematic maps, two toposheets obtained from SOI were scanned for digitization in GIS environment. Digitation was done in order to demarcate the study area from georeferenced toposheets. Similarly, soil map and land use maps were scanned, georeferenced and digitized to get final thematic map of soil and land use/ land cover.

Topography of the earth surface can be well understood by interpreting the contour lines in the study area. Contour map was prepared from toposheets. All the contours present in the toposheets were digitized to make contour map of the study area. Contour interval for the map was 20 m. After the preparation of contour map, rasterization of the same was done to get digital elevation model (DEM).

Digital elevation model (DEM) is an image which stores the data that can be envisioned as heights on a surface. Slope map (in per cent) was derived from digital elevation model. The slope map prepared from digital elevation model was in raster form. According to the need of the study, reclassification was done to reclassify the slope map into four classes viz. low (0-1 per cent), less moderate (1-3 per cent), moderate (3-5 per cent) and high (More than 5 per cent).

3.2.2 Rasterization of maps

Rasterization (vector to raster conversion) is the process of converting vector data into a grid of pixel values. This involves basically placing a grid over the map and then coding of the pixels according to the occurrence.

Except slope map, all the thematic maps prepared were in vector format. In order to process them for further analysis, it is necessary to convert all of them into raster format. Therefore soil map, slope map and land use/cover map was rasterized in GIS environment. Thus all the thematic maps were prepared for further analysis.

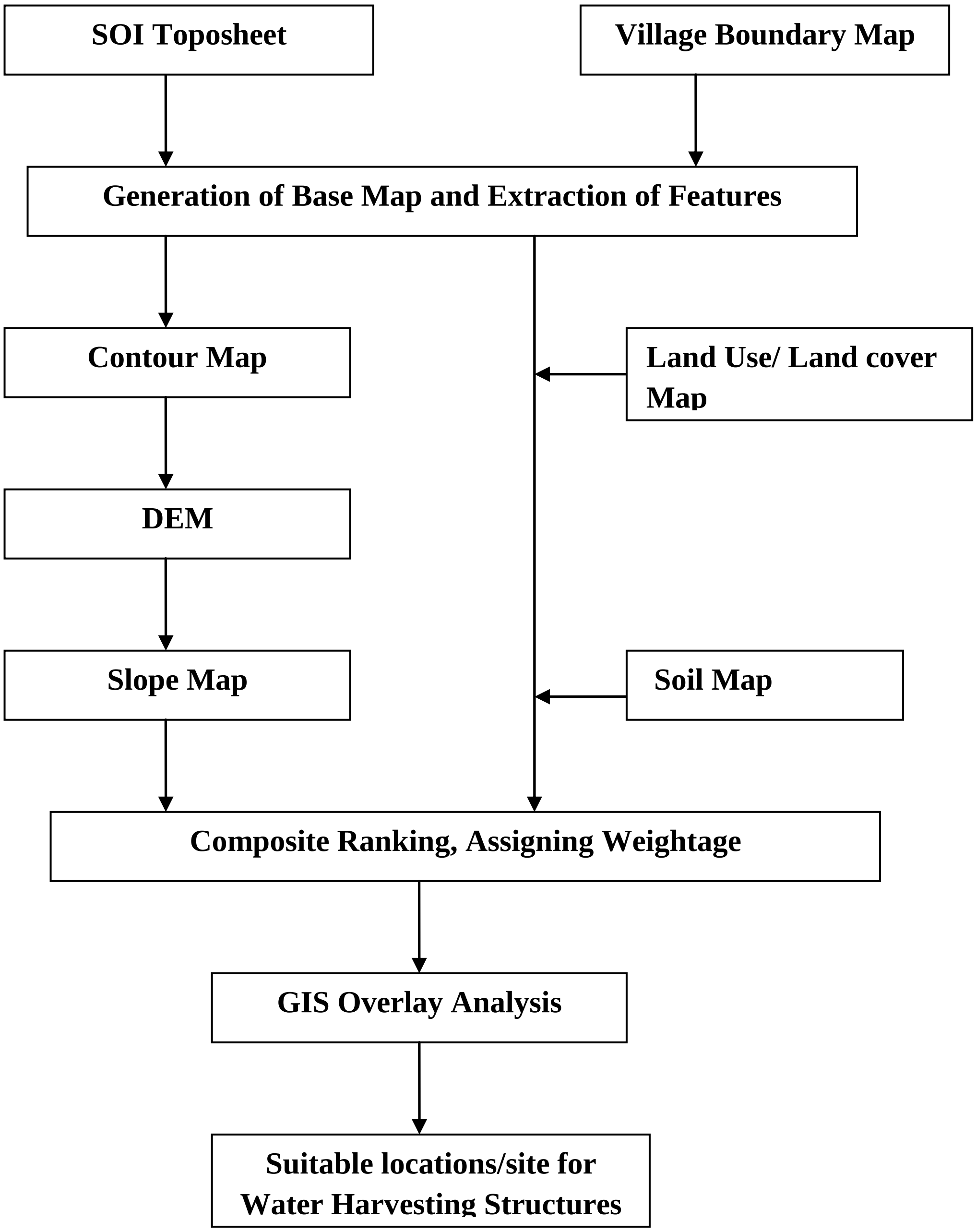

Fig. 3.3 Flow Chart for Suitable Site Selection for Water Harvesting

3.2.3 Fixing Criteria, Ranking and Weightage

Ranking is the preference given to criteria according to their response to water harvesting process. Highest rank was given to the criteria which were most suitable for water harvesting and lowest rank was given to least suitable for water harvesting process as surface storage.

Soil plays important role for holding the water at surface level. So the maximum weightage was assigned to this factor. Further, among the classes, clay loam soil is most favourable class, compared to the other type of soils because of its relative higher percentage of clay content than other soil type. So ranking was given in the order of 1, 1 and 3 for sandy loam, loamy sand and clay respectively. Highest ranking was given to clay and lowest ranking was given to sandy loam and loamy sand.

While considering topography of the study area, gentle slopes serve to store surface water. Hence gentle slopes were considered most suitable for water harvesting. Areas of steep slopes were considered least favourable. Based on the aforesaid facts, ranking was given in the order of 1, 2, 3 and 4 for the classified slopes of high, moderate, less moderate and low respectively. Highest ranking was given to low slope (0-1per cent) and lowest ranking was given to high slope (> 5 per cent).

While considering land use/land cover factor, preference was given to water body followed by fallow land, vegetation and settlement in terms of suitability for the site selection. So ranking was given in the order of 1, 1, 1, 4 and 5 for land with scrub, forest land, settlements, fallow land and water body. Highest ranking was given to water body followed by fallow land and lowest ranking was given to land with scrub, forest and settlements.

Weightage is the term coined for assigning the value (out of 100) to a particular theme according to its importance to the study. High weightage was given to most important themes. Total weightage must be 100.

In the present study, considering the soil, slope and land use of the study area suitable weightages were adopted. For this purpose, several experts have been consulted and literatures were reviewed (A.S. Padmavathy *et al.*, 1993; K. Noorkaratnam *et al.*, 2005). Accordingly, highest weightage was given to soil followed by slope and lowest weightage was given to land use / land cover. Weightage was given in the order of 46, 33 and 21 for soil, slope and land use / land cover respectively. The details of criteria, ranking and weightage are given in Table 3.3.

Detailed discussions of aforesaid factors are given in Results and Discussion chapter.

Table 3.3 Details of criteria, ranking and weightage applied for suitable site for water harvesting.

Sr. No	Criteria	Class/ units	Rank	Weightage for theme
1	Soil	Loamy sand	1	46
		Sandy loam	1	
		Clay	3	
2	Slope	Low (0-1 %)	4	33
		Less moderate (1-3%)	3	
		Moderate (3-5%)	2	
		High (>5%)	1	
3	Land use/land cover	Land with scrub	1	21
		Forest land	1	
		Fallow land	4	
		Settlements	1	
		Water body	5	

3.2.4 Weighted overlay analysis

Weighted overlay is a technique for applying a common measurement scale of values to diverse dissimilar inputs in order to create an integrated analysis.

Weighted overlay accepts integer raster as an input, such as raster of land use or soil type. Continuous (floating point) raster must be reclassified into integer before they can be used. Generally, the values of the continuous raster are grouped into ranges. Each range must be assigned value before it can be used in the weighted overlay tool. The reclassify tool allows such raster to be reclassified. The output raster can be weighted by importance and added to produce a final output raster.

Steps for running weighted overlay are:

Selection of an evaluation scale

↓

Addition of rasters

↓

Setting scale values

↓

Assigning weights to input rasters

↓

Running the weighted overlay tool

1. Selection of an evaluation scale

In the weighted overlay dialog box, select an evaluation scale to use. Values at one end of the scale represent one extreme of suitability . Values at the other end represent the other extreme. The default evaluation scale is 1 to 9 by 1 (least suitable 1, most suitable 9 with increment of 1). If input rasters are already reclassified to a common measurement scale using the reclassify tool, it is important to select an evaluation scale that matches the scale which was used during reclassification.

2. Addition of rasters

Click the Add raster row button to open the Add weighted overlay layer dialog box. Click the input raster drop down arrow and click a raster or click the Browse button to browse to an input raster and click Add. Click the input field drop down arrow to change the field if desired. Click OK. The raster is added to the weighted overlay table. Click the Add raster row button again to enter the next raster and so on.

Note: if land use is one of the inputs, description field that describes each land use type will be sufficient enough to assign weights to this raster in the weighted overlay dialog box.

Note: only discrete, integer raster can be used in the weighted overlay dialog box.

Reclassify continuous raster files before adding them into weighted overlay dialog box.

3. Setting scale values

The cell values for each input raster in the analysis are assigned values from the evaluation scale. This makes it possible to perform arithmetic operations on raster that originally held dissimilar types of values. The default values can be assigned to each cell according to importance or suitability. For instance, a land use raster added has values representing the land use type (water body = 5, fallow land = 4, settlements = 3, Forest land=1, vegetation = 1).

4. Assigning weights to input rasters

Each input raster can be weighted or assigned a percentage influence, based on its importance. The total influence for all rasters must equal 100 percent. For instance, it might be more important to build a shopping centre on soils that are stable than to locate in a popular shopping area.

5. Running the weighted overlay tool

The cell values of each input raster are multiplied by the raster's weight (or percent influence). The resulting cell values are added to produce the final output raster.

In this way weighted overlay analysis was carried out to obtain final result map of suitable sites for rain water harvesting in the study area.

3.2.5 Site selection

Water harvesting is the collection and usage of precipitation from the catchment surface. The suitability of an area for water-harvesting depends on its ability to meet the basic technical requirements of the system. In addition, whatever technique is selected must be compatible with local social conditions and farming practices. In planning the systems, appropriate data must be available on the climate, soil, crops, topography and the socioeconomics of the project area. Among the tools and methods of data acquisition for planning, designing and implementing water harvesting systems are field visits, site inspection, topographic and thematic maps, aerial photos and satellite images and geographic information system as an aid to selecting the most suitable method (Oweis *et al*., 1998).

Although water harvesting systems may be implemented on a wide range of slopes, topography is still a major factor in the selection of an appropriate technique. Generally, but not invariably, steeper slopes with shallower soils are used as catchment where as cropping is allocated to gentler slopes, where soil is deeper. This allows less productive, shallow soil to contribute its share of rain to the deeper, more productive soil.

The infiltration rate among other factors depends on the porosity of soil, which determines the water storage capacity and affects the resistance of water to flow into deeper layer. The highest infiltration capacities are observed in loose sandy soils while heavy clay or loamy soils have considerable smaller infiltration capacities. The relative percentage of clay in the soil decides the water harvesting capacity of that soil. Soils that contain higher percentage of clay are most favourable for water harvesting. Generally, this is only feasible when using micro-catchments to harvest water for human and animal consumption or for the production of high value crops. Soil texture should be considered, because it affects soil erosion in the catchment. Both soil texture and depth influence the total water storage capacity of the soil profile, and this, in turn, controls the amount of water that can be made available for crops during the dry periods.

Many researchers have adopted different criteria integrating various geological and hydrological parameters to select suitable sites for rain water harvesting. The parameters which play an important role in site selection are hydrogeomorphological data (drainage density, slope, land forms, land use/land cover) and geological data.

In the present study, the guidelines given by different sources were reviewed and followed for selecting the site for locating water harvesting structures and the same are discussed in detail in the Results and Discussion chapter.

CHAPTER IV

RESULTS AND DISCUSSION

A study was carried out using GIS techniques for selection of suitable sites for water harvesting in Tippasandiram watershed of Cauvery basin. The results obtained from various aspects of the investigation carried out are systematically presented in this chapter. The results obtained from the various thematic maps and weighted overlay analysis are presented. The results of selection of site specific rain water harvesting structures for surface water harvesting and impact of existing water harvesting structures of the study area are also presented.

The results and discussion are presented on the following categories.

1. Thematic map analysis
2. Weighted overlay analysis
3. Selection of site specific rainwater harvesting structures
4. Selection of horticultural crop and suitable irrigation methods
5. Impact of existing water harvesting structures

4.1 Thematic map analysis

4.1.1 Land use/ Land cover classification

Land use refers to man's activities and other uses of land. Land cover refers to natural vegetation, water bodies, rock/soil, artificial cover, and other features resulting from land transformations. Land use pattern of any watershed influences the runoff and evaporation to compute hydrological elements more accurately. So more accurate land use/ land cover map is necessary for the study.

Runoff and infiltration are greatly depending on land use/ land cover. It is well known that surface rain water harvesting is high in the water bodies and fallow land compared to the cultivable land and irrigation land. Hence, this theme was considered as one of the principal terrain parameters in the rain water harvesting site selection.

The land use/ land cover map was digitized and classified from already existing land use/ land cover map obtained from Institute of Remote Sensing, Anna University, Chennai. The classified map of land use / land cover of study area is presented in Fig. 4.1.

There are five land covers shown in map viz. land with scrub, forest land, fallow land, settlements and water bodies. Land use pattern of the study area is given in percentage in table 4.1 and Fig.4.2 represents the distribution of the study area based on land use pattern of the study area.

Table 4.1 Land use statistics of the study area.

Sr. No.	**Land use class in study area**	**Area in hectare**
1	Land with scrub	461.28
2	Forest land	330.52
3	Fallow land	306.52
4	Settlements	5.36
5	Water bodies	3.32

The following pie chart shows the land with scrub, forest land, fallow land, settlements and water bodies. It is unambiguously seen that, most of the study area in present situation is under land with scrub followed by forest land and fallow land. There is only one water body in this study area. Most of the land with scrub is occupied by paddy, ragi, tomato and groundnut crops.

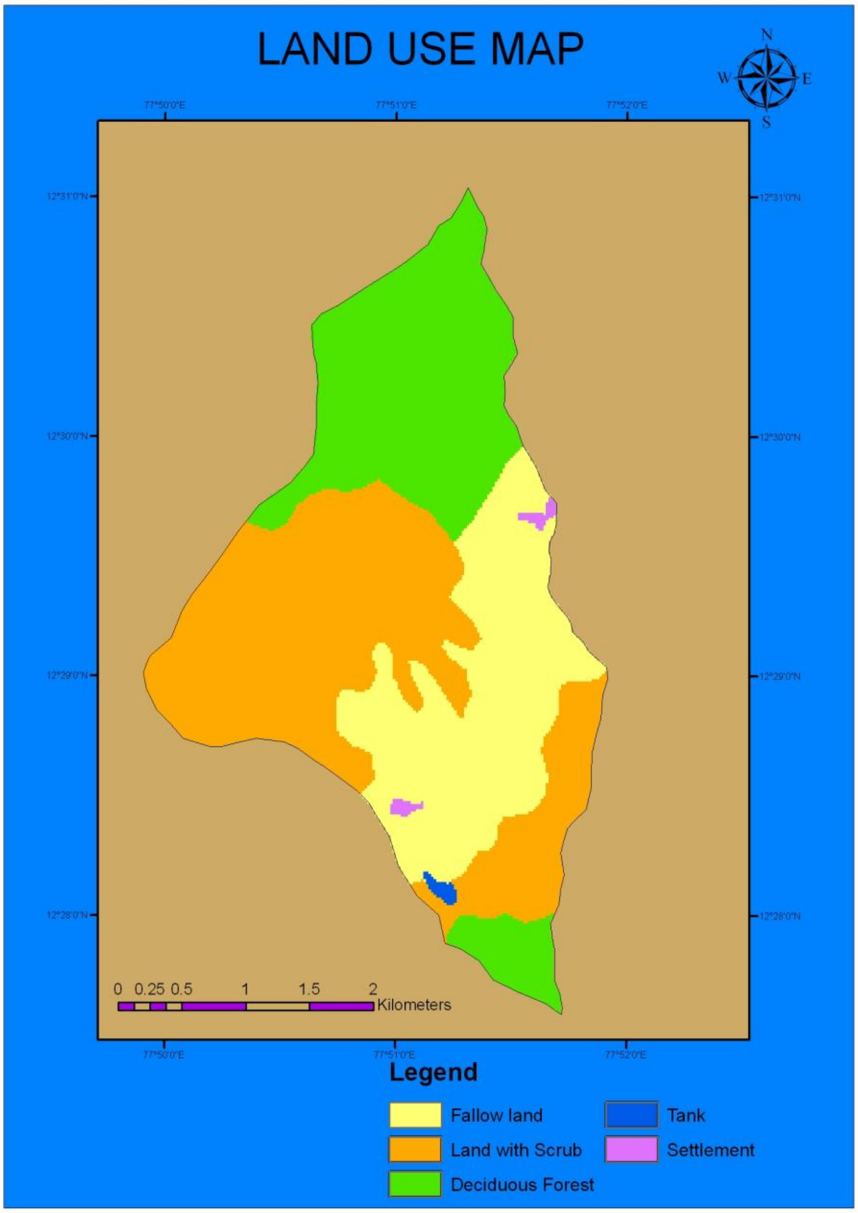

Fig. 4.1 Land use/land cover map of Tippasandiram Watershed

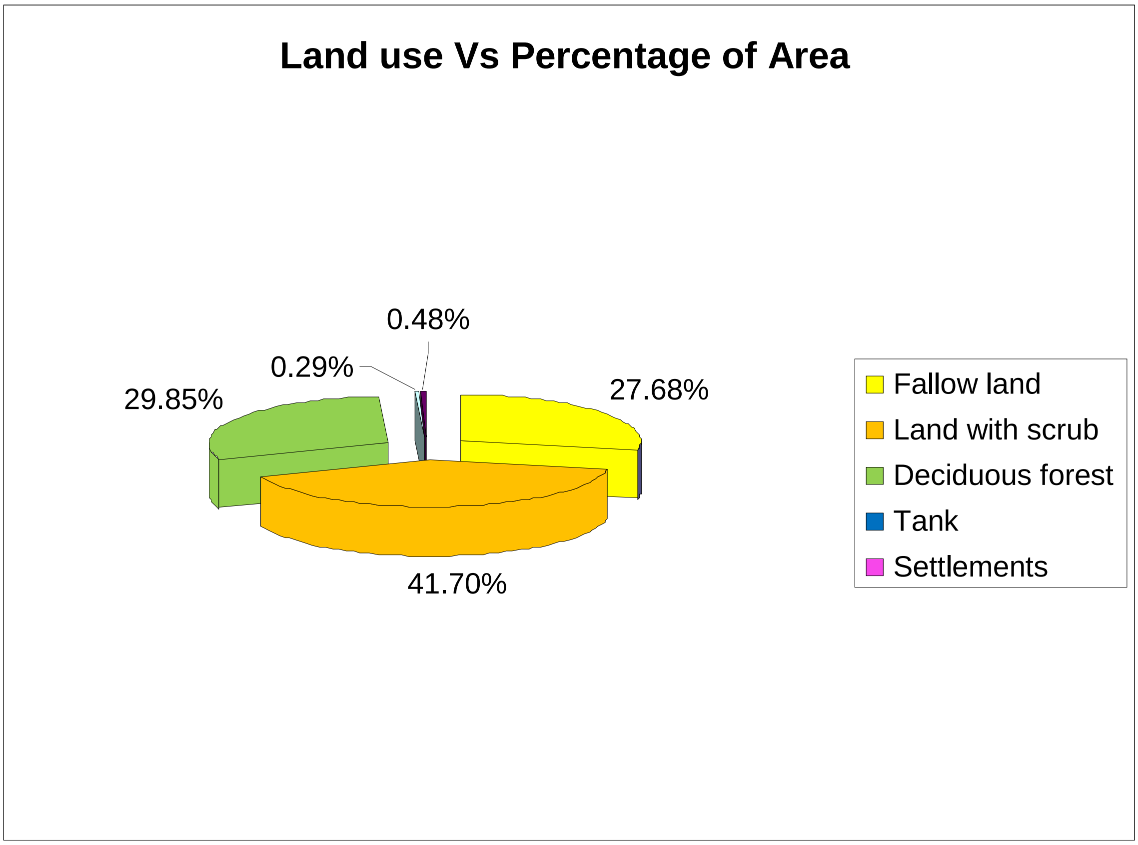

Fig.4.2 Land use pattern of the study area

4.1.2 Slope map

Slope of a terrain is another important factor which controls the infiltration rate. Slope is very important when selecting and implementing any water harvesting structures. Slopes play a major role in surface water runoff characteristics. When land slope increases, runoff also increases. On the other hand, water becomes stagnant when the slope tends to flat. Hence the areas of gentle slope are the best suited for surface water harvesting.

According to Critchley *et al.* (1991), water harvesting is not recommended for areas where slopes are greater than 5% due to uneven distribution of run-off and large quantities of earth work required which is not economical. In this study, areas that have slope value higher than 5 per cent was excluded from selection criteria.

Slope map of the study area was prepared using digital elevation model (DEM). This slope map was then reclassified into four groups as shown in table 4.2. The slope map is given in the Fig. 4.3.

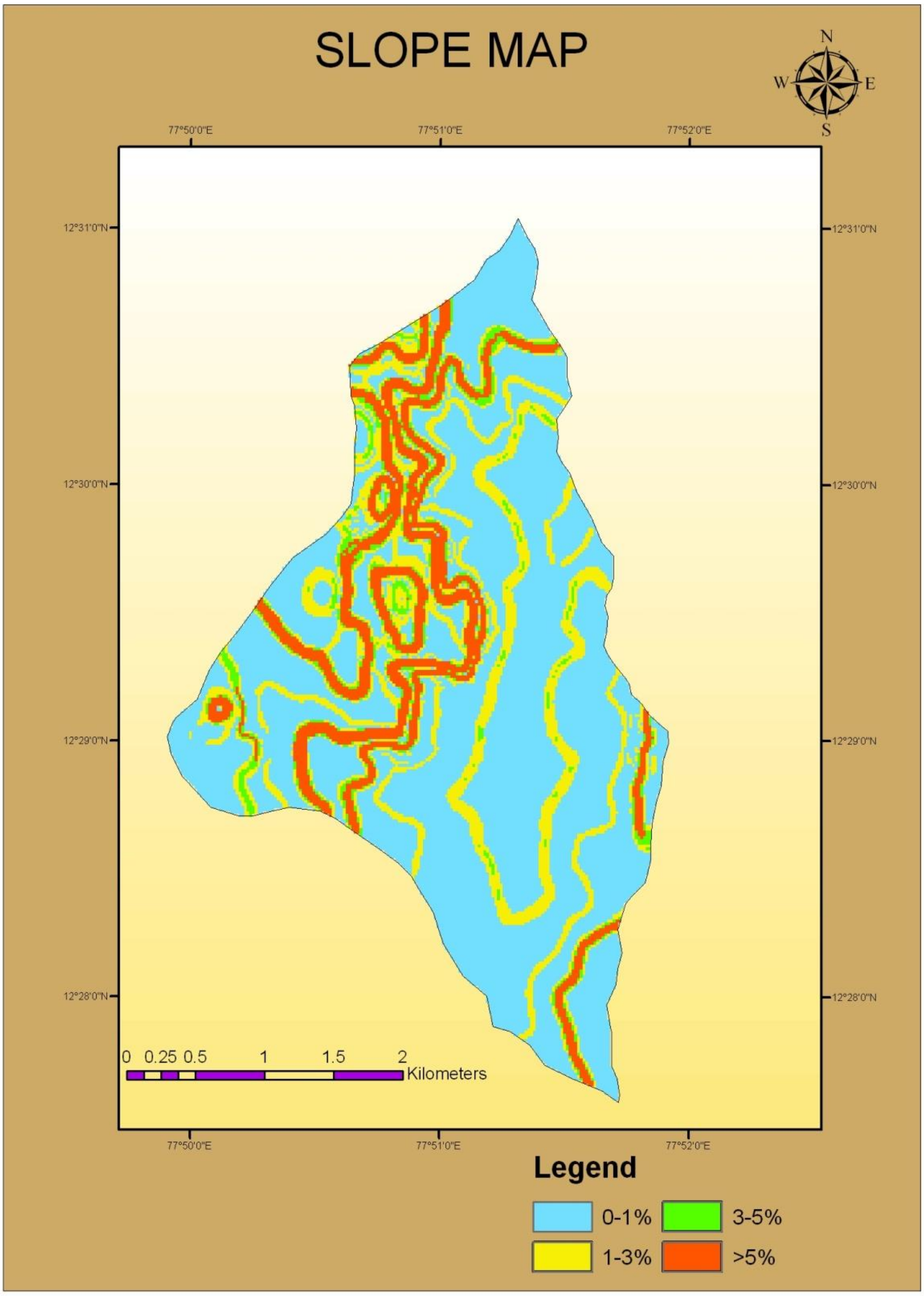

Fig.4.3 Slope map of Tippasandiram Watershed

Table 4.2 Reclassified slope range

Sr. No.	Slope class	Slope in percentage	Area in hectare
1	Low	0-1	719.64
2	Less moderate	1-3	202.52
3	Moderate	3-5	48.08
4	High	>5	136.76

While interpreting the slope of the study area in the slope map, most of the area shows more or less flat topography excepting a few parts. Area under different slope classes is given in percentage in Fig. 4.4.

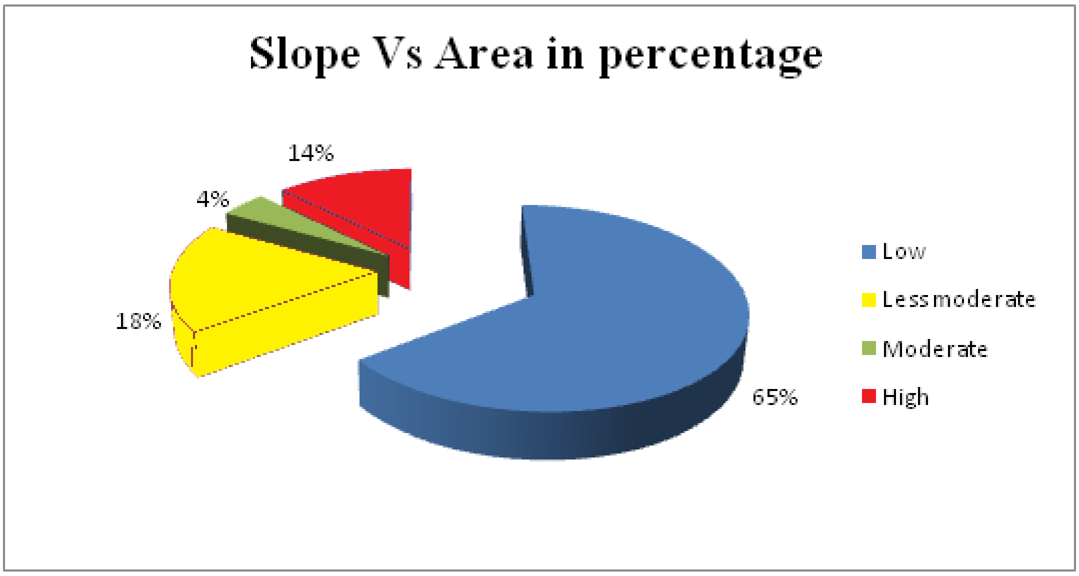

Fig.4.4 Pie chart showing area under different slopes classes in percentage

4.1.3 Soil map

Soil is another important input variable in this study. The infiltration rate of the soil determines the type of structure to be located and also the surface runoff potential depends on the soil texture of the area.

Digitized soil map at 1:50,000 scale was obtained from Remote Sensing and GIS Centre, Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore. This soil map was classified according to different soil series (Fig. 4.5).

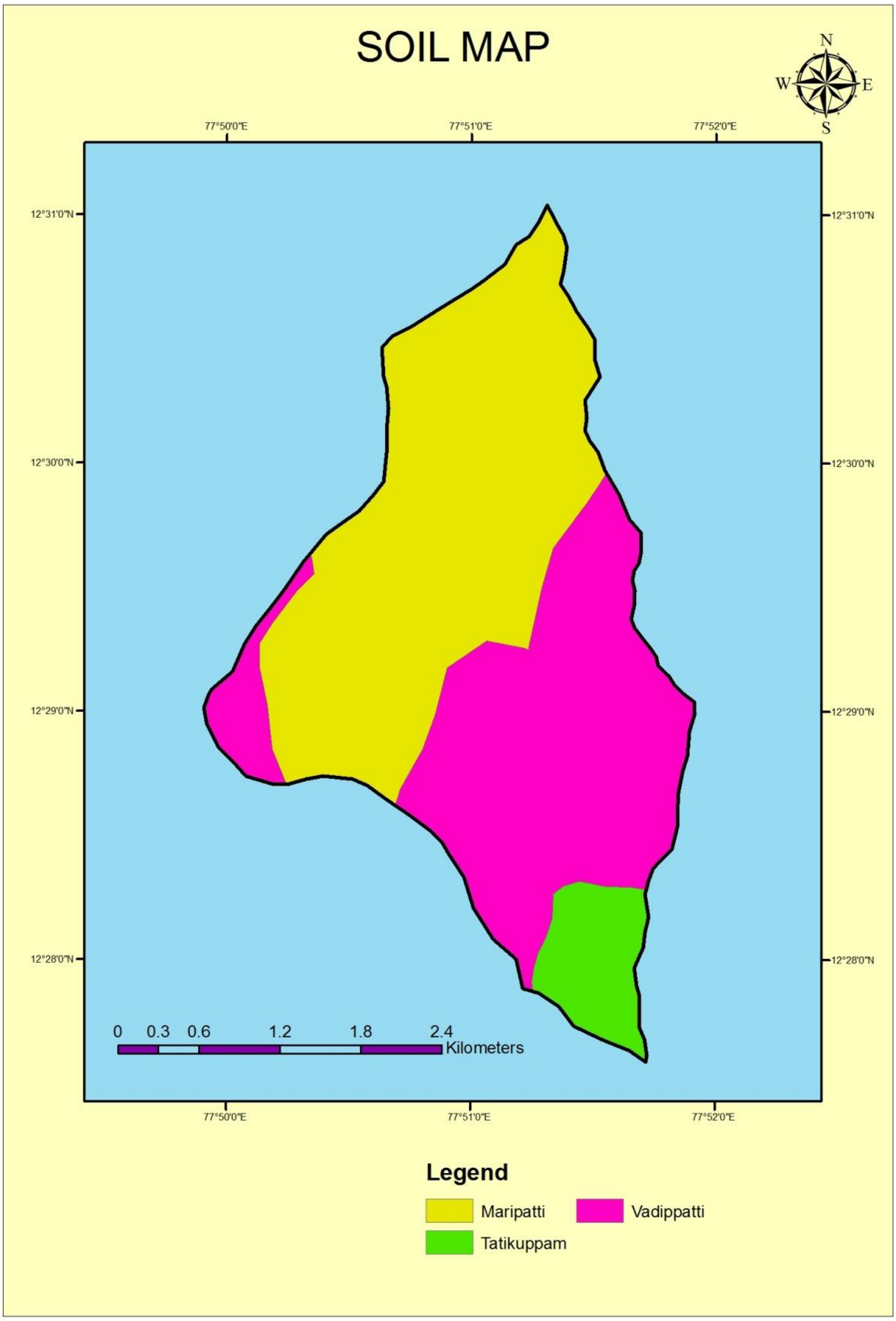

Fig.4.5 Soil Series map of Tippasandiram Watershed

There are three soil series found in the study area, which are Marippatti series, Tatikuppam series and Vadippatti series. Area under different soil series is given in Table 4.3 and Fig. 4.6.

Table 4.3 Area under different soil series present in the study area

Sr.No.	Name of the soil series	Area in hectare
1	Marippatti	523.6110
2	Vadippatti	504.3492
3	Tatikuppam	79.0398

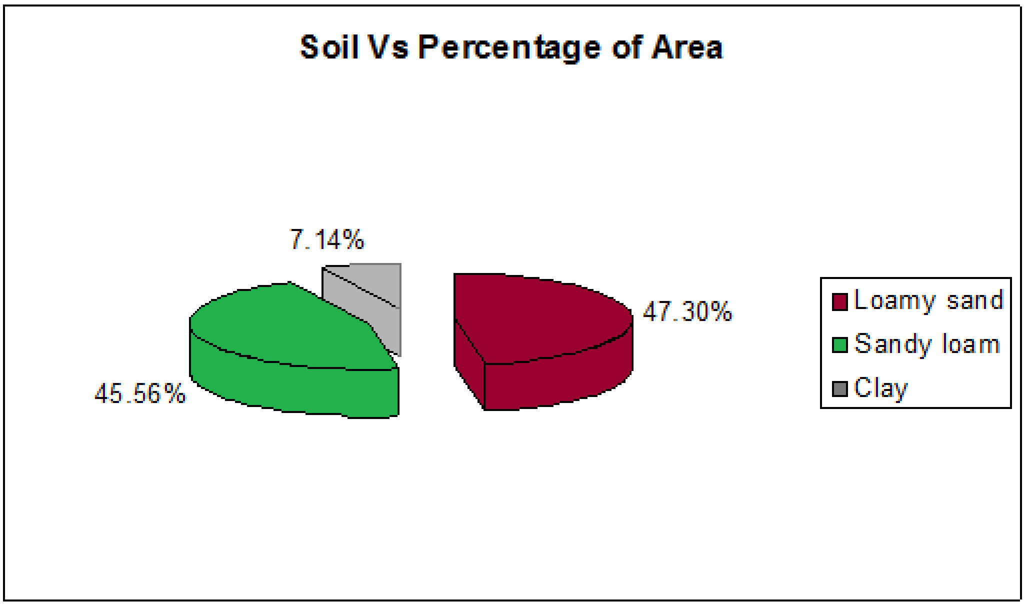

Fig 4.6 Pie chart showing area under different soil series

Detailed characteristics of each soil series are given in appendices I to III.

For water harvesting process, texture of surface soil layer plays important role to understand the infiltration characteristics of the soil. The infiltration rate is among other factors depends on the porosity of soil, which determines the water storage capacity and affects the resistance of water to flow into deeper layer. The highest infiltration rate is observed in loose, sandy soils while heavy clay or loamy soils have low infiltration rate. Keeping this fact in mind, soil map was prepared on the basis of textural classes of the soil. There are three textural classes present in the study area. They are sandy loam, clay and loamy sand. Different soil series that are found in the study area comprise these three textural classes. Soil series and their textural types are shown in Table 4.4. Detailed characteristics of soil textural classes are given in subsequent paragraphs.

Table 4.4 Types of texture under different soil series

Sr.No.	Soil series	Type of texture
1	Marippatti	Loamy sand
2	Tatikuppam	Clay
3	Vadippatti	Sandy loam

Textural names are given to soil based on the relative proportion of each of the three soil separates – sand, silt and clay. Soils that contain higher percentage of clay, are called clay, those with high silt content are silt and those with high sand percentage are sand. The relative percentage of clay in the soil decides the water harvesting capacity of the soil. Soils that contain higher percentage of clay are most favourable for water harvesting. Relative percentage of sand, silt and clay in different soil series of the study area is shown in Table 4.5. Soil map of study area on the basis of textural classes is given in Fig.4.7.

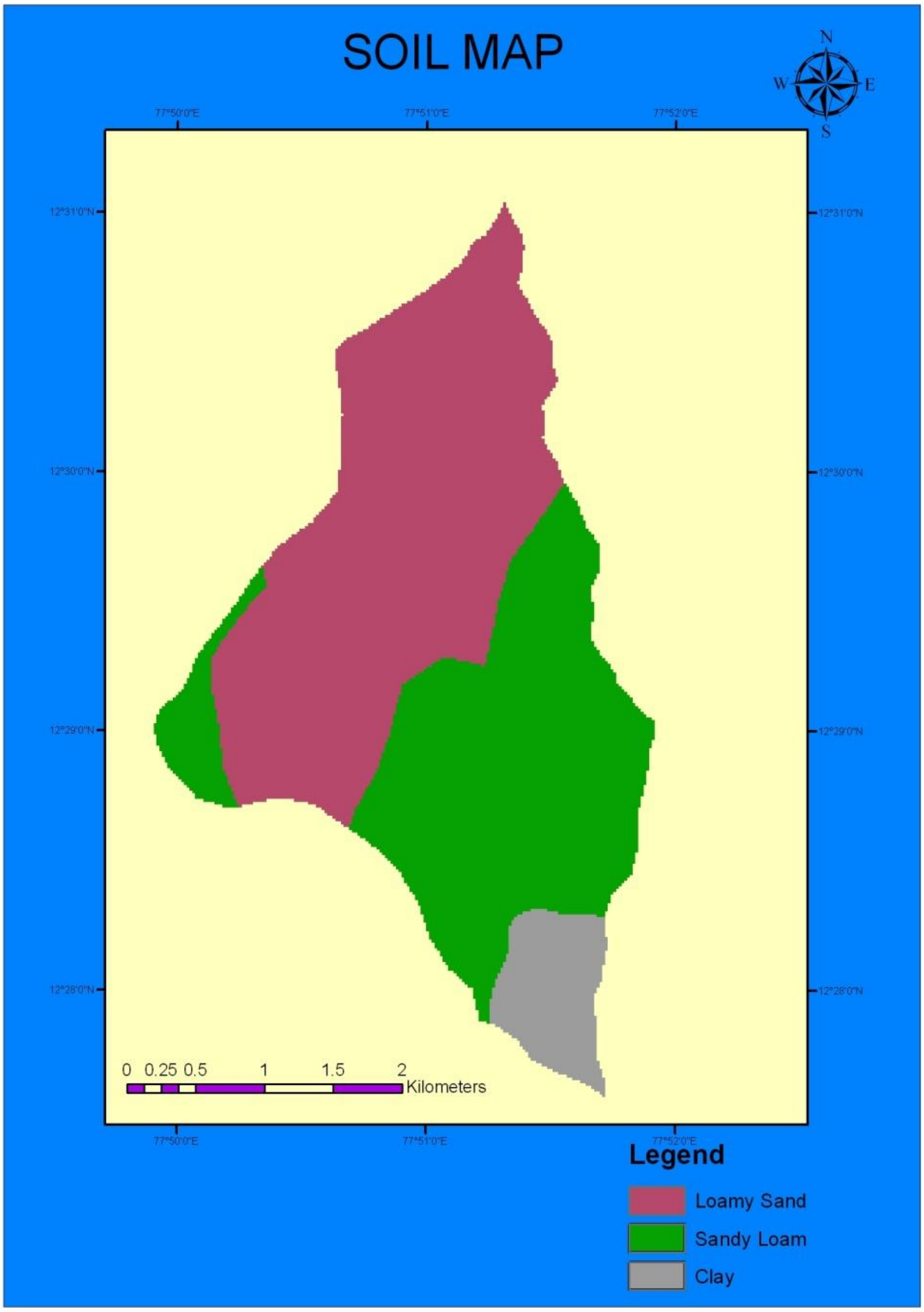

Fig.4.7 Soil map of Tippasandiram Watershed on the Basis of Textural Classes

Table 4.5 Relative percentage of sand, silt and clay in different soil series

Sr.No.	Soil series	Relative percentage			Texture
		Sand	Silt	Clay	
1	Marippatti	79.10	11.00	9.90	Loamy sand
2	Tatikuppam	46.42	9.75	43.83	Clay
3	Vadippatti	79.35	7.25	13.40	Sandy loam

From the above table it is seen that, texture of the Marippatti soil series is loamy sand and Tatikuppam is clay where as Vadippatti soil series contains the texture of sandy loam. From the above table 4.3, it is seen that most of the study area is occupied by loamy sand followed by sandy loam. Clay occupies comparatively a smaller portion than that of loamy sand and sandy loam.

4.2 Weighted overlay analysis

The weighted overlay technique was applied for common measurement scale of values of diverse and dissimilar inputs in order to create an integrated analysis.

For present study, weighted overlay was done to select suitable sites for water harvesting of surface water runoff. For this study, highest weightage was given to soil and then subsequently to slope and land use /land cover. Each class/ units of different criteria, ranked according to their response to water harvesting process. Higher the rank, more is the response to water harvesting process.

Paramount importance was given to soil with the weightage of 46 out of 100. As clay soil influences the water storage by lowering the rate of infiltration, it was ranked 3 as highest among the individual soil classes. Similarly lowest rank 1 was given to both sandy loam and loamy sand according to their response to water harvesting process.

Next criterion was given to slope with the weightage of 33. Slope mainly deals with runoff process and infiltration rate. When land slope increases, the runoff also increases which results in decreasing the infiltration rate. Since gentle slope is better suited for water harvesting sites, gentle slope i.e. low slope (0 to 1 per cent) was given highest rank of 4 and subsequently rank 3, 2 and 1 was given to less moderate (1 to 3 per cent), moderate (3 to 5 per cent) and high (>5 per cent) slope classes respectively.

Lowest weightage of 21 was given to land use/land cover, as it plays a small role in water harvesting process. Among the land use, water body was given highest rank of 5 followed by fallow land (rank of 4) as it favours water storage. Since there are no possibilities for water harvesting in settlements, cultivation and forest lands, lowest rank of 1 was given to each of them.

The result of weighted overlay analysis is shown in weighted overlay map (Fig.4.8).

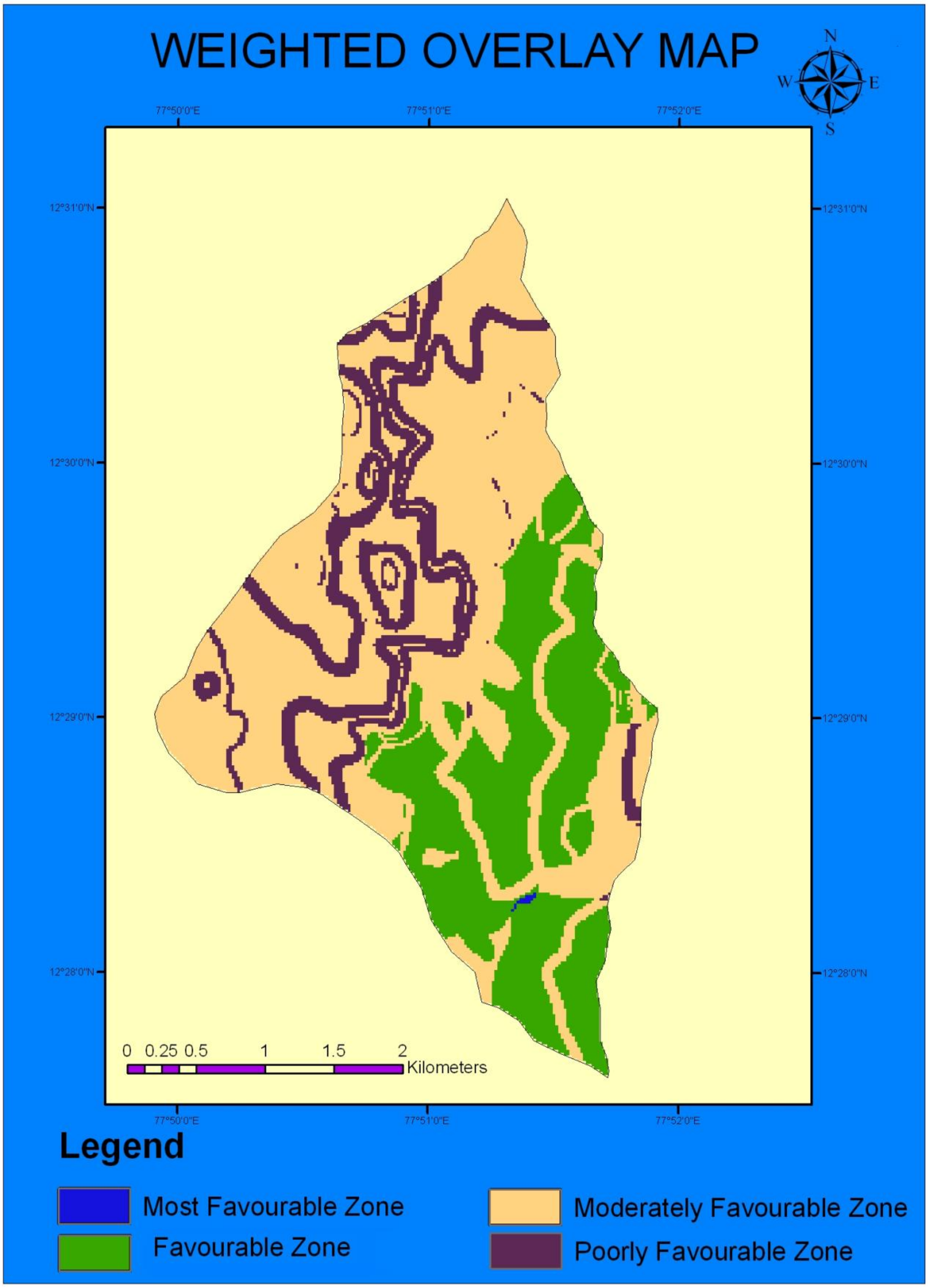

Fig 4.8 Map Showing Different Zones for Water Harvesting

From the weighted overlay analysis, four categories of water harvesting potential zones in the study area were identified. They are classified as most favourable zone, favourable zone, moderately favourable zone and poorly favourable zone. Weighted overlay map shows that most of the study area (more than ½ of the total area) falls under moderately favourable zone for water harvesting process. Aerial extent of the different potential water harvesting zones is given in Table.4.6.

Table.4.6 Aerial extent of the different potential Water Harvesting Zones.

Water Harvesting Zones	**Area in hectares**
Most favourable zone	0.72
Favourable zone	318.82
Moderately favourable zone	618.34
Poorly favourable zone	169.12

4.3 Selection of site specific water harvesting structures

Planning of surface water harvesting and suggesting specific sites for water harvesting structures are considered to be equally important. Water harvesting techniques for surface runoff would be effective when they are chosen in accordance with the specific site condition. After detailed analysis of the study area using Geographic Information System (GIS) as a tool, the various suitable water harvesting structures such as check dam, farm ponds, bundhis etc. are recommended based on present field condition. As there are four zones i.e. most favourable, favourable, moderately favourable and poorly favourable, there is more limitation on the use and recommendation of water harvesting structures. Details of recommended structures and their location are discussed in subsequent paragraphs.

4.3.1 Water harvesting Bundhis

Bundhis (local name in India) are almost similar to the minor irrigation tanks except that they do not have extensive canal system and their command area is limited to the fields of downstream.

The main objectives are,

- To collect and impound surface runoff during monsoon rains and facilitate infiltration to raise groundwater level in the zone of influence of the bundhi.
- To facilitate irrigation in the fields lying in close proximity of the water harvesting bundhi.
- To moderate the peak flow, partly by storing and partly through flooding.

There should be an adequate good cultivated land in the downstream of bundhi to reap the benefits of the water stored. Slopes of the area should be low to moderate.

In case of Tippasandiram watershed, the identified most favourable zone comes under Tatikuppam soil series of clay texture and slope class of low (0-1 per cent). Since it is flat topography and land use pattern of this area comes nearly to the cultivable land, it is recommended to construct water harvesting bundhis to irrigate the cultivable lands and to utilize for other agricultural allied works.

4.3.2 Farm ponds

Farm ponds are made either by constructing an embankment across a watercourse or by excavating a pit or the combination of both. Normally, such structures are provided within individual farms.

The main objectives are:

- To provide water storage for life saving irrigation in a limited area.
- To provide drinking water for livestock and human beings in arid areas.
- To serve as water storage for providing critical irrigation to a limited number of fruit plants for establishment purpose and
- To moderate the hydrology of small watersheds.

Farm ponds are generally created by excavating pits in areas having flat topography, low soil permeability and should be free from any faults. Preferably these ponds should be nearer to agricultural areas.

In the present study, the identified favourable zone contains Vadippatti soil series of sandy loam texture and slope class of low (0-1 per cent). Since it is a flat topography and the land use pattern of this study area comes under fallow land category, it is recommended to construct farm ponds to raise horticultural crops in the fallow land.

4.3.3 Check dam

In general, check dams are constructed at lower order streams, the slope of the terrain should be flat to gentle so as to retain maximum quantity of water with less height of check dam. They are proposed where water table fluctuations are very high and the stream is influent and/or internally effluent. To have an economical design, the catchment area should be more than 25 ha, also the soils should be less to medium permeable to allow some recharge to the downstream side of the dam if necessary. It should be located nearer to agricultural areas and settlement to convey the water. Check dams have greater importance than other structures since it has got a complimentary benefit of controlling soil erosion.

In the present study, Moderately favourable zone comes under Marippatti soil series of loamy sand and Vadippatti soil series of sandy loam. It has different slope classes of less moderate (1-3 per cent), moderate (3-5 per cent) and high (more than 5 per cent). Since land use pattern of the zone comes under forest and cultivable land, it is recommended to construct check dams to collect runoff from the hilly regions of the study area.

No recommendation of the water harvesting structures suggested in the poorly favourable zone of the study area due to its site specific condition.

As the study area is sloping from south to Northeast and a small stream network is present in the Tippasandiram watershed, it is suggested that water harvesting measures should be located at down side slope of the stream so that natural drainage flow will influence the surface water harvesting in the constructed water harvesting structures and also helps in preventing the wells, from drying, which are located adjacent to the stream lines. The map showing the different water harvesting zones and stream network is given in Fig.4.9.

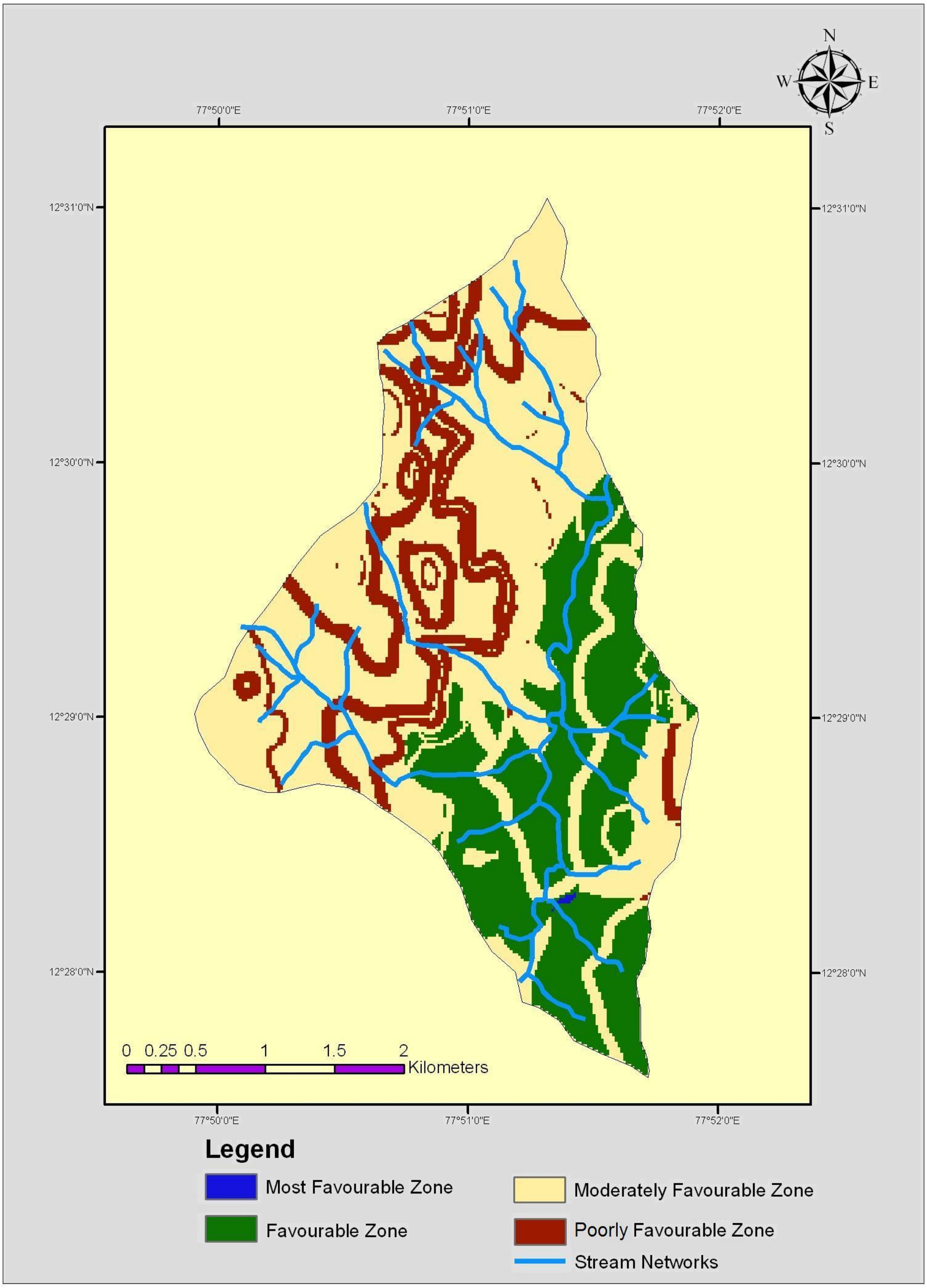

Fig 4.9 Study area showing location of stream network and favourable water harvesting zones

4.4 Selection of suitable horticultural crop and irrigation method

The major crop of Krishnagiri district with 300.17 km² of cultivation is mango. The district produces 300,000 tonnes of mango annually. Almost 20% of the mango varieties like 'Thothapuri' and 'Alphonso' produced in this district are processed into pulp. In addition to mango pulp processing, tons of mango are processed into juice every year in this district. Approximately 25 industries located in this district to process the mango pulp. Much of the populations in this district are employed through mango cultivation directly and other labour classes are benefited through employment in processing units of the fruit. There are about 150 mango nurseries which produce mango saplings in and around 'Santur Village'. The district exports mango based products worth Rs.1,000 million. Under the horticulture development program, the government owned horticulture farms are also functioning in this district. (Directorate of Horticulture and Plantation Crops, 2004)

Since Krishnagiri district is being a potential area for mango cultivation, the same horticultural crop is recommended for the present study area. If the total area (1107 ha) of Tippasandiram watershed receives an average annual rainfall of 813 mm, 164.4mcft of runoff can be stored by leaving the loss of 40% for evaporation, infiltration etc. In semi arid zone, a mango tree requires 75 lit of water/day to 143 lit of water/day. Then, a single tree requires maximum of 52,195 lit/year. The estimated quantity of 164.4 mcft will irrigate 438 hectares of land under mango cultivation. (Singh *et al.* 2007)

A detail of the aforesaid calculation is given in the appendix IV.

Effective utilization of harvested water is as important as water harvesting. Israel is a small country with an average annual rainfall of 300 mm and it could manage its water requirement by means of micro irrigation techniques. Even though the following irrigation methods are being currently adopted for various crops and area, they have their own merits and demerits. They are,

- Furrow irrigation by surface method
- Pair row/skip row irrigation
- Overhead-sprinkler method
- Pitcher method or porous cup method
- Drip irrigation/Micro irrigation

Irrigation methods have to be chosen based on the crop, soil type and water availability of the area. Today drip irrigation is applied successfully to many horticultural crops. Mango appears to be well adapted to this method. While considering the water availability of Tippasandiaram watershed for mango crop, it is recommended to use drip irrigation system for the following reasons.

- Saves water up to 70% compare to flood irrigation. More land can be irrigated with the water thus saved.
- Crop grows consistently, healthier and matures fast.
- Early maturity results in higher and faster returns on investment.
- Fertilizer use efficiency increases by 30%.
- Cost of fertilizers, inter-culturing and labour use gets reduced.
- Fertilizer and Chemical Treatment can be given through Micro Irrigation System itself.
- Undulating terrains, Saline, Water logged, Sandy & Hilly lands can also be brought under productive cultivation.

4.5 Impact of existing Water Harvesting Structures

Tippasandiram watershed was visited directly and reconnaissance survey was carried out. Questionnaire was prepared and field survey was also conducted to analyze the study area. There were 40 open wells. Cultivation covers 609 ha of the study area. Paddy is the staple crop cultivated during Khariff season. Ragi, Sorghum, Pearl millet, Mango and Groundnut crops are being cultivated during Rabi season. Fallow land was not cultivated both in Kharif and Rabi season. Soil and water conservation measures (Contour bunding, Horticultural & Agro Forestry Plantation, Farm ponds, Silt detention structures and other water harvesting structures) were executed by Agricultural Engineering Department (AED), Krishnagiri in the study area during the period of 2006-2007 under the River Valley project (RVP). Because of the measures taken by AED, farmers those who are having open wells endorse the raise of groundwater table in their area. Those who dug out wells near to the water harvesting structures drew water all through the year. But those who are cultivating far away from the water harvesting structures and those who are cultivating by expecting the canal/ rain water resources did not reap the harvest of soil and water conservation measures made by the Department of Agricultural Engineering, Government of Tamil Nadu.

The zones identified by the present study using GIS tool will definitely favour the rain water harvesting process for the maximum yield of agricultural commodities for those who are expecting canal or rain water resources for their cultivation.

4.6 Cost Analysis for Water Harvesting Structures

Developing a budget for a water harvesting system may be as simple as adding up the prices for each of the components and deciding what structure can be affordable and feasible. For agriculture without access to reliable groundwater or surface water, and too remotely located to hook up to the existing water supply infrastructure, the information in this chapter will assist in determining how large a system can be installed for a set budget, and the range of costs for an ideal system. For some, the opportunity to provide for all or a portion of their water needs with rainwater is an exercise in comparing the costs with other options to determine which is most cost effective. This chapter provides some information on cost ranges for standard components of rainwater systems for both potable use and for irrigation. It also has a brief section on comparing costs with other types of water supply .Cost analysis for the recommended structures such as Water Harvesting Bundhis, Farm Ponds and Check Dams are discussed in the subsequent paragraphs.

4.6.1 Water Harvesting Bundhis

Bundhis are small irrigation tanks consist of surplus weir, earthen embankment and sluice. Because of its additional structures, they cost more than farm ponds and check dams. A water harvesting bundhi of capacity 0.41 Mcft with water spread area of 0.415 ha is estimated to cost Rs. 9,50,000/- during the year of 2008 – 2009 (Agricultural Engineering Department, Coimbatore).

A detailed estimate and abstract estimate of Water Harvesting Bundhis are described in detail in appendix VIII.

4.6.2 Farm pond

Normally, farm ponds are provided within individual farms either by constructing an embankment across a watercourse or by excavating a pit or the combination of both. Farm ponds are generally created by excavating pits in areas having flat topography. Generally, these ponds are constructed nearer to the agricultural lands. A farm pond of size 30 x30 m at top, height of 1.5 m with a side slope of 1:1, bottom size of 27 x 27 m and capacity of 1300 cubic meter with an earthen bund all round the pond is estimated to cost Rs. 50,000/- during the year of 2008-2009 (Agricultural Engineering Department, Coimbatore).

A detailed estimate and abstract estimate of Farm ponds are described in detail in appendix IX.

4.6.3 Check dam

There are three types of check dams viz., temporary check-dams, which are constructed every year, semi permanent check dams, with a concrete structure at the base and permanent check-dams, with concrete pillars. The construction, use of water, and demolition of temporary check-dams are repeated each year.

Temporary check dams are constructed with locally available materials. Construction begins at the end of November and is completed by late December. Laterite soil is processed and placed in front of huge boulders, with an emergency outlet at the middle or at the sides. The cost of constructing a check-dam is between Rs.25,000 and Rs. 30,000.

A semi-permanent check dam is constructed yearly on top of a permanent foundation, also known as an apron. Government funds are made available for constructing the foundation. However, the permanent foundations are not completely effective as they increase sedimentation. For a permanent check-dam, wooden planks are placed in grooves provided in the concrete pillars, between which processed soil is placed. The construction cost for such a permanent structure is between Rs. 5,00,000 and Rs. 8,00,000. In 50% of the check-dams under study, farmers use the traditional method of construction, in which soil and boulders are the only raw materials (Balooni *et al*.2008).

A check dam with a weir length of 0.5 m, height of 0.8 m and head over crest of 0.6 m is estimated to cost Rs. 50,000/- during the year of 2008-2009 (Agricultural Engineering Department, Coimbatore).

A Detailed estimate and abstract estimate of check dams are described in detail in appendix X.

CHAPTER V

SUMMARY AND CONCLUSION

Rain is the main source of pure water to the world. The demand for water is increasing at a very faster rate due to various reasons such as population growth, industrial development and agricultural needs. Almost all the sources of water available are being utilized to overcome those demands. Rain water being the only source of recharging all sources of water, the need for managing it properly is very important.

In India, rainfall is the main reason for two extreme problems of floods and drought. More than 70% of annual rainfall occurs during the monsoon season. Due to the irregularity in onset and offset of monsoon, the whole agricultural pattern of India is affected. During the extreme drought conditions, the drinking water need of the people is also affected. On the other hand, the seasonal flood affects the habitat and livelihood of the people. During the recent floods in Tamil Nadu more than 15mcft of water has been let into the sea and there were more than 3600 tanks were breached. These show the improper management of rain water. Thus there is a need for proper management of rain water.

The Remote Sensing and GIS tools have opened new paths in water resource studies. The concept of integrated Remote Sensing and GIS has proved to be an effective tool in water harvesting studies.

Tippasandiram watershed of Cauvery basin at Krishnagiri district was taken up for the study to identify suitable sites for rain water harvesting using Arc GIS. The results of the study will help the Government and Non Government Organizations (NGOs) to implement suggested development measures in the different zones for rain water harvesting. Also it will help the farming community to construct the site specific water harvesting structures at favourable zones in order to improve the surface water level of the watershed, thereby irrigation frequency will be increased to facilitate maximum yield.

Toposheets of the study area obtained from SOI were scanned for digitization in GIS environment. Digitation was done in order to demarcate the study area from georeferenced toposheets. Similarly, soil map and land use maps were scanned, georeferenced and digitized to get final thematic map of soil and land use/ land cover.

Topography of the earth surface can be well understood by interpreting the contour lines. Contour map was prepared from toposheets. All the contours present in the toposheets were digitized to make contour map of the study area. Contour interval for the map was 20 m. After the preparation of contour map, rasterization of the same was done to get digital elevation model.

Digital elevation model is an image which stores the data that can be envisioned as heights on a surface. Slope map (in per cent) was derived from digital elevation model. The slope map prepared from digital elevation model was in raster form. According to the need of the study, reclassification was done to reclassify the slope map into four classes namely, low (0-1 per cent), less moderate (1-3 per cent), moderate (3-5 per cent) and high (More than 5 per cent).

Except slope map, all the thematic maps prepared were in vector format. In order to process them for further analysis, it is necessary to convert all of them into raster format. Therefore soil map, slope map and land use/cover map was rasterized in GIS environment. Thus all the thematic maps were prepared for further analysis.

Ranking was given to criteria according to their response to water harvesting process. Highest rank was given to the criteria which were most suitable for water harvesting and lowest rank was given to least suitable for water harvesting process.

Soil plays an important role for holding the water at surface level so the maximum weightage was assigned to this factor. Further, among the classes, clay loam soil is most favourable class, compared to the other type of soils because of its relative higher percentage of clay content than other soil type. Highest ranking was given to clay and lowest ranking was given to sandy loam and loamy sand.

While considering topography of the study area, gentle slopes (less than 3 per cent) served to build up hydraulic gradient. Hence gentle slopes were considered most suitable. Areas of steep slopes were considered least favourable. Considering the aforesaid facts, highest ranking was given to low slope (0-1per cent) and lowest ranking was given to high slope (more than 5 per cent).

While considering land use/land cover factor, preference was given to water body followed by fallow land, vegetation and settlements in terms of suitability for the site selection. Hence, highest ranking was given to water body followed by fallow land and lowest ranking was given to land with scrub, forest land and settlements.

Weightage is the term coined for assigning the value (out of 100) to a particular theme according to its importance to the study. High weightage was given to most important themes. Total weightage must be 100.

Considering the soil, slope and land use of the study area, highest weightage of 46 was given to soil followed by slope (weightage of 33) and lowest weightage of 21 was given to land use / land cover. Highest weightage was assigned for soil and secondary importance was given to slope. Lowest weightage was given to land use / land cover.

After assigning suitable ranking and weightage to the various parameters, weighted overlay analysis was carried out to identify the suitable sites for water harvesting. Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis.

After weighted overlay analysis, final result map was obtained which gives suitable sites for water harvesting. There are four zones found for water harvesting process which are most favourable zone, favourable zone, moderately suitable zone and poorly favourable zone having an aerial extent of 0.72, 318.82, 618.34 and 169.12 ha respectively. Weighted overlay map shows that most of the study area falls under moderately favourable zone.

Conclusions

Water harvesting structures for rain water would be effective when they are chosen in accordance with certain specific site conditions such as soil, land use/land cover, slope etc. After detailed analysis of zonation map (Weighted overlay map), generated using Remote Sensing and Geographic Information System technique, the various suitable water harvesting structures such as check dam, farm ponds, bundhis etc. are recommended based on present field condition.

1. In Tippasandiram watershed, the identified most favourable zone comes under Tatikuppam soil series of clay texture and slope class of low (0-1 per cent). Since it is flat topography and land use pattern of this area comes nearly to the cultivable land, it is recommended to construct water harvesting bundhis to irrigate the cultivable lands and other allied agricultural works.

2. Favourable zone contains Vadippatti soil series of sandy loam texture and slope class of low (0-1 per cent). Since it is also a flat topography and the land use pattern of this study area comes under fallow land category, it is recommended to construct farm ponds to raise horticultural crops in the fallow land.

3. Moderately favourable zone comes under Marippatti soil series of loamy sand and slope classes of less moderate (1-3 per cent), moderate (3-5 per cent) and high (> 5 per cent). Since land use

pattern of the zone comes under forest and cultivable land, it is recommended to construct check dams to collect runoff from the hilly regions of the study area.

4. No recommendation of water harvesting structures suggested in the poorly favourable zone of study area due to its site specific condition.

5. As the study area is sloping from south to Northeast and a small stream network is present in the Tippasandiram watershed, it is suggested that water harvesting measures should be located at down side slope of the stream so that natural drainage flow will influence the surface water harvesting in the constructed water harvesting structures.

6. Since Krishnagiri district is being a potential area for mango crop cultivation, the same horticultural crop is recommended for the present study area. The estimated quantity of 164.4 mcft will irrigate 438 hectares of land under mango cultivation. But maximum water requirement of 143 lit/plant was taken for the calculation. But in the real situation irrigation schedule may vary based on the crop stage, soil moisture content and other climatic factors. Hence, irrigation can be extended using the available water for more than 600 ha.

7. Mango crop appears to be well adapted to drip irrigation. While considering the water availability of Tippasandiaram watershed for mango crop, it is recommended to use drip irrigation system. The influence of drip irrigation system on the yield of mango has to be studied.

8. Even though existing water harvesting structures had considerably raised the water table in the study area, the recommendations suggested by the study will be helpful to improve the surface water level of the watershed, thereby irrigation frequency will be increased to facilitate maximum yield.

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APPENDIX I

Properties of Maripatti Soil Series

- **Physical properties**

Minimum Depth (cm)	Maximum Depth (cm)	Particle size fraction %			Texture
		Clay	Silt	Sand	
0	18.0	9.90	11.0	79.10	Loamy sand

- **Exchangeable properties**

PH	EC (dsm^{-1})	Exchangeable cations				CEC	BSP (%)	ESP (%)	Organic carbon (%)
		…….cmol (p^{+}) kg^{-1}………………..							
		Ca	Mg	Na	K				
6.85	0.08	5.26	2.4	0.16	0.29	9.20	88.15	1.74	0.15

- **Available Nutrients**

P_2O_5	K_2O
………………………………………. (Kg/ha) …………………………………………….	
2.00	45.00

APPENDIX II

Properties of Tatikuppam Soil series

- **Physical properties**

Minimum Depth (cm)	Maximum Depth (cm)	Particle size fraction %			Texture
		Clay	Silt	Sand	
0	22.0	43.83	9.75	46.42	Clay
22.0	48.00	49.72	6.08	44.20	Clay
48.00	65.00	42.36	10.12	49.52	Clay
65.00	82.00	47.52	9.36	43.12	Clay

- **Exchangeable properties**

PH	EC (dsm^{-1})	Exchangeable cations				CEC	BSP (%)	ESP (%)	Organic carbon (%)
		…….cmol (p^+) kg^{-1}………………..							
		Ca	Mg	Na	K				
6.43	0.17	7.10	1.30	0.80	0.40	12.10	79.34	6.61	0.45
6.52	0.24	11.50	5.10	0.66	0.30	20.30	86.50	3.25	0.36
6.68	0.09	9.50	4.40	0.60	0.54	19.10	78.74	3.14	0.23
6.72	0.16	8.20	2.50	0.34	0.42	16.50	69.45	2.06	0.18

- **Available Nutrients**

P_2O_5	K_2O
……………………………………… (Kg/ha) …………………………………………….	
7.28	156.30
7.32	158.00
7.00	162.00
7.14	160.00

APPENDIX III

Properties of Vadippatti Soil series

- **Physical properties**

Minimum Depth (cm)	Maximum Depth (cm)	Particle size fraction %			Texture
		Clay	Silt	Sand	
0.00	11.00	13.40	7.25	79.35	Sandy loam
11.00	33.00	22.40	6.00	71.60	Sandy clay loam
33.00	56.00	18.60	8.45	72.95	Sandy loam
56.00	81.00	20.40	3.00	76.60	Sandy clay loam
81.00	105.00	12.65	3.50	83.85	Sandy loam
105.00	132.00	10.84	10.00	79.11	Sandy loam

- **Exchangeable properties**

PH	EC (dsm^{-1})	Exchangeable cations				CEC	BSP (%)	ESP (%)	Organic carbon (%)
		…….cmol (p^+) kg^{-1}………………..							
		Ca	Mg	Na	K				
6.56	0.73	14.40	0.60	0.18	0.39	23.30	66.82	0.77	0.17
6.28	0.86	12.90	1.80	0.14	0.31	23.80	63.66	0.59	0.21
6.15	0.83	13.80	2.50	0.23	0.35	26.90	62.75	0.86	0.33
6.94	0.80	13.40	1.30	0.08	0.35	22.30	67.85	0.36	0.08
7.12	0.86	9.10	2.90	0.26	0.31	29.40	42.76	0.88	0.06
6.90	0.99	11.60	1.20	0.11	0.31	20.00	66.10	0.55	0.04

- **Available Nutrients**

P_2O_5	K_2O
……………………………………… (Kg/ha) …………………………………………	
3.00	56.00
1.00	45.00
3.00	50.00
1.00	50.00
1.00	45.00
1.00	45.00

APPENDIX IV

Calculation

Total area of Tippasandiram watershed	:	1107 ha.
Area for poorly favourable zone	:	169 ha
Area for water harvesting	:	938ha
Average annual rainfall	:	813 mm
Plant spacing	:	10 X 5 m
Maximum plant water requirement	:	143 lit/day/plant
Water requirement of a tree	:	143 X 365
	:	52, 195 lit / year
Water collected from the entire area	:	938 X 10000 X 0.813
	:	7625940 m^3
Considering 40 % loss (FAO)	:	7625940 X 0.4
	:	3050376 m^3
Available water for cultivation	:	7625940 m^3 - 3050376 m^3
	:	4575564 m^3 = 164.4 mcft

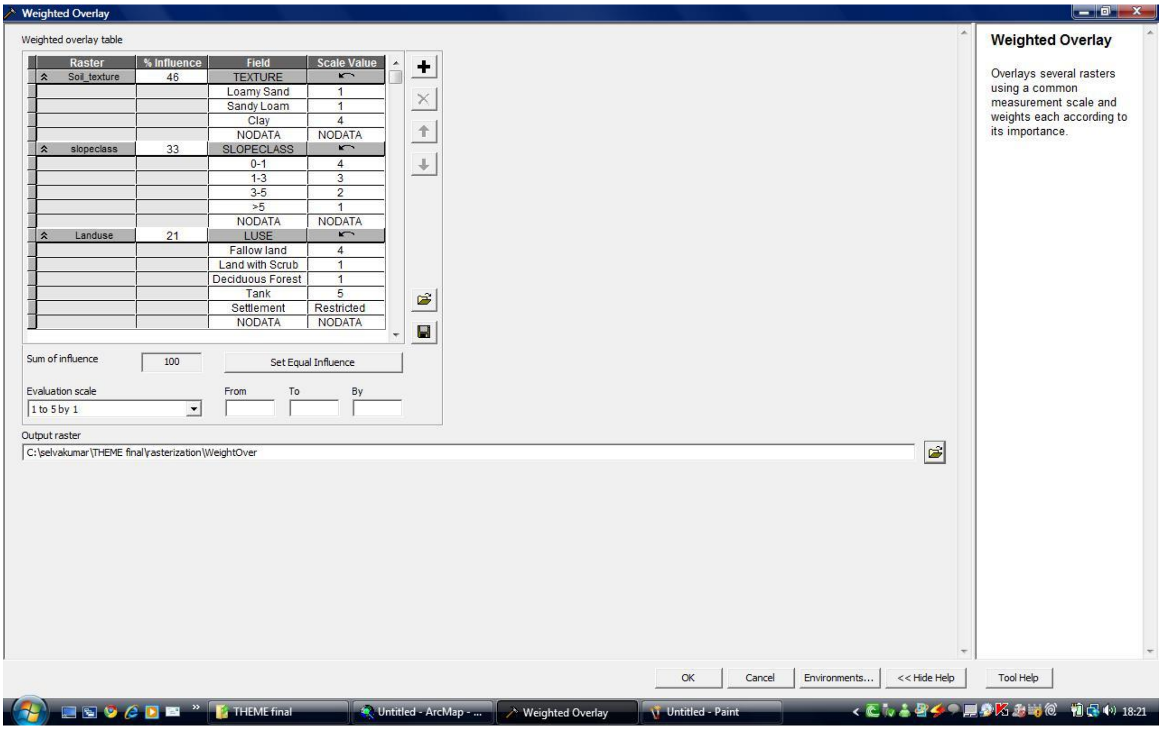
No. of trees / ha	:	10000 m^2 / (10 X 5)
	:	200 Nos.
Water required for irrigation / year / ha	:	52, 195 X 200
	:	10,439,000 lit
Possible area can be irrigated using Available water	:	(4575564 X1000) / 10,439,000
	:	438 ha

Note:

In this calculation, maximum water requirement of 143 lit / plant has been taken. But in the real situation irrigation schedule may vary based on the crop stage, soil moisture content and other climatic factors. Hence, irrigation can be extended using the available water for more than 500 ha.

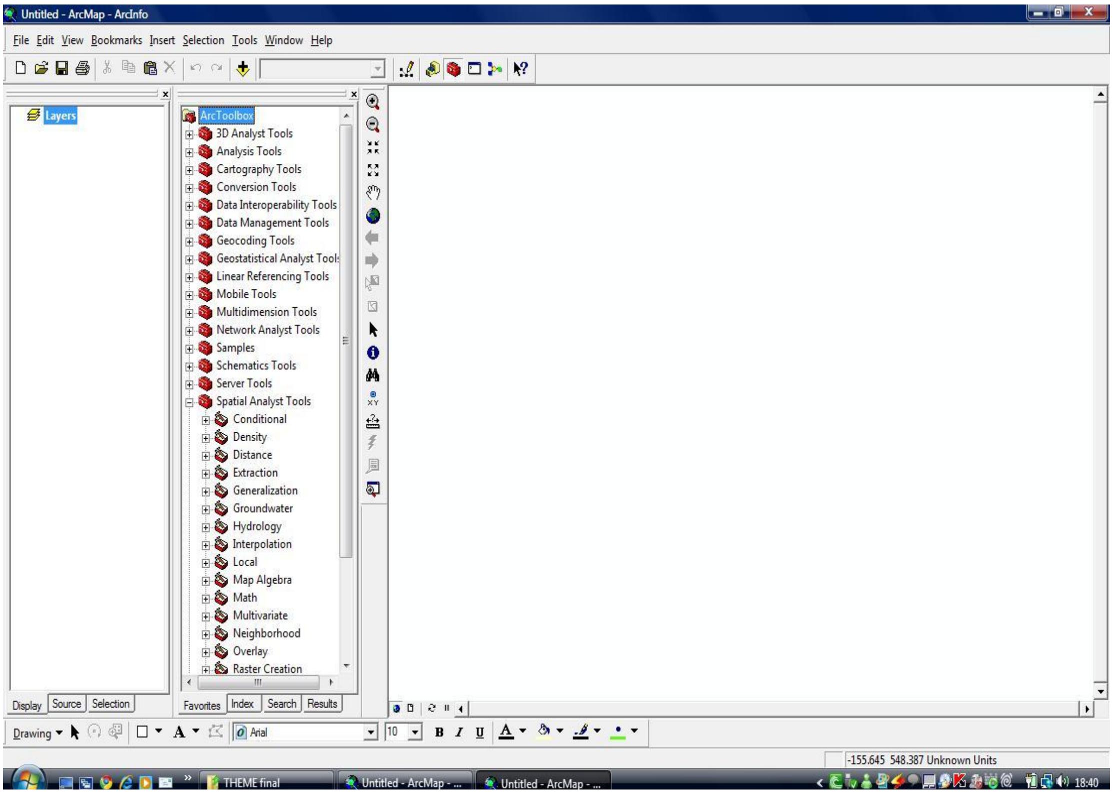
APPENDIX VII

Weighted overlay analysis window



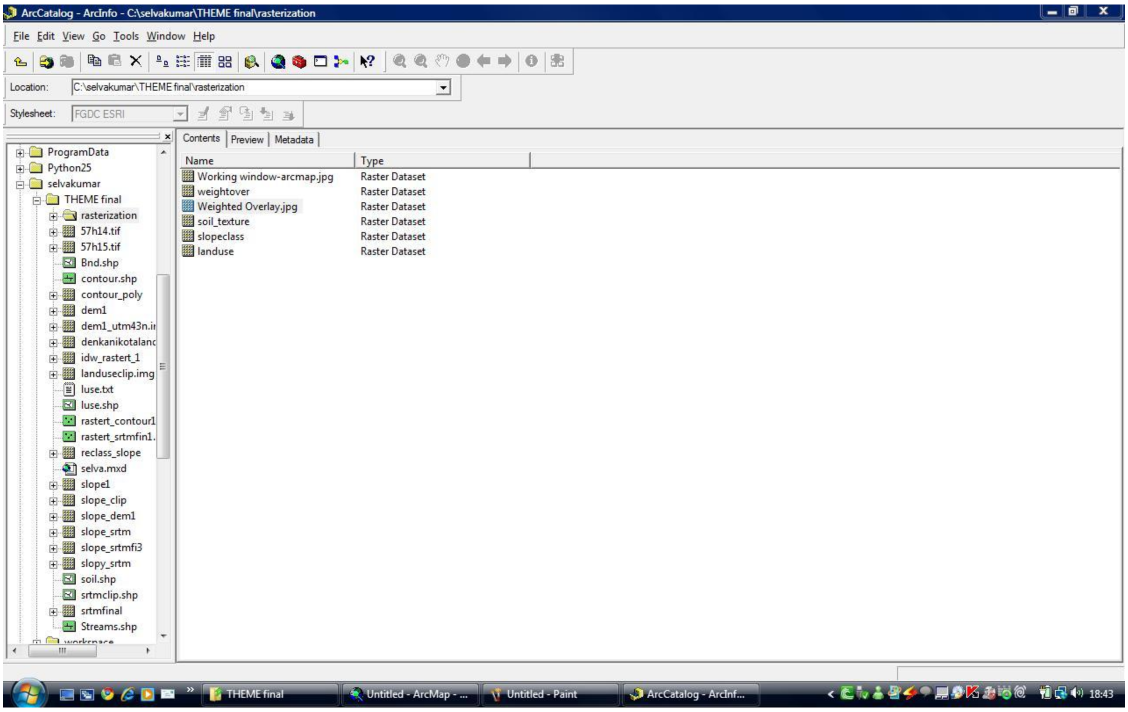
APPENDIX V

Working window of ArcMap-ArcInfo



APPENDIX VI

Working window of ArcCatalog-ArcInfo



APPENDIX VIII

Cost Analysis for Water Harvesting Bundhis

Detailed Estimate

S.No	Description of work	Nos.	Measurements (m)			Quantity
			Length (m)	Breadth (m)	Depth (m)	
1	Clearing scrub jungles	1X1	150.00	35.00	__	5250.00 m^2
2	Earth work in all soils except hard rock requiring blasting and conveying for formation of bund with lead to 0 to 100 m. Deploying earth moving machineries and tippers including benching, formation of bunds, breaking clods, sectioning etc. complete	1X1	100.00	30.00	1.4	4200.00 m^3
3	Lead for safe disposal of the earth excavated by machinery for 1 km distance	1X1	100.00	30	1.40	4200.00 m^3
4	H.G.S.SS.20.B.Earthwork excavating and depositing on bank within initial lead of 10 M & initial lift of 2m. In hard stiff clay, stiff black cotton, hard red earth, shales, murram, gravel, stoneyearth, and earth mixed with small size boulders. For top soil removal	1X1	5.00	0.6	0.45	3.00 m^3
5	H.G.S.SS.20.B. Earth work excavating and depositing on bank within initial lead of 10 m & initial lift of 2m. In hard stiff clay, stiff black cotton, hard red earth, shales, murram, gavel, stoneyearth, and earth mixed with small size boulders. For new tank bund formation.	1X1	30 & 15	10.50	0.30	417.00 m^3

6	Extra for every additional 10 m. Lead or part thereof over the initial lead. I lead	1X1	30 &15	(2.10+34.80)/ 2	-	1137.00m^3
7	A rate for new tank bunds and closing breaches for extra watering and consolidation.	1X1	13&30	(44.50+21.90)/2	0.00	1951.10 m^3
Add 5% for undulations						97.56
Add top soil removal quantity						308.00
Total						**2356.66 m^3**

Abstract estimate for Bund Formation

S.No	Description of work	Rate (Rs)	Unit	Qty	Amount (Rs)
1	H.G.S.SS.20.B. Earthwork excavating and depositing on bank within initial lead of 10 M & initial lift of 2m. In hard stiff clay, stiff black cotton, hard red earth, shales, murram, gravel, stoneyearth, and earth mixed with small size boulders. For top soil removal	57.50	Cu.m	514	29555.00
2	Plain cement concrete 1:5:10 using 40 mm size H.B. Stones for 10 cu m. Including curing etc. complete	30.60	Cu.m	2315.00	70839.00
3	Random rubble masonry in cement mortar 1:5 including curing etc. Complete	3.65	Cu.m	2313.36	8443.75
4.	Cement concrete 1:3:6 using 20 mm HBStones including curing etc complete for coping the weir	6.05	Cu.m	2424.00	14665.20
5	Cost of Rough stone dry packing for talus and revetment.	680.05	Cu.m	25.10	17069.26
6	Plastering in cement mortar 1:4 including curing etc. Complete.	126.98	Sq.m	37.20	4723.51
			Total		**Rs.6,55,006.15/-**

Abstract Estimate for Surplus Weir

S.No	Description of work	Rate (Rs)	Unit	Qty	Amount (Rs)
1	Clearing scrub jungles	2.40	Sq.m	5250.00	12600.00
2	Earth work in all soils except hard rock requiring blasting and conveying for formation of bund with lead to 0 to 100 m. Deploying earth moving machineries and tippers including benching, formation of bunds, breaking clods, sectioning etc. complete	34.60	Cu.m	4200.00	145320.00
3	Lead for safe disposal of the earth excavated by machinery for 1 km distance	5.75	Cu.m	4200.00	24150.00
4	H.G.S.SS.20.B. Earthwork excavating and depositing on bank within initial lead of 10 M & initial lift of 2m. In hard stiff clay, stiff black cotton, hard red earth, shales, murram, gravel, stoneyearth, and earth mixed with small size boulders. For top soil removal	28.75	Cu.m	295	8481.25
5	H.G.S.SS.20.B. Earth work excavating and depositing on bank within initial lead of 10 m & initial lift of 2m. In hard stiff clay, stiff black cotton, hard red earth, shales, murram, gavel, stoneyearth, and earth mixed with small size boulders. For new tank bund formation.	30.60	Cu.m	2315.00	70839.00
6.	Extra for every additional 10 m. Lead or part thereof over the initial lead. I lead	3.65	Cu.m	2313.36	8443.75
7.	A rate for new tank bunds and closing breaches for extra watering and consolidation.	6.05	Cu.m	2424.00	14665.20
			Total		**Rs. 2,87,632.95/-**

General Abstract for Water Harvesting Bundhis

Cost of bund formation	289702.03
Cost of weir construction	655006.15
Sundries	5291.00
Total	**Rs.9,50,000.00/-**

APPENDIX IX

Coast Analysis for Farm Pond

Detailed Estimate

S.No	Description of work	Nos.	Measurements (m)			Capacity (m^3)
			Length (m)	Breadth(m)	Depth (m)	
1	Earth work in all soils except hard rock requiring blasting and conveying for formation of bund with lead to 0 to 100 m. Deploying earth moving machineries and tippers including breaking clods, sectioning etc. Complete for formation of Farm pond	1	3.50	2.60	0.45	4.10
2	Extra for every additional 100m. Lead or part there of over the initial lead of 100m.for safe disposal of the excavated soil from farm pond. Pond Quantity as above Deduct Top soil quantity that could be utilized by farmer.	1X1	29.7	29.6	0.30	693.75
3	Rough stone dry packing for inlet and outlet portion	1X2	4.00	2.50	0.22	4.40

Abstract Estimate

S.No	Description of work	Rate (Rs)	Unit	Amount (Rs)
1	Earth work in all soils except hard rock requiring blasting and conveying for formation of bund with lead to 0 to 100 m. Deploying earth moving machineries and tippers including breaking clods, sectioning etc. Complete for	34.60	Cu.m	42155.94
2	Extra for every additional 100m. Lead or part there of over the initial lead of 100m.for safe disposal of the excavated soil from farm pond. Pond Quantity as above Deduct Top soil quantity that could be utilized by farmer.	7.30	Cu.m	5064.37
3	Rough stone dry packing for inlet and outlet portion	545.08	Cu.m	2398.35
4.	Sundries			381.34
			Total	**50,000 /-**

APPENDIX X

Cost Analysis for Check Dams

Detailed Estimate

S.No	Description of work	Nos.	Measurements (m)			Capacity (m^3)
			Length(m)	Breadth(m)	Depth (m)	
1	Earth Work excavation to a depth of 0.45 m	1	3.50	2.60	0.45	16.08 m^3
2	Cement concrete 1:5:10 using 40mm HBGS jelly including cost of all material, labour etc.,	1X1	3.50	2.60	0.45	16.08 m^3
3	RR masonry in cm 1:5 including cost of all materials labour, transport etc, Body wall.	1X1	3.5	1.3	1.5	8.54 m^3
4	Plastering with cm 1:5, 20 mm thick top of body wall	1X1	3.5	0.6	0.45	7.42 m^3
5	Earth work in all soils except hard rock requiring blasting and conveying for formation of bund with lead of 0 to 100m. deploying earth moving machineries and tippers including benching, formation of bunds, breaking clods, sectioning etc complete pit 1	1X1	25	10	0.50	125 m^3

Abstract Estimate

S.No	Description of work	Rate (Rs)	Unit	Amount (Rs)
1	Clearing of light jungles	1.65	Sq.m	742.50
2	Earthwork excavating and depositing on bank within initial lead of 10m & initial lift of 2m. In hard stiff clay, stiff black cotton, hard red earth, shales; murram, gravel, stoneyearth, and earth mixed with small size boulders.	57.50	Cu.m	924.60
3	Cost of cement concrete 1:5:10 using 40 m.m. size H.B. Stones	1798.13	Cu.m	28913.93
4	Random rubble masonry in cement mortar 1:5 including curing etc. Complete	1619.66	Cu.m	13831.89
5	Plastering in cement mortar 1:4 including curing etc. Complete	126.97	Sq.m	942.19
7	Earth work in all soils except hard rock requiring blasting and conveying for formation of bund with lead 0 to 100 m. deploying earth moving machineries and tippers including benching, formation of bunds, breaking clods, sectioning etc. complete	34.60	Cu.m	4325.00
6	Sundries			319.89
				Total 50,000 /-