Research Report on

RAINFALL – RUNOFF MODELLING AND GROUNDWATER DYNAMICS OF IRRIGATION TANK CLUSTERED CATCHMENT IN SEMI ARID REGION

SUBMITTED TO

INDIAN NATIONAL COMMITTEE ON IRRIGATION AND DRAINAGE

MINISTRY OF WATER RESOURCES
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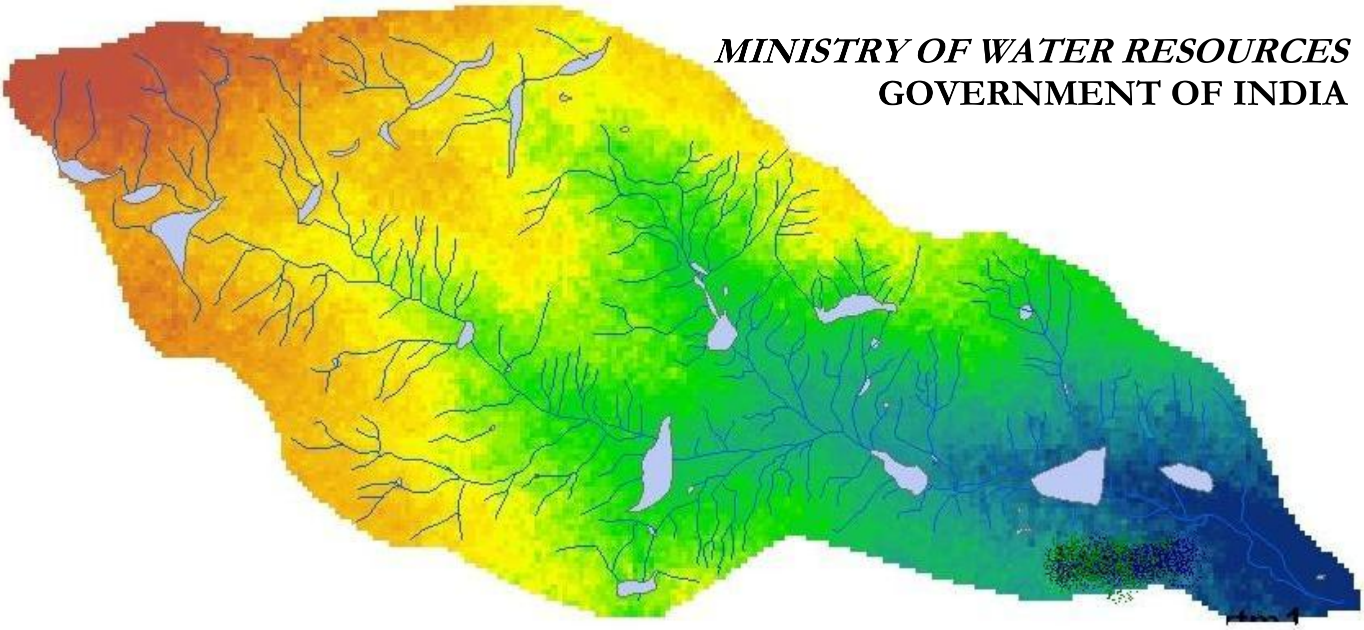

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SUMMARY

Water resource management in a semi arid region is complex and gains its importance in order to tackle the increasing demand for water in the context of hydrological extremes. Modelling of semiarid area hydrology is complex than humid areas. The complexity of the hydrological processes seen in semi-arid regions makes it difficult to predict the spatial and temporal variation of the processes that occur within these regions. To simulate both spatial and temporal characteristics of the catchment and for considering all the hydrological components, integrated models are needed. The integrated modelling approach that simulates both surface water and groundwater enhances the reliability of the models in accurate quantification of water resources potential of a region.

Tanks are the predominant water storage structures in semi arid region especially in South Asia for conserving the runoff water and to use it in deficit periods. Tamil Nadu state is in semi arid region, which has about 39,402 tanks for harnessing the runoff water. Some of them are cascaded or clustered, where water is stored and being utilized in non monsoon periods for irrigation and other purposes. The presence of tanks in the watershed will results in modified rate of flow, time of travel and reduced peak flow. Hydrological behavior of tank clustered catchments is totally different from that of a catchment without any intervening storage structures. Incorporating the hydrological effects of tanks in rainfall runoff modelling will make it into a more complex. This study aims at potential assessment of water resource both its spatial and temporal variations in a irrigation tank clustered catchment with the application of physically based hydrological modelling.

The objectives of this research at a basin level are to estimate the surface water and groundwater potential using empirical methods. This involves. 1. To analyze the spatial and seasonal pattern of rainfall over the

entire Vaippar basin. 2. Assess the spatial and temporal distribution of surface water ground water potential. The specific objectives of the research is to carry out a micro level sub-basin study in an irrigation tank clustered catchment which involves (i) To characterize the study area to replicate the physical conditions of surface, unsaturated and saturated zones in the integrated model; (ii)To carryout overland flow routing of a tank cascaded basin using physically based modular approach; (iii)To simulate the ground water flow in the unconfined aquifer in transient condition; and (iv)To study the surface water and groundwater dynamics on incorporation of tank cascades in the integrated model.

The Vaippar basin is chosen as the study area which lies between latitudes of 8°57´N and 9°48´N and longitude of 77°16´E and 77°22´E covering a total catchment area of 5423 km^2. The basin is located in the southern part of Tamil Nadu state and falls in semi arid region. Rainfall analysis was done for the whole Vaippar basin and distributed rainfall variations over various season are shown as maps. Spatial variation of surface water and groundwater potential are assessed for the Vaippar Basin. The Soil Conversation Service (SCS) method is used for the assessment of runoff generation. The soil and Land sue map were overlaid in GIS and Distributed Curve Number (CN) model assigns each polygon a CN that corresponds to its land use-land cover and soil hydrologic group. The overlaid Land-Soil polygon map from ArcGIS is used for assessing the runoff generated for each polygon for the whole basin. Similarly Groundwater potential is also estimated using Water Table Fluctuation Method of GEC norms for the whole basin using ArcGIS.

The micro level study has been taken up in Sindapalli Uppodai sub-basin, lies in southern parts of Tamil Nadu. The entire sub-basin falls under the semi-arid classification. Sindapalli Uppodai receives drainage from its own catchment. Sindapalli sub-basin consists of 16 tanks as clustered, mainly used for irrigation purposes. The whole catchment process is distributed throughout the heterogeneous, complex basin which requires grids based computation where lumped modelling is unsuitable which ultimately requires physically based model. An attempt has been made in this study to characterize and to simulate the flow process through a tank cascaded system with the application of coupled MIKE SHE and MIKE 11, a fully integrated physically based deterministic and distributed model. With the help of primary and secondary data, the complex integrated model has been set up by coupling MIKE SHE and MIKE 11 model.

A scientific database has been developed which is one of the basic requirements of any modelling process. The database consists of physiographic, meteorological and hydrologic characteristics of the study area and data are collected in various departments both in the form of paper maps and tables. Intensive field visits have been made for primary data collection. Arc GIS 9.0 and Map Info 6.0 both used in preparing the GIS database required to do this research project. The drainage network map was delineated using Survey of India topographic sheets and was updated using CARTOSAT Imagery. Field visit was made to assess the current status of the tank cascade system. Land use map was prepared using the high resolution Resourcesat data. Soil sampling was carried out for textural analysis and soil map was prepared. The main input data for the model are DEM data, precipitation and reference evapotranspiration. Manning’s M, was assigned for each land use type. Digital Elevation Model of the study area was obtained from ASTER data and GPS survey. Overland flow was routed through the tank cascades in MIKE 11 (rivers and lakes module) and coupled with MIKE SHE which gives the accurate quantity of surface water available to underlying aquifers as recharge through infiltration. The time series data of rainfall and climate parameters are given as input and the Overland flow at tank outlets was simulated and time series discharge values at tank outlets for entire simulation period were interpreted from Stage Vs Discharge curves, which are used for calibration and validation of the model.

The unsaturated and groundwater interaction simulation requires evapotranspiration, soil properties and specific yield values. The reference Evapotranspiration time series was obtained using FAO's ETo calculator upon feeding the climate parameters data. Water retention curves and hydraulic conductivity were calculated using Pedo transfer function in ROSETTA calculator and hence unsaturated zone has been characterized in a distributed manner. Field observed aquifer parameters such as horizontal and vertical conductivity; specific yield and specific storage were used for groundwater zone characterization. Groundwater flow has been simulated mathematically by 3D Darcy equation through ground water solver of Integrated MIKESHE model using aquifer parameters for the same simulation period and the spatial and temporal variation of hydraulic head of the saturated groundwater zone was simulated. Seventy one observation and pumping wells were being monitored within and periphery of sub-basin out of which 11 observation wells were used for calibration and validation of the model

The tank cascaded catchments' features and processes of the surface tank cascade system, stream networks, unsaturated and saturated zones were characterized and simulated successfully by the coupled model in an integrated manner. The model simulation has been evaluated through calibration and validation of simulated tank yield and head elevation values of observation wells with that of observed data. Three years from 2009 to 2011 of observed water level data of tanks and observation wells were used for the calibration and validation of the model. The model was calibrated over a period of one wet and dry year from January 2009 to December 2010 and validated for the normal year from January 2011 to December 2011. The error matrix, correlation coefficient and Nash-Sutcliffe coefficient values of calibration and validation process indicate good simulation potential and prediction capability of the coupled model developed for the tank cascaded catchment.

Model was run in three scenarios to find out the effects on discharge and water level upon incorporation of tank cascades and natural depressions in the integrated model. The scenarios were (i) MIKESHE without incorporation of tank cascade (ii) MIKE SHE with tank cascades (MIKE 11) and (ii) MIKE SHE with tank cascades and natural depressions. The different scenario runs indicated a significant change in the discharge at tank outlet and water level due to incorporation of tank cascades. Impact of adding natural depressions was also analyzed. Water balance for the study area has been done and found to be matching with the observed value. The scenario simulation, with and without considering tank cascaded system indicates large difference in the overland flow, ground water levels and recharging pattern in the saturated zone. The scenario simulation confirms the capturing of the effects of tanks by the coupled model and proves the importance of inclusion of surface water bodies as it has great influence on water balance analysis of an integrated modelling.

Hydrological modelling incorporating tank cascade system attempted in this study helps in determining the accurate estimation of surface and groundwater potential. Integrated simulation and estimation helps in better water allocation, budget planning and resource management for the catchments consisting of invening surface storage structures like ponds, lakes and reservoirs. The accurate quantification of water resources potential will help the planners and decision makers towards conserving and managing the water resources on a micro watershed level.

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LIST OF ABBREVIATIONS

ASTER	Advanced Space borne Thermal Emission and Reflection
DEM	Digital Elevation Model
ET	Evapotranspiration
FAO	Food and Agriculture
FENM	Finite Element Numerical Method
GIS	Geographic Information System
GPS	Global Positioning System
HRU	Hydrologic Response Unit
INCID	Indian National Committee on Irrigation and Drainage
LAI	Leaf Area Index
MoWR	Ministry of Water Resources
NABARD	National Bank for Agriculture and Rural Development
OL	Overland
OW	Observation Well
PCG	Preconditioned Conjugate Gradient
PET	Potential Evapotranspiration
PIW	Paya Indah Wetlands
PW	Pumping Well
RD	Root Depth
RRM	Rainfall Run-off Modelling
SHE	System Hydrologic European
SOR	Successive over- relaxation
TNAU	Tamilnadu Agricultural University
ha-m	Hectare meter
km^2	Square Kilometer
m^3 /sec	Meter cube / second
MCM	Million Cubic Meter

SCS-CN	-	Soil Conservation Service Curve number
GRASS	-	Geographic Resources Analysis Support System
IUH	-	Instantaneous Unit Hydrograph
SWAT	-	Soil Water Assessment Tool
m	-	Meter
FEM	-	Finite Element Method
FDM	-	Finite Difference Method
WTF	-	Water Table Fluctuation
ISRO	-	Indian Space Research Organization
kmph	-	Kilometer per hour
TWAD	-	Tamilnadu Water Supply and Drainage
$^{\circ}C$	-	Degree Centigrade
PWD	-	Public Works Department
SOI	-	Survey of India
MSL	-	Mean Sea level
ERDAS	-	Earth Resource Development Assessment System
LISS	-	Linear Imaging Self Scanner
DHI	-	Danish Hydraulic Institute
ET_o	-	Reference Evapotranspiration
IMD	-	India Meteorological Department
b.g.l	-	Below Ground Level
GEC	-	Groundwater Estimation Committee
ME	-	Mean Error
MAE	-	Mean Absolute Error
RMSE	-	Root Mean Square Error
ha	-	Hectare

PROJECT COMPLETION REPORT

1. Title of the Scheme

Rainfall – Runoff Modelling and Groundwater Dynamics of Irrigation Tank Clustered Catchment in Semi Arid Region

2. Name and Address of the PI and other Investigators

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4. Financial details (Sanctioned cost; amount released; expenditure; unspent balance (if any) and return of unspent balance)
Total Project Cost : Rs.35,27,000/- (A copy of the financial details are enclosed)

5. Utilization Certificate
Utilization Certificates for all the Financial years are enclosed.

6. Statement of equipment purchased under the scheme
The statement of the equipment purchased are enclosed.

7. Original objectives and methodology as in the sanctioned proposal
The objectives are reported in Chapter 1.

8. Any changes in the objectives during the operation of the scheme
No

9. All data collected and used in the analyses with source of data

The collected data are presented in **Chapter 4** for the sub-basin study

10. Methodology actually followed (Observations, Analysis, results `and inferences)

The methodology followed for the basin level study is presented in Chapter 3. For the sub-basin study, the observations, analysis and the results are presented from **Chapter 4 to Chapter 7.**

11. Conclusions/Recommendations

Given in section 8.3 of Chapter 8

12. How do conclusion/recommendations compare with current thinking
Given in section 8.4 of Chapter 8

13. Field Test conducted
Given in section 8.5 of Chapter 8

14. Software Generated if any

Given in section 8.6 of Chapter 8

15. Possibilities of any patterns/copy right. If so action taken in this regard

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16. Suggestions for further work

Given in section 8.8 of Chapter 8

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Appendix I

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19. ORGANIZATION OF THE REPORT

The Completion Project Report is organized and presented as eight chapters as per Appendix 8. The **Chapter 1** provides the brief descriptions of the problems, its importance of study and objectives. A detailed review of literature related to hydrologic modelling, surface water assessment, ground water assessment and application of physically based integrated modelling in various studies are presented in **Chapter 2.**

Chapter 3 contains the complete observations, analysis, results and discussion of the **basin level** study. The secondary data and descriptions of Vaippar basin has been presented in Chapter 3. The methodology, analysis and the results of the analysis such as spatial and seasonal pattern of rainfall, surface water and ground water potential estimation of the study area are detailed in **Chapter 3.**

The integrated hydrologic modelling study incorporating the tank cluster system of semi-arid region has been done at the sub-basin level, which has been detailed in **Chapters 4, 5, 6, 7 and 8. Chapter 4** deals with the detailed description of the micro level study basin and the collection of secondary data and field tests/survey conducted for primary data for the development of the database. **Chapter 5** elaborates the ground water resource estimation in the sub-basin using GEC norms' methodology, analyses and results of the study.

Chapter 6 describes the methodology, processes involved and characterization of the study area using the physically based model MIKE SHE and MIKE 11 for the integrated surface and ground water dynamics study of the sub basin with the incorporation of tank cluster system.

The results and discussions and the inference of the study of the physically based modelling study are presented in **Chapter 7. Chapter 8** presents the conclusions and recommendations of the present study.

CHAPTER 1

INTRODUCTION AND OBJECTIVES

1.1 GENERAL

Water- the elixir of life is the crucial natural resource and the core of natural ecosystems and climate regulation, without beginning or end and it moves on, above and below the surface of the earth, being stored on surface in depressions and below the ground in soil pores, without which no life can survive on the earth. It is under threat that in forthcoming years there will be reduced access to safe drinking water and drought becomes more frequent in semi-arid regions. This, in turn, will diminish the supply of water for irrigation and food production. Water is not merely a consumer product, but a precious and endangered natural resource, vital to future generations as well as our own and in-turn for the existence of the earth itself. Hence water must be managed and protected in a sustainable manner.

The variability of hydrological conditions of a country may be so vast from region to region that it may affect the pattern of life of the people in those regions. Therefore, a scientific study of hydrology and its application to water resources development and utilization is of tremendous importance for the development of the nation. Modelling finds its importance in this arena. Hydrologic modelling is a powerful technique of hydrologic system investigation, prediction, understanding the hydrologic processes and development of integrated approaches for management of water resources.

1.2 SEMI-ARID HYDROLOGY

More than 25 percent of the earth's land surface is classified as semi-arid with an annual precipitation of between 250 and 500 mm, and an average annual potential evapotranspiration exceeding 800 mm. Surface water in the semi-arid land is known to fluctuate both in space and time and since its variability increases with aridity, this characteristic is most marked in arid and semiarid zones. The study of various phases of the hydrological cycle and the relationship between rainfall and runoff in such regions, therefore require more importance. These regions are characterized by larger relative extremes in components of the hydrologic cycle than in the humid climates, including low annual precipitation, high potential evaporation, low annual runoff but short-term high-volume runoff and runoff losses in ephemeral channels.

1.2.1 Tank Clusters of Semi-Arid Basin

Semi-arid regions of South Asia are mostly characterized by the presence of small water storage earthen structures called tanks. The entire rainfall in this semi-arid region is confined to 40 to 70 days period resulting in the need for storing water for use in agriculture and recharge purposes. In India there are around 120,000 small-scale tanks, irrigating about 4.12 million ha. In many areas, the tank storage structure is the only water source to store rainwater and help farmers through crop growing period and provide stability to agricultural production.

A tank cascade/clusters is a series of tanks connected together, organized within the sub-catchments i.e. outflow of one or more tanks on the upstream side of the catchment is fed as inflow to the tank located in the downstream end forming a cluster. It drains to a common reference point of a natural drainage course, thereby defining a sub-watershed unit that increases in size along downstream. Excess water flowing from one tank in the cascade is captured in the next tank downstream. Tank storage is a major component which will affect runoff both in magnitude and time. Routing through the streams without considering the intervening tank storages will not give an accurate estimation of water potential available at various times. The Figure 1.1 given below explains the flow of water from one tank to other tanks in the tank cluster system.

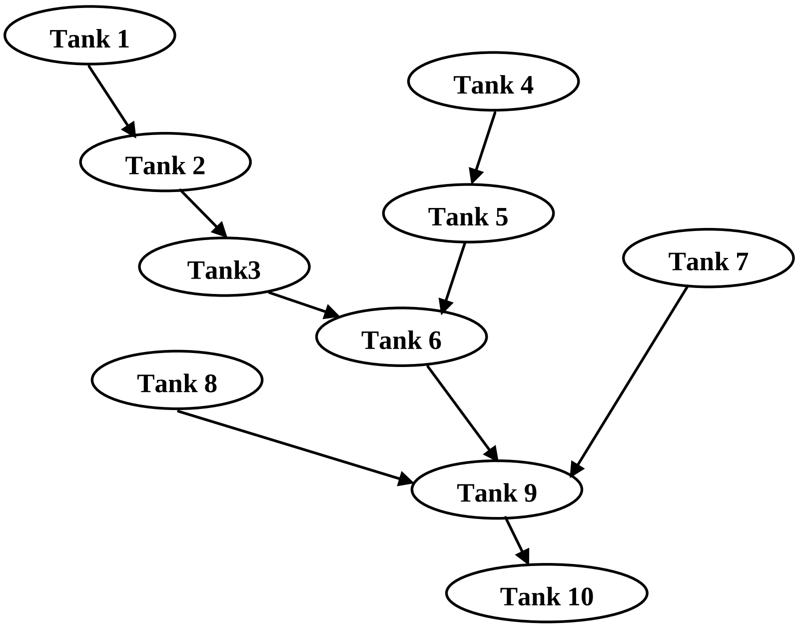

Figure 1.1 Schematic Representation of Tank Cluster system

1.3 HYDROLOGIC MODELLING

A model is a mimic of a physical system which replicates natural complex hydrologic systems and rather it is a management tool where predictions through simulations are being done. The transformation of precipitation over a basin into stream flow is the result of many interacting processes which manifest themselves at various scales of time and space. This is due to the variety and the heterogeneity of media in which water travels.

The highly dynamic, nonlinear nature of most catchment systems is a reflection of the complex interaction between the various processes at different scales. In order to do this, various types of hydrological models are used to estimate water availability in different zones which allows decision makers to take the most effective decision for planning and operation by considering the interactions of physical, ecological, economic, and social aspects of a real world system.

1.3.1 Physically Based Models

Hydrological models can also be classified into conceptual models and physically based models. Earlier lumped-conceptual rainfall runoff models were used to assimilate the runoff in which the hydrological cycle was conceptualized into storage units were the whole catchment characteristics were lumped into single computational node with simplified mathematical descriptions i.e. the entire basin is assumed to have homogeneous hydrological response such as same slope, single infiltration rate for the entire basin which will be easy to compute and works out for small areas in regional scale, whereas in case of heterogeneity, complex catchment characteristics occur, where lumped modelling is unsuitable, which ultimately requires physics based, distributed, deterministic type model.

In the physically based model, the movement of water is modeled either by Partial Difference Equations of mass, momentum and energy conservation discretized in time and space or by empirical equations derived from independent experimental research. The whole catchment process is distributed throughout the basin in case of complex, heterogeneous area which requires either HRU or grids for computation. Accuracy will be relatively more in distributed model and it requires extensive data which is expensive. Compared to other models, physically-based models do not require long hydro-meteorological records for their calibration since their input parameters are directly related to the watershed's physical characteristics (i.e., topography, soil types, vegetation and geology).

1.4 INTEGRATED HYDROLOGIC MODELLING

The integrated modelling approach considers both surface water and groundwater and enhances the reliability of the model results compared to individual surface and groundwater modelling approaches. Integrated surface and groundwater modelling have become an essential tool in watershed management, with two fundamental roles. The first is to improve the understanding the watershed and the way they interact. The second, more practical role is to use this understanding to manage and protect water resources. Advantages of the integrated model approach are that it does derive recharge based on a detailed quantitative procedure and results from the integrated modelling effort appear more accurate and reasonable than results obtained by simpler models. The integrated model simulates the entire natural hydrologic cycle.

1.4.1 Surface Water - Flow Routing through Tank Cascades

Hydrology of a tank cascaded basin in the semi-arid region is different from a plain terrain hydrology. Tanks and depressions arrest the rain water during the monsoon period which increases the detention time and delays the attenuation of the peak. The basin characteristics such as size of basin, water spread area, volume of basin, geological formations i.e. type of soil in underlying layers, water holding capacity, hydraulic conductivity of soil and climatic parameters such as temperature, humidity fixes the detention time of the storage systems and more the detention time, more the susceptibility of recharge, groundwater replenishment and usage. Tanks play a major role in the context of sustainability & water balance accounting. Routing of water through the system tanks encompasses the determination of hydrographs at tank outlets so that the water availability at a specified time is simulated.

1.4.2 Groundwater Dynamics

Groundwater dynamics differs from the surface processes in both time and space. Its movement could not be seen and makes use of larger time steps when compared to surface processes and occurrence is spatially heterogeneous and subjected to fluctuations. Underground dykes or impermeable strata break its homogeneity. Most ground-water models employed today are distributed and physically based. Ground water models have been applied for ground water simulation without considering surface water in any detail in most cases.

1.4.3 Surface and Groundwater Interactions

Integrated surface-groundwater modelling tools have evolved rapidly in recent years, and are now being applied to the analysis of catchment functioning in real-world settings. The complexity of the hydrological processes seen in semi-arid regions makes it difficult to predict the spatial and temporal variation of the processes that occur within these regions. To simulate both spatial and temporal characteristics of the catchment and for considering all the hydrological components integrated models are needed. The integrated modelling approach that considers both surface water and groundwater enhances the reliability of the model results compared to individual surface and groundwater modelling approaches. Advantages of the integrated model approach are that it does derive recharge based on a detailed quantitative procedure and results from the integrated modelling effort appear to be more accurate and reasonable than results obtained by simpler models. The integrated model simulates the entire natural hydrologic cycle. Problems like wetland protection and floodplain area protection, conjunctive use of surface water and ground water, water quality impact of surface water on groundwater, impacts of land use, urbanization, and climate change on water resources require fully integrated hydrologic model.

1.5 NEED FOR THE STUDY

In a semiarid region like Tamil Nadu, water scarcity is more pronounced due to limited water resources and urbanization. Hydrological extremes are more common in the semiarid regions due to reduction in number of rainy days, variations in the intensity and duration of rainfall i.e. rainfall with high intensity and shorter duration accounts for high peak (flash floods) whereas less intense longer duration precipitation results in rainfall lesser than the evapotranspiration rates which results in drought.

Modelling semiarid area hydrology is complex than humid areas and water the base of hydrologic cycle interacts with several components on earth such as vegetation, land surface, underground aquifers and atmosphere should be managed in an integrated manner so that the increasing demand for water could be met out. In general, change in quantity of surface water and evapotranspiration decides the amount of water to be infiltrated through the vadose zone to reach the underlying aquifers and hence all the activities are interconnected in such a way that the effect on one component will have a serious impact on other which absolutely requires integrated surface and groundwater modelling. Integrated surface-ground water modelling technique has evolved rapidly in recent years and now being applied on a watershed basis to analyze catchment behavior.

Estimating the runoff at the catchment outlet has long been recognized by hydrologists as a challenging task. The hydrological behavior of tank clustered catchments is totally different from that of a catchment without any intervening storage structures. The presence of tanks in the watershed will results in modified rate of flow, time of travel and reduced peak flow. Further, the tank storage has the outlet components such as seepage, high amount of evaporation and irrigation releases.

Incorporating the hydrological effects of tanks in rainfall-runoff modelling will make it into a more complex one. And in the past, water bodies on the land surface such as lakes/tanks which are the major sources of irrigation and also act as detention and retention storage units were given less importance and their effect being lumped while modelling as it requires more concentration on small scale level which is more complex. Hence this study aims at potential assessment of water resource both its spatial and temporal variations in an irrigation tank cascaded catchment with the application of physically based hydrological modelling.

1.6 OBJECTIVES OF THE STUDY (AS IN SANCTIONED PROPOSAL)

The objective of the study is to estimate the surface water and ground water potential using empirical methods at the basin scale. And to simulate the surface and groundwater dynamic through physically based integrated modelling approach incorporating tank cascaded catchment at sub-basin level.

BASIN LEVEL STUDY:

1. To analyze the spatial and seasonal pattern of rainfall and groundwater level over the Vaippar basin;

2. To carry out the integrated water assessment for the study basin using empirical models in order to

   (i) Assess the spatial and temporal distribution of surface water;

   (ii) Assess the spatial and dynamic variation of groundwater.

SUB-BASIN LEVEL STUDY

3. To develop Object-Oriented GIS framework for the selected tank clustered catchment; and

4. To simulate the rainfall – runoff process and the groundwater dynamics through physically based integrated modelling approach for the tank clustered catchment.

The MIKE SHE an integrated, physically based distributed model, is chosen for the present study to simulate the hydrologic behavior of the irrigation tank clustered semi-arid region. The **specific objectives** are:

4 (i) To characterize the study area to replicate the physical conditions of drainage with tank cascaded network, unsaturated and saturated zones in the integrated model;

4 (ii) To carry out overland flow routing through tank cascade using physically based modular approach;

4 (iii) To simulate the groundwater flow in the unconfined aquifer in transient condition; and

4 (iv) To study the surface water and groundwater dynamics on the incorporation of tank cascades in the integrated model.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Prior to the start of any project analysis, prerequisite knowledge in the field of concern is of due importance. The review of literature enlightens the knowledge and enhances the analyzing capability and versatility of the author. Literature has been collected in International (or) National perspective and reviewed. In this present study, literature related to surface and groundwater assessment and modelling approaches for surface and ground water studies were reviewed. The reviews of various literature propelled the methodology formulation for the flow routing through tank cascades/clusters in a semi-arid basin using a physically based modular approach.

2.2 HYDROLOGIC MODELLING

As stated by Dingman (2002), a model is a representation of a portion of the natural or human-constructed world which can initially be classified as physical, analog, or mathematical. A physical model is a scaled-down version of a real system (Brooks *et al.*, 1991). In an analog model, the observations of one process are used to simulate another physically analogous natural process. The mathematical model consists of explicit sequential set of equations, numerical and logical steps, which converts numerical inputs into numerical outputs (Dingman, 2002). Mathematical models are further subdivided into several classes. Empirical models derived from experiments or observed input-output relationships, and theoretical (physically-based) models based on physical laws and theoretical principles (Brooks *et al*., 1991). In a deterministic model, every parameter is fully determined by governing equations, whereas in a stochastic (probabilistic) model, the model parameters or input variables are totally or partially described by probability equations.

Warren and Gary (2003) mentioned that a distributed model considers the spatial variability of input parameters in contrast to a lumped model. Deterministic hydrologic models can be subdivided into single-event models and continuous simulation models. Single event models simulate a particular event or process for a short time period, whereas a continuous model can simulate the phenomenon for several years. In an analytical model, the governing equations are solved by mathematical analysis, whereas in the numerical model, the governing equations are solved approximately using arithmetic operations.

2.3 SURFACE WATER ASSESSMENT

Ashish Pandey et al (1993) had estimated the runoff for the Karso agricultural watershed a part of the Damodar barakar catchment. This method involves various types of information related to Hydrologic soil Group, vegetation and antecedent moisture condition of the watershed. The land use and the soil map of the watershed had been digitized using ArcInfo. The land use and soil map had been overlaid to get the different land-soil polygon map. Each polygon has a particular CN. The average weighted CN for the entire watershed had been found out by Soil Conservation Service (SCS) model has been applied in the study for the estimation of runoff from an agricultural watershed. The Karso watershed is about 2793 ha, is a part of Damodar

Barakar catchment, which is situated in Hazaribagh district of Jharkhand State. This method involves various types of information related to Hydrologic soil Group, vegetation and antecedent moisture condition of the watershed. The soil map and land use map have been prepared by the information available at Soil Conservation Department, Damodar Valley Corporation, Hazaribagh and topographical maps were collected from Survey of India, Calcutta. ERDAS IMAGINE-8.4 software was used for the rectification of reference map, soil map and land use map of the watershed. The vector layers were generated in ArcInfo and used as input to derive modified Soil Conservation Service (SCS) Curve Number for the study area. The SCS model was then applied to estimate the runoff for the daily storm and was validated comparing it with the measured runoff of few selected events of monsoon period for the year 1993.

Warwick and Haness (1994) used ArcInfo to determine hydrologic parameters directly for the HEC-1 hydrologic model while separate line coverage defining the runoff routing are created manually. Suwanwelarkamtorm (1994) derived semi-distributed hydrologic modelling using GIS for the management of watersheds and assessed the effect of land-use change using an integrated approach with HEC-1 and ILWIS. The ability of the model to simulate future and past flood hydrographs based on hypothetical future and past land-use conditions were demonstrated. The results of the simulation runs show that when the forest area is reduced, more runoff will occur in every sub-catchment and also at the outlet.

A procedure for zoning of water resources potential was presented by Krishnaveni M. & Kaarmegam M (1995), for the Vaippar basin. The hydrologic response units were categorized as high to low yielding areas. Overlaying the soil and land use maps delineated the hydrological response units. The runoff was estimated using Soil Conservation Service (SCS) methods for the 75% dependable rainfall for the monthly rainfall data for a period of 56 years. The soil cover complex map, which was the logical combination of soil and land use maps, used to delineate the hydrologic response units. Each hydrological response units were assigned a curve number, which is the index to quantify the soil and land use type. The classifications of zones based on curve number and on the seasonal runoff were same for the areas having moderate rainfall. From the runoff potential map, the spatial distribution of runoff within the basin was easily identified and which was used for the water resources management.

Muzik (1996) applied the SDUH concept on a mostly forested, 229 km^2 watershed located on the eastern slopes of the Rocky Mountains in Alberta, Canada. The watershed was divided into 1 km^2 grid cells. The SCS CN method was used to estimate excess rainfall with a uniform rainfall intensity of equal one-hour intervals. Each cell was assigned a CN value and hence the excess rainfall generated was spatially distributed. The incremental one-hour spatially distributed excess rainfalls were then spatially averaged to obtain a representative uniform excess hyetograph for the watershed. Muzik's results were very good considering that no parameter optimization was used.

Johnson et al. (1997) developed a distributed hydrologic model, known as the Terrestrial Hydrologic Model (THM) to utilize rasterized databases to simulate the runoff. In this model, three options were available for estimating the hydrologic abstractions: a constant infiltration rate (F-index), the SCS CN method, and the Green-Ampt equation. The kinematic wave routing technique (Woolhiser and Liggett, 1967; Morries and Woolhiser, 1980) was used for modelling overland flow in each cell. A modified Muskingum-Cunge (Cunge, 1969) channel routing technique was used to simulate channel flow in each channel cell. Rainfall data could be entered as a uniform value for the whole study area or by supplying a gridded rainfall coverage which changes for each cell over time.

2.4 GROUNDWATER ASSESSMENT USING GEC NORMS

The assessment of water resources of the Indian country dates back to 1901 when First Irrigation Commission assessed the Surface Water Resources as 144 million hectare meters (M.ham) (NABARD, 2006). In 1949 Dr. A. N. Khosla based on empirical formula estimated the total average annual runoff of all the river systems of India including both surface and ground water resources as 167 M.ham (Central Ground Water Board, 1995). The first systematic methodology to estimate the groundwater resources of the country was evolved by Groundwater over Exploitation Committee in 1979. In 1982, Government of India constituted 'Groundwater Estimation Committee' (GEC) drawing Members from various States and Central organizations engaged in hydrogeological studies and ground water development. The Committee submitted its recommendations in the year 1984 and suggested a methodology (GEC-1984) for estimation of dynamic ground water resources.

Increasing thrust on ground water and changed scenario of data acquisition led the Government of India to form another Committee in 1995 to review the existing methodology for groundwater resource estimation and to suggest revisions if necessary. The committee submitted its report in 1997 wherein a revised and elaborate methodology for resource estimation has been suggested, more commonly called as GEC-1997. While estimating the groundwater resources in the hard rock terrains some limitations have been observed. To address these limitations another Committee on Groundwater Estimation Methodology in hard rock terrain was formed in 2001 to review the existing methodology for resource estimation in hard rock terrains. The Committee made certain suggestions on the criteria for categorization of blocks to be adopted for the entire country irrespective of the terrain conditions. Based on GEC-1997, the dynamic ground water resources of India were estimated for the entire country with 2004 as the base year. The groundwater potential zone will be on the basis of the local hydrogeological condition.

Devi (2003), made Ground water assessment quantitatively by water budget method in the confluence of Pennar and Papaghni rivers at Putlampalli village near Kamalapuram in Cuddapah district, Andhra Pradesh, India. A quantitative measure of the balance between the total water gains and losses of the basin for. a particular period of time was done in this study. The hydrograph analysis clearly reveals the fluctuations in the water levels have a direct relationship with the intensity and amount of rainfall in the catchment area. Groundwater balance studies are carried out by taking into consideration aspects such as rainfall, runoff, percolation, evapotranspiration, groundwater recharge, discharge, change in soil moisture, and changes in groundwater storage and by following the norms recommended by the Groundwater Estimation Committee (GEC 1997).

Saeed *et al*., (2007) studied the Water balance in the irrigated areas for managing the irrigation and drainage system. Mona Drainage Basin of Chaj Doab located on the right bank of Lower Jhelum Canal and the left bank of River Jhelum was taken for the study. This area has a pivotal role in the agricultural economy of the Pakistan because of its strong infrastructure for irrigated agriculture. The main objective of this study was to determine the water balance in the selected area and suggest measures for the sustainability of irrigated agriculture. Average annual water balance has been calculated for the study area. Recharge and discharge components have been quantified.

Recharge components include rainfall, seepage from irrigation canals and watercourses, deep percolation from fields and seepage and deep percolation from tubewell supplies. Discharge components include tubewell pumping and evaporation from waterlogged areas. It has been observed that recharge to groundwater is less as compared to discharge in the area. Due to the increased demand for irrigation and domestic water, the use of groundwater has been increased. To meet the increased irrigation requirements, farmers have installed private tube wells in the area. For the sustainability of irrigated agriculture canal supplies are to be increased. This will also help reduce demand for groundwater use. A groundwater regulatory framework needs to be developed for its sustainable use was the recommendation in this study.

Kumar *et al*., (2009) carried out a study to select the best method to estimate groundwater recharge in a hard rock terrain. Various standard empirical methods, like soil-moisture balance method, water table fluctuation (WTF) method and commonly adopted norms set by Groundwater Estimation Committee (GEC), Government of India was used to estimate recharge for the Munijhara watershed in the Nayagarh block of Orissa (India). The empirical formulae gave recharge rates ranging from 13 cm to 32 cm/year with an average of 22.4 cm and standard deviation of 5.34, independent of other influencing factors like soil, topography and geology. The soil-moisture balance study indicated that recharge is more dependent on the continuous heavy rainfall total annual volume of rainfall. Annual groundwater recharge based on the WTF approach varied from 10.3 to 16.85 cm with a mean of 13.5 cm, standard deviation of 1.57 cm and coefficient of variation 11.57%. This recharge accounted for 8 to 14% of rainfall received. With a water budget approach based on GEC norms, recharge was calculated as 17 cm per year. The study showed that the magnitudes of annual groundwater recharge as estimated by the WST method and GEC norms are in conformity with other recent findings in India under the same climate conditions.

2.4.1 Groundwater Assessment using Remote Ssensing and GIS

Amaresh Kumar Singh (1999) has done a study on groundwater potential modelling on Chandraprabha sub-watershed, Uttar Pradesh using remote sensing, geoelectrical and GIS. Here the groundwater potentiality of the area has been assessed through the integration of the relevant layers, which include hydrogeomorphology, slope aquifer, thickness and clay thickness in Arc/Info grid environment. Criteria for GIS analysis have been defined on the basis of groundwater conditions and appropriate weightage has been assigned to each information layer according to relative contribution towards the desired output. The groundwater potential zones map generated through this model was verified with the yield data to ascertain the validating of the model developed. The verification showed that the groundwater potential zones demarcated through the model are in agreement with the bore well yield data. Thus the study has clearly demonstrated the capabilities of Remote Sensing and GIS techniques in the demarcation of the different groundwater potential zones.

Manoj (2002) had done ground water assessment model using GIS. Thematic maps such as geology map, geomorphology map, soil map, land use map, slope map showing the spatial distribution of rainfall were prepared by digitizing in map info, which is one of the GIS software. After consulting with experts in the concerned fields a pair-wise comparison matrix was prepared for the themes. Solving the matrix for Eigenvector weightage of each theme was got. After assigning respective weights and ranks all these maps were overlaid using ArcView software and groundwater potential zones were delineated

Sandwidi. J.P et al (2005) had assessed the groundwater recharge in the Kompienga dam basin using water table fluctuation method. The results had shown that the 3 to 4 % of the annual basin rainfall had occurred as recharge. This recharge in the range of previous studies within similar research zone of crystalline basement rocks consisted of fractured porosity has been revealed to be occurring through preferential and diffuse flow. These two parameters of the recharge rate and flow mechanisms are key parameters to the Kompienga groundwater resource management profitably to the living population.

Megan French. N et al (2007) had done the groundwater assessment for the Western Albemarle County. Groundwater assessment was done using samples from private wells tested with a kit developed by a previous Capstone project. The results were consolidated with data on well construction, flow rate, and water quality, maintained by the Virginia Department of Health, the Department of Mines, Minerals and Energy; and the County Office of Groundwater Resources. The well water assessment results were mapped in ArcGIS and presented to members of a project advisory board for user testing in decision-making about regional development based on groundwater capacity information. Detailed user testing is planned for members of the County Board of Supervisors, and other representatives of stakeholder groups with an interest in land use in Albemarle County and surrounding areas. The results of this work are expected to serve as a model for natural resource assessment and use in development planning for other communities nationwide confronting the issue of urban sprawl and its impact on rural areas.

2.5 TANK CASCADE WATER BALANCE MODELLING

Krishnaveni.M (1998) carried out water balance analysis of tank cascade system. Kullursandai, a tank cascaded sub-catchment, in Vaippar basin was the study basin for her research study. GIS-based Watershed

Information System (WIS) was developed in this study and applied for the study catchment. In this study, SCS method was applied to estimate the direct runoff and various components of inflows and outflows of the tanks are estimated involving the storage of the tanks by mass balance analysis. Water balance analysis was carried out to find out the surpluses from the cluster of tanks and the yield at the reservoir was arrived at on a daily basis. In this study the GIS-based WIS is found to be potentially useful for the estimation of yield from a tank clustered catchment and the modified SCS model is found reliable in estimating the direct runoff on a daily basis. It was found that 50% of the runoff water is intercepted by tanks.

Jayatilaka *et al* (2003) developed a water balance model Cascade, formulated to account for the dynamic hydrologic components of irrigation tank cascade system in Anuradhapura, Sri Lanka. The model is designed to estimate tank water availability on a daily basis, for the purpose of improving productive use of water resources in the tank cascade system. It represents the physical system using a node–link system configuration, and incorporates water balance components of different types of irrigation tanks including rainfall runoff, rainfall on the tank, evaporation of tank water, tank seepage and percolation, irrigation water release, spillway discharge and return flow from upstream tanks. An important feature of Cascade is that it employs a modified runoff coefficient method for estimating runoff from rainfall, which incorporates a modified Antecedent Precipitation Index as an indicator of catchment wetness. This provided a simplified method for representing the non-linear runoff generation process. The model calculates tank seepage and percolation-based on functions derived from an analysis of the observed tank water reduction during time periods without rainfall. The model was calibrated using field data collected at four tanks over a period of 21 months, which represented different agrometeorological conditions encountered under both Maha and Yala growing seasons at the Thirappane tank cascade system in Anuradhapura, Sri Lanka. The model results agreed well with the measured data particularly in the two tail end tanks of the cascade.

Vidyavathi (2007) analyzed the integrated approach for accessing the water availability in various tanks of the watershed. Routing is done through sub-watershed or tank watershed and channels and hydrographs are generated at downstream of the flow network. Channel routing corresponds to one-dimensional unsteady Kinematic FENM. Reservoir routing is adopted in the case of tank routing. A program in FORTRAN which involves the procedure of routing along the entire flow network is developed which facilitates the conversion of routed hydrographs for tanks in terms of depth unit or volumetric units (ham). The program developed is run to assess the water availability in various tanks.

2.6 WATERSHED MODELS

Vijay Singh (2006) discussed the watershed models. A watershed model simulates hydrological processes in a watershed-scale compared to many other models which simulate mostly at the relatively small, field-scale. The first watershed model was the Stanford Watershed Model, developed in 1966 by Crawford and Linsley. Since then, numerous watershed models have been developed. Currently, the better-known watershed models include ADAPT, ANN AGNPS, ANSWERS-2000, APEX, BASINS, CANWET, CASC2D, CREAMS, DWSM, EPIC, HBV, HEC-1, HSPF, the Institute of Hydrology Distributed model, KINEROS, MIKE 11, MIKE SHE, NTRM, NWSRFS, PRMS, RORB, SIMPLE, SLURP, SPUR-91, SRM, SSARR, SWAT, SWMM, SWRRB, the Tank model, THALES, TOPMODEL, the UBC Watershed model, and the Xinanjiang model. Compared to other watershed models, the MIKE SHE model supports a fully dynamic exchange of water between all the major hydrologic components including surface water, soil water and groundwater.

2.7 INTEGRATED SURFACE AND GROUNDWATER MODELS

Hemker and Smits (2004) developed integrated surface and groundwater models by Duflow and MicroFem. Duflow is a computer program for one-dimensional hydraulic modelling of surface water. MicroFem is a finite-element model that simulates saturated groundwater flow in multiple aquifer systems. Both model codes simulate steady-state as well as transient flow. A method is presented to couple the flow systems in Duflow and MicroFem. The results of both models are exchanged to bring the flow systems in equilibrium with each other in an iterative way. To demonstrate its use a regional coupled model is build of a water-supply well field with induced surface-water infiltration. Compared to individual surface-water and groundwater flow models, coupled models have a surplus value in all situations where the flow systems have a significant mutual interaction.

Melinda Wolfert *et al* (2005) used SWIFT2D surface-water flow and transport code, which solves the Saint Venant’s equations in two dimensions, coupled with the SEAWAT variable-density groundwater code to represent hydrologic processes in coastal wetlands and adjacent estuaries. A sequentially coupled time-lagged approach was implemented, based on a variable-density form of Darcy's Law, to couple the surface and subsurface systems. The integrated code also represents the advective transport of salt mass between the surface and subsurface. The integrated code was applied to the southern Everglades of Florida to quantify flow and salinity patterns and to evaluate effects of hydrologic processes. Model results confirm several important observations about the coastal wetland: (1) the coastal embankment separating the wetland from the estuary is overtopped only during tropical storms, (2) leakage between the surface and subsurface is locally important in the wetland, but submarine ground-water discharge does not contribute large quantities of freshwater to the estuary, and (3) coastal wetland salinities increase to near seawater values during the dry season, and the wetland flushes each year with the onset of the wet season.

Stamou *et al* (2005) developed Integrated Surface water - Groundwater Flow models at the National Technical University of Athens, Greece and Cardiff University, UK to investigate surface water-groundwater interactions. The models are based on physical processes and are capable of describing more accurately the recharge and discharge flow paths between surface and ground waters. It consists of a 3-D surface water flow sub-model (FLOW-3DL) and a 3-D saturated groundwater flow sub-model. 2-D surface water model DIVAST, which has been extended to include 2-D saturated groundwater flow. Both models use the finite difference method and orthogonal grids. The momentum and mass conservation equations are the governing equations for both surface and groundwater flows. They have been applied to two simple cases and their results have been compared to computations using only surface water models (FLOW-3DL and DIVAST) to demonstrate the need to use for accurate and satisfactory calculations. Furthermore, the results of the two are compared for a channel, which fully penetrates an aquifer. It shows a similar behavior; the 2-D model exhibits a slightly slower response of the aquifer water levels to the water level changes in the channel than the 3-D model.

David Goodrich *et al* (2008) applied a methodology designed to improve the representation of water surface profiles along open drain channels within the framework of regional groundwater modelling. The proposed methodology employs an iterative procedure that combines two public domain computational codes, MODFLOW and HEC-RAS. In spite of its known versatility, MODFLOW contains several limitations to reproduce elevation profiles of the free surface along open drain channels. The Drain Module available within MODFLOW simulates groundwater flow to open drain channels as a linear function of the difference between the hydraulic head in the aquifer and the hydraulic head in the drain, where it considers a static representation of water surface profiles along drains. The proposed methodology developed herein uses HEC-RAS, a one-dimensional computer code for open surface water calculations, to iteratively estimate hydraulic profiles along drain channels in order to improve the aquifer/drain interaction process. The approach is first validated with a simple closed analytical solution where it is shown that Piccard iteration is enough to produce a numerically convergent and mass preserving solution. The methodology is then applied to the groundwater/surface water system of the Choele Choel Island, in the Patagonian region of Argentina. Smooth and realistic hydraulic profiles along drains are obtained while backwater effects are clearly represented.

Kang *et al* (2009) investigated the interaction of surface water and groundwater in order to determine the effects of best management practices on the entire system of water resources. A linked modelling approach was selected to consider SW–GW interaction. A distributed and physically based DANSAT predicts the movement of water and pesticides in runoff and in leachate at a watershed scale. The same spatial scale was used for both surface and groundwater models while different time scales were used because surface runoff occurs more quickly than groundwater flow. DANSAT and MODFLOW were separately calibrated using the integrated approach which uses own lumped base flow components in DANSAT, and using the steady-state mode in MODFLOW, respectively. They found integrated approach as a better one for predicting the temporal trends of monthly runoff.

2.8 MIKE SHE MODELLING

The MIKE SHE model is a fully integrated watershed model that simulates all the major processes occurring in the land phase of the hydrologic cycle. Developed by three European organizations (Danish Hydraulic Institute, British Institute of Hydrology and the French consulting company SOGREAH) and sponsored by the Commission of the European Communities, it was originally named SHE (Système Hydrologique Européen) model. This deterministic, fully distributed, and physically-based model is used mostly at the watershed scale and from a single soil profile to several sub-watersheds with different soil types. The model's distributed nature allows a spatial distribution of watershed parameters, climate variables, and hydrological response through an orthogonal grid network and column of horizontal layers at each grid square in the horizontal and vertical, respectively. Being physically-based, the topography along with watershed characteristics (vegetation and soil properties) is included into the model. The MIKE SHE model has a modular structure, enabling data exchange between components as well as the addition of new components. The flexible operating structure of MIKE SHE allows the use of as many or as few components of the model, based on the availability of data (Abbott *et al*., 1986a).

Kumar (1995) applied Systeme Hydrologique Europene (SHE), a physically based, distributed catchment model for Narmada (up to Manot) basin in Madhya Pradesh. The Calibration and Validation of the model were achieved on the basis of physical reasoning and through the consideration of the variation of runoff response from the basin. The calibration was carried out for the period 1982 to 1984 by varying only a few of the parameters and was then validated against 1985 and 1897 hydrographs on the basis of changes in the initial level of the phreatic surface. Some deficiencies in the simulations were noted but, in general, there was good agreement between observed and simulated responses.

Jens Christian Refsgaard (1995) described the recent developments of the Système Hydrologique Européen (SHE) towards the MIKE SHE. The development of the Système Hydrologique Européen (SHE) started in 1977 as a joint effort by three European organizations: Institute of Hydrology (UK), the French consulting firm SOGREAH and the Danish Hydraulic Institute. The SHE is often quoted in the literature a prototype of the distributed, physically based group of models. In this paper, the comprehensive results of further developments of the MIKE SHE version, which have taken place during the last five years, are summarized. MIKE SHE simulates water flow, water quality and soil erosion processes for the entire land phase of the hydrological cycle. It is intended for scientific and engineering hydrology. MIKE SHE is a fourth generation, user-friendly modelling package comprising a number of comprehensive pre- and post-processors including digitizing, graphical editing, contouring, grid-averaging and graphical presentation with options for display of animations.

Demetriou and Punthakey (1999) discussed sustainable groundwater management options using the MIKE SHE integrated hydrogeological modelling package in the Wakool Irrigation District in Australia which was affected by a rising water table due to excess irrigation and poor drainage. Rising groundwater pressures in these deeper aquifers are also contributing to the rising shallow water table. Various scenarios such as the implementation of on-farm recycling ponds in conjunction with laser leveling, deep-rooted perennials, tree planting, installation of deep groundwater pumps and the effect of shallow groundwater pumping, were investigated. The results of these simulations indicate that the best option is the implementation of shallow pumping.

Douglas N. Graham and Michael B (2005) discussed the flexibility in the integrated watershed modelling with MIKE SHE, one of the few commercially available codes that have been widely used for integrated hydrologic modelling. MIKE SHE's process based framework allows each hydrologic process to be represented according to the problem needs at different spatial and temporal scales. This flexibility has allowed MIKE SHE to be applied at spatial scales ranging from single soil profiles to the field scale, and up to the watershed scale. Furthermore, each process can be represented at different levels of complexity. MIKE SHE has advanced tools for water quality, parameter estimation and water budget analysis, solute transport, particle tracking, geochemical reactions, and advection-dispersion

Shalini Oogathoo (2006) discussed the changes in watershed hydrology due to the increased anthropogenic activities, producing frequent floods and droughts as well as water quality problems. MIKE SHE, a watershed-scale model, was used to simulate surface runoff from the Canagagigue Creek watershed is one of the fastest developing areas in Ontario. Various management scenarios affecting the surface hydrology were also evaluated. The model was calibrated for four years (1994-95 to 1997-98) and validated for another four years (1990-91 to 1993-94). The model was able to simulate surface runoff reasonably well on annual, seasonal, monthly, and daily intervals, representing all the hydrological components adequately.

Andersen *et al* (2008) applied the fully-distributed hydrological model, MIKE SHE to the semi-arid Andarax River Basin, SE Spain, to examine the hydrological behavior and to assess the water resources. The

Andarax River basin is characterized by a large spatial variability of geological and hydrological characteristics. The model was calibrated and validated against observed discharge from one station and piezometric heads from six selected boreholes located along the Andarax River for the period August 1, 2000 to July 31, 2006. Overall the hydrological behavior is characterized by the little difference between precipitation and evapotranspiration and thus little excess precipitation for generation of runoff and infiltration.

Li *et al* (2008) evaluated the ability of MIKE SHE to simulate basin runoff. Stream flow data measured from an overland flow dominant watershed (12 km2) in north-western China were used for model evaluation. Model calibration and validation suggested that the model could capture the dominant runoff process of the small watershed. They found that the physically based model required calibration at appropriate scales and estimated model parameters were influenced by both temporal and spatial scales of input data. They concluded that the model was useful for understanding the rainfall-runoff mechanisms.

Chulgyum Kim Im *et al* (2008) used the fully distributed, physically-based hydrologic modelling system, MIKE SHE, in the study to investigate the whole-watershed hydrologic response to land use changes within the Gyeongancheon watershed in Korea. The initial model performance was evaluated by comparing observed and simulated streamflow from 1988 to 1991. Results indicated that the calibrated MIKE SHE model was able to predict stream flow well during the calibration and validation periods. Proportional changes in five classes of land use within the watershed were derived from multi-temporal LANDSAT TM imageries taken in 1980, 1990 and 2000. These imageries revealed that the watershed experienced a conversion of approximately 10% non-urban area to the urban area between

1980 and 2000. The analysis was made to quantitatively assess the impact of land use changes on watershed hydrology. There were increases in total runoff and overland flow.

Antony Anbarasu Selvaraj (2009) analyzed the groundwater potential of Nambiyar basin using MIKE SHE model in an integrated model. The 1046km^2 rocky terrain semi-arid basin has 2 reservoirs and 222 irrigation tanks. The author conceptualized only the river in MIKE 11. Irrigation tanks were modeled in MIKE SHE itself. A 30m x 30m resolution ASTER DEM has been used for defining topography and all data pertaining to MIKE SHE and MIKE11 were prepared in ArcGIS. A very low average correlation value of 0.32 was only achieved due to non-availability of field experimental data.

Bahaa-eldin Rahim *et al* (2010) used the fully distributed physically based MIKE SHE modelling system was used to simulate the individual hydrological components of the total water balance for the PIW watershed in the west of Peninsular Malaysia. Results reveal that the overall water balance is predominantly controlled by climate variables. Estimation of total water balance is a substantial issue for watershed modelling in order to simulate the major components of the hydrological cycle to determine the stress of different anthropogenic activities on the available water resources within a catchment. Application of the model to the PIW watershed provides a detailed estimation of the total water balance for a first-order catchment in which actual ET represents approximately 65 and 58%, while OL flow to the PIW lake system represents 12.38 and 12.3% of the total rainfall during the calibration and validation periods, respectively. The difference between the inflow and outflow was taken as storage in depth. Overall, the model gives a reasonable output of total error of less than 1% of the total rainfall, which in turn indicates that the interaction among components is satisfactorily sustained.

Hall *et al* (2011) constructed The Murray regional model, using MIKE SHE, and consisted of unsaturated zone, saturated zone, channel flow and overland flow components. It had a constant grid spacing of 200 m and covered an area of 722 km^2. Calibration was from 1985 – 2000 and validation from 2000 – 2009 using 45 groundwater bores and 7 surface water flow gauges. Land development, drainage and climate scenarios were simulated and their results are discussed in this paper. The process of model conceptualization, construction, calibration and simulation is discussed and provides an appropriate framework for model evaluation and a high level of confidence in modelling results. The Murray MIKE SHE model provided regional groundwater levels, areas of groundwater inundation, estimated drainage volumes from development areas, effects of sea-level rise, and changes in surface water flows for a variety of climate, drainage and development scenarios. The results were used to determine regional-scale hydrological effects resulting from future urban development.

2.9 SUMMARY

Upon reviewing the literature of different technical expertise, SCS curve number method and GEC norms were used in this for assessing the surface and ground water potential at the basin scale. And for the detailed experimental subbasin, it is understood that the MIKE SHE model used the fully-dynamic Saint Venant’s equations to estimate surface runoff. Also, this model simulates all the processes in the hydrologic cycle by fully integrating the surface, subsurface and groundwater flow. The model also includes river flow simulation via the MIKE 11 model. The literature has shown MIKE SHE has been used effectively in several water resources studies, where the conventional rainfall-runoff model or lumped catchment model do not meet the criteria. Overall, the unique feature of MIKE SHE hydrology component is the integration of various hydrological processes in the model, at different time scales. Besides, the model is user-friendly. Moreover, in the context of hydrologic analysis, integrated surface and groundwater modelling taking into account of the tank clustered catchment were not carried out. Hence it is a new attempt in the strategy of representing a complete integrated analysis which involves incorporation of tank clusters in the integrated model MIKE SHE to simulate overland flow through tank cascades and to predict the water availability in underground shallow aquifers which is a complex and challenging task.

CHAPTER 3

BASIN LEVEL STUDY

3.1 STUDY AREA – VAIPPAR BASIN

The Vaippar basin lies between latitudes of 8°57´N and 9°48´N and longitude of 77°16´E and 77°22´E covering a total catchment area of 5423 km^2. The basin is located in the southern part of Tamil Nadu state, which is bounded on the west by the Western Ghats, on the east by the Gulf of Mannar (Bay of Bengal), on the north by Vaigai and Gundar basins on the south by Tamaraparani basin. The study area is covered by the Government of India toposheet Nos. 58G, 58K and 58L on 1:2,50,000 scale. An index map of the basin is presented in Figure.3.1

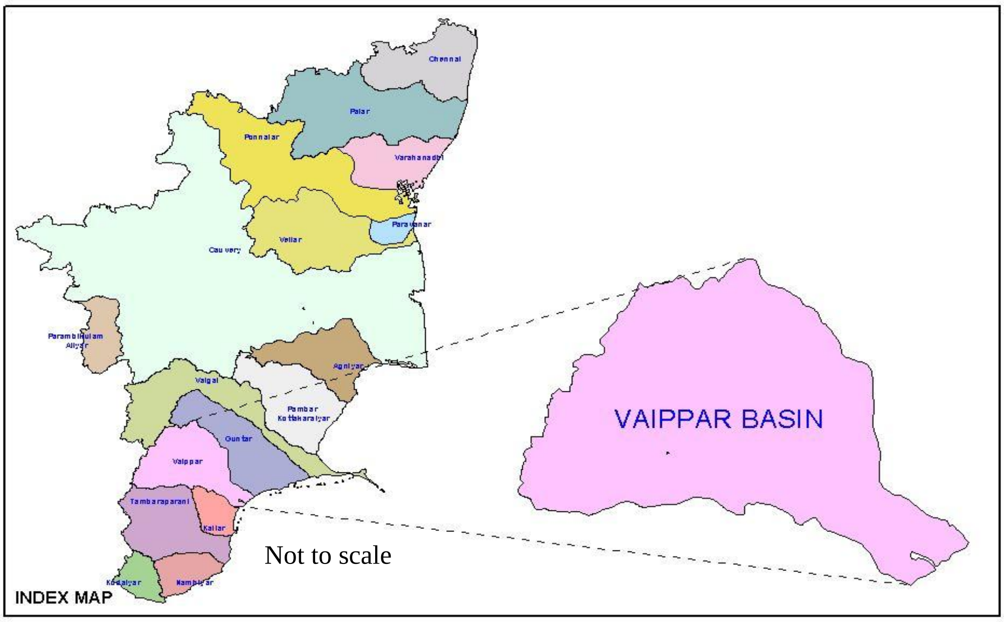

Figure 3.1 Index Map of Vaippar Basin

The basin spreads over parts of the administrative limits of Virudhunagar, Tirunelveli, Madurai, Thoothukudi districts covering the taluks and blocks listed in Table 3.1. The administrative districts of Virudhunagar (68%), Madurai (7%), Tirunelveli (5%) and Thoothukudi (20%) falls under Vaippar basin covering 9 municipalities, 6 town panchayats and 13 rural town panchayats. The administrative revenue boundaries are indicated in Figure.3.2

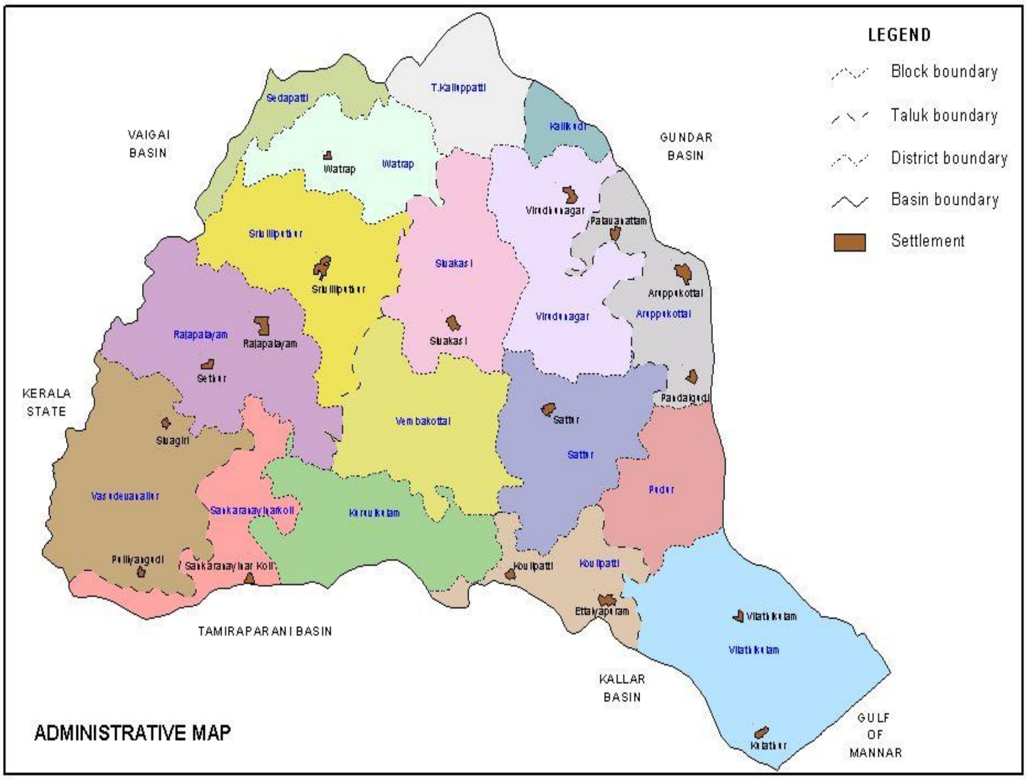

Figure 3.2 Administrative Boundary Map of Vaippar Basin

3.1.1 Physiographic Features

The Vaippar river originates from the Echamalai Mottai, Neduntheri Mottai and Kiladiparai hill ranges of Western Ghats with an elevation of 1651m above M.S.L near Sivagiri in Tirunelveli district and flows generally in the Easterly and Southeasterly direction for a length of 146 km and joins with the Gulf of Mannar. The catchment area consists of hilly regions falling in the Kodaliparai Mottai, Vasudevanallur reserve forest, Periya Sudangi Malai etc. These mountain ranges fall in the rain shadow regions of the Western Ghats and hence receive only a meager rainfall. The catchment area of Vaippar basin lies entirely within the state.

Table 3.1 The administrative details of boundaries under Vaippar basin

S.No	District	Taluk	Block
1	Thirunelveli	Sivagiri	Vasudevanallur
		Sankaran Koil	Sankaran Koil
			Kuruvikulam
2.	Thuthukudi	Kovilpatti	Kovilpatti
		Vilathikullam	Vilathikullam
			Pudur
3.	Virudhunagar	Sathur	Sathur
			Vembakottai(Part)
		Rajapalayam	Rajapalayam
			Srivilliputhur(Part)
		Srivilliputhur	Srivilliputhur(Part)
			Watrap
		Sivakasi	Sivakasi(Part)
			Vembakottai(Part)
		Virudhunagar	Virudhunagar
			Sivakasi(Part)
		Aruppukottai	Aruppukottai
			Kariapattu
			Thiruchulli(Part)
4.	Madurai	Thirumangalam	Kallikudi
		Peraiyur	T.Kallupatti
			Sedapatti

The various river systems of Vaippar basin is presented below. There are twelve major tributaries to Vaippar namely;

1. Nichabanadhi
2. Kalingalar

3. Deviar
4. Nagariyar
5. Sevalperiyar
6. Kayalkudiar
7. Vallampatti Odai / Uppodai
8. Sindapalli Uppodai
9. Arjunanadhi
10. Kousiganadhi
11. Uppathurar
12. Senkottaiyar

3.1.1.1 River Systems

Vaippar is the main river of Vaippar basin which drains the lower half of the basin. The other system consists of Arjunanadhi and Koushikanadhi draining the upper half of the basin. In addition to these, there are three country streams, namely Uppathurar, Perilonpatti Odai and Senkottaiar of minor nature draining the plains and lower reaches of the basin. The Vaippar runs mainly towards East, but after the confluence with the Arjunanadhi runs towards the Southeast. The Koushikanadhi almost runs towards the South.

The general direction of flow in the basin is towards the East in the lower left half of the basin, and towards the Southeast in the upper top half and in the lower reaches of the basin. The system generally drains the Eastern slopes of the Western Ghats. On the way, it picks up the runoff generated from the plains in between Western Ghats, Vaigai and Tamaraparani basins. The drainage pattern of Vaippar Basin is presented in Figure.3.3. Kottaimalaiar, Kalingalar, Rasingear and Deviar all are running towards the East join together to give birth to Niksheba Nadhi. Nagariar draining towards the East and Mudangiar flowing towards the Southeast join together to form the major tributaries to the Sevalperiar which runs in the Southeastern direction. Kayalkudiyar running towards the Southeast joins the Sevalperiar and Niksheba Nadhi almost at Vembakottai where the river is identified as Vaippar.

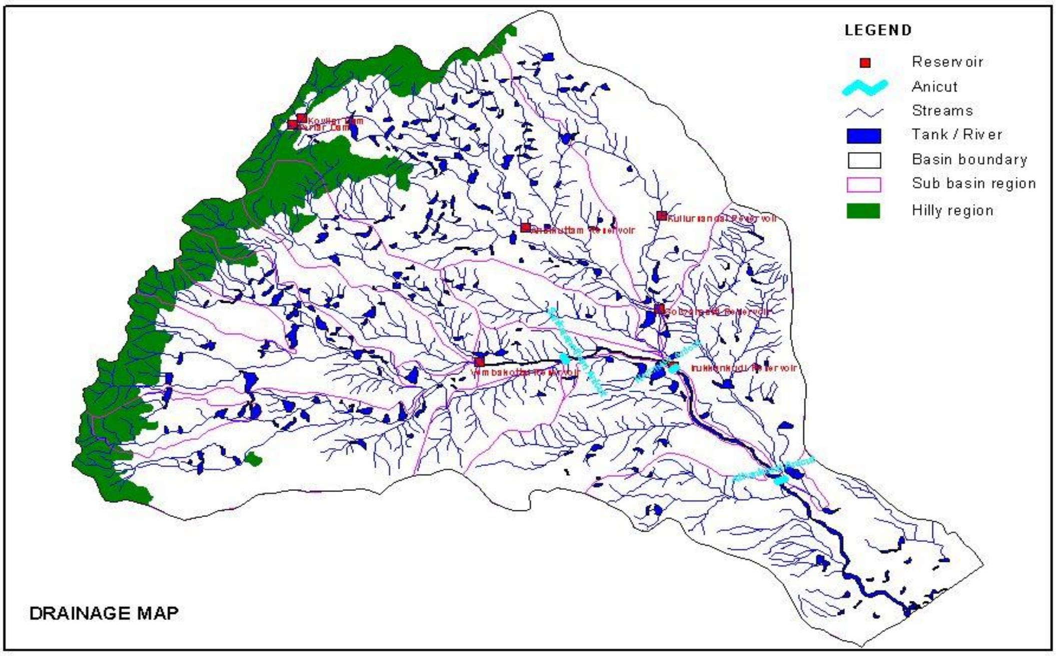

Figure 3.3 Drainage Map of Vaippar Basin

Arjunanadhi is formed due to the confluence of Periyar, Kovilar and Chittar from the Saptur-Vathirayiruppu hills at an elevation of 1644 m M.S.L. After receiving the flows from the Thiruthangal Odai from the Srivilliputhur area, Arjunanadhi runs down to receive the Mathisenai Uppodai and afterward the main Arjunanadhi is formed. Koushikanadhi confluences with the Arjunanadhi at Golwarpatti and down, the system are identified as Arjunanadhi. Vaippar, after receiving the flows from Arjunanadhi and Sindapalli Uppodai at Irukkankudi, runs as the main river towards the Southeast. On the way, Uppathurar, Senkottaiar and Perilonpatti Odai all contribute to flow in Vaippar. At Vilathikulam in Thoothukudi district, the

Vaippar is fully developed to create an impression that is one of the major river systems in the state. A river basin, in general, will have a number of tributaries from the catchment contributing to form the main river, the flows of which will be distributed through a number of distributaries in the plains. On the contrary, Vaippar basin has only tributaries and with the main river formed with it drains into the Gulf of Mannar.

There are eight reservoirs in the basin. They are (i) Periyar across Periyar River; (ii) Kovilar across Kovilar river; (iii) Anaikuttam at the confluence of Arjunanadhi and Thiruthangal Odai; (iv) Kullursandai across Koushikanadhi;(v) Vembakottai at the confluence of Niksheba Nadhi, Sevalaperiar and Kayalkudiyar. A reservoir at Irrukankudi at the confluence point with Arjunanadhi and Vaippar. A new reservoir has been under construction at Sathankoil in the basin. Of these, only at Periyar and Kovilar alone, the sites are suitable for constructions of reservoirs. The rest are all in plains. There are two anicuts in operation across the Vaippar river; Sankarnatham below Vembakottai reservoir and Athankarai just upstream of Vilathikulam. The flows are regularly monitored and measured at these two places. A considerable amount of flow data is available for the Athankarai anicut. Any flow which crosses this anicut is considered to be a waste to the sea since there is a little scope of using on the downstream of Athankarai.

3.1.1.2 Morphometric Analysis

Morphometric analysis is required to understand the basin response in producing the runoff for a given amount of rainfall. It involves basically the evaluation of the basin characteristics. A systematic description of the geometry of a drainage basin requires the measurement of (i) linear aspects of the drainage networks; (ii) areal aspects of the basin; (iii) relief aspects of channel network and contributing ground slopes. Linear aspects include length ratio, bifurcation ratio and lengths of overland flow. Areal aspects include form factor, circulatory ratio, elongation ratio, drainage density and stream frequency. Relief aspect includes the relief ratio. The following are the values:

(i)	Length ratio	…	from 1.24 t0 2.48
(ii)	Bifurcation ratio	…	from 3.40 to 6.12
(iii)	Length of overland flow	…	250m
(iv)	Form factor	…	0.55
(v)	Circularity ratio	. . .	0.48
(vi)	Elongation ratio	. . .	0.84
(viii)	Stream Density	. . .	2.40(Number/ Sq. Km)
(ix)	Relief ratio	. . .	20.17 (m/ km)

The average value of the length ratio is 1.86 and that of the bifurcation ratio is 4.76. These values are reasonable for a drainage basin to have the generated runoff drained from the catchment as easily as possible. However, the length of overland flow is 250 m which may have been quite high for a well-drained basin. This only indicates that the water might stay on the surface of the earth for a long period of time before being drained. Nevertheless, it can be taken as an advantage in the sense that the infiltration and hence the soil moisture may get benefited. Also, the lag time may increase and hence the peak flow might decrease. The values of form factor, circularity ratio and elongation ratio all indicate that the basin is more of fern shape. This means that the concentration time at the outlet of the basin may be high. Consequently, longer duration rainfalls may produce higher peak flows and shorter duration rainfalls may make the flow disturbed over a long period of time.

The drainage density (2.01) and stream density (2.40) is generally low indicating that the drainage network may be inadequate to drain the flows. Perhaps these values may reflect the low amount of rainfall over the basin indicating that the need for the drainage network is minimum. However, the relief ratio (20.17) is quite high indicating that the mean basin slope is very steep. In such cases, one can expect a short duration high peak flows, which is not found in this basin. The reason is that only the upper reaches are steep where flash floods are common and reported, but the middle and lower reaches are more or less moderately sloped or almost flat terrain.

3.1.2 Geology

Geology deals with the different types of rocks. The rock types can be broadly classified into hard rock and sedimentary rocks. The study of geology has become more relevant and important from the groundwater occurrence and development point of view. Each rock type has its own water holding and water transmitting capacity. In hard rock areas, the degree of weathering, thickness of weathered mantle and fissured and joined zones are the controlling factors for the assessment of groundwater resources. A study of the geology of the basin will help to understand the various rock types and soil groups present.

Soil type plays an important role in controlling the infiltration of a place and hence the surface runoff. The places of high infiltration, which are underlain by appreciable thickness of weathered and fissured and joined zones with deeper water levels, will be suitable for the location of percolation ponds and hence for the development of groundwater resources. On the other hand, places of low infiltration will be suitable for the location of tanks and ooranies and hence help the development of surface water potentials. The general geology of Vaippar basin is presented in Figure 3.4

The Vaippar basin areas are underlined by an **Archean group of rocks** of Dharwar age, younger intrusives and **recent to sub-recent alluvial sands**. The Archean group of rocks includes basic metamorphic rocks such as amphibioties, biotite schists, crystalline limestones, quartzites, complex gneisses and charnockites intruded by younger granite, pegmetites and quartz veins. The regional foliation of these rocks varies from NNE-SSW to NNW-ESE and E-W directions with the dip of SE, NE and South direction. The dip of the formation varies between 40° to 70° and sometimes vertical.

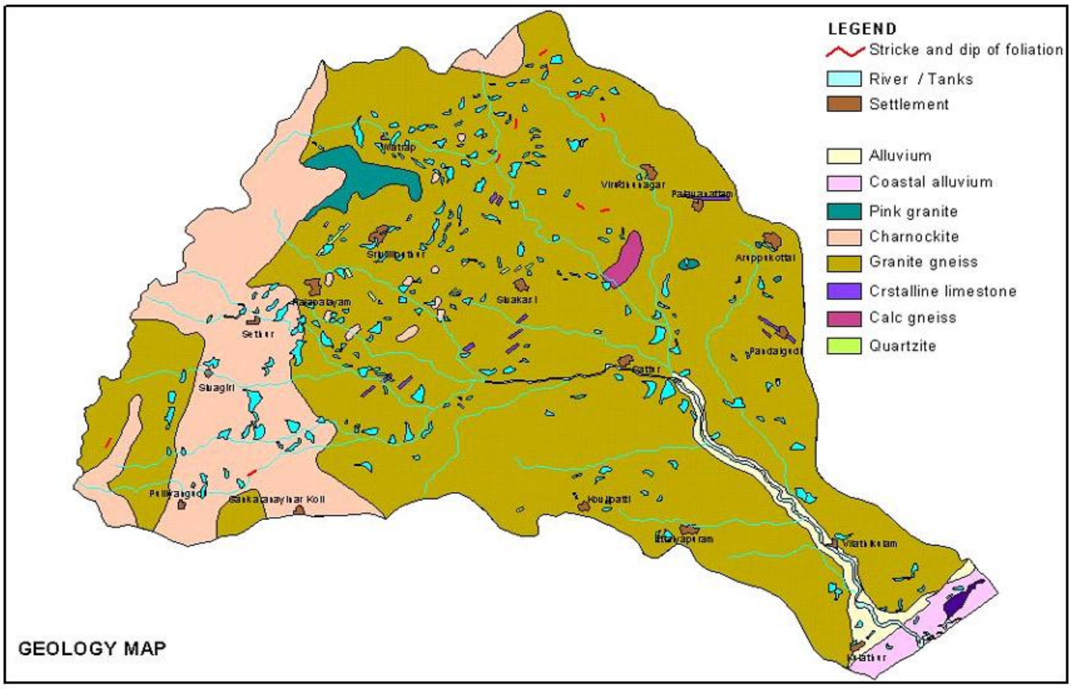

Figure 3.4 Geology Map of Vaippar Basin

3.1.2.1 Archean Group of Rocks

A brief review has been regarding the occurrence of different types of rocks. Basic metamorphic rocks occur as small bands and lenticular inclusion in gneissic rocks. They are dark colored, coarse grained, friable and are easily weathered. These rocks are subjected to weathering and hold an appreciable quantity of water. Quartzites occur as linear and parallel bands along the gneissic rocks and occupy as low hills. These rock types are found near Alagapuri, Vadugapatti, Kadambur, Kovilpatti, and Uthumalai hills. These rocks are reddish white, coarse-grained and show well developed multiple sets of joints. They have impounding characteristics and arrest the groundwater movement. Calc-gneisses, crystalline limestones and calciphyres are associated together with gneisses and occur around Palavanatham, Pandalkudi, Krishnaperi, Kumaralingapuram and along Sankarankovil-Rajapalayam road. Complex gneisses which include garnetiferous variety hornblende gneiss, mica gneiss, pink and gray granitic gneiss and occasional graphitic gneiss are found near Silangadi and West of Sivagiri. Coarse-grained pink and granitic gneisses occur around Arrupukotai, Virudhunagar and Mahalingaswami hills North of Watrap. The granitic rocks are liable to easy weathering but predominant clay content makes the rocks less permeable. Charnockites occur in the western part of the basin in the Western Ghat hills around Puliyangudi, Sankarankovil, Sivagiri and Srivilliputtur areas. These rocks are very tough and resistant to easy weathering.

3.1.2.2 Recent to Sub-Recent Formations

The lateritic capping, thin alluvial formations along Vaippar, different soil types and Kankar formations fall under sedimentary formations. The lateritic cappings are quite prevalent over the weathered Charnockites and gneissic rocks as irregular patches and are seen to occur around Sankarankovil. The thickness may vary from 0.5 m to 1 m along the stream courses. The alluvial formations are found to occur in Vaippar 1km below Sattur and the width of the formation ranges between 200 m and 500 m on either side of the river and gradually extend to 0.5 km to 1.5 km at Vilatikulam. The thickness varies from 6m to 15 m. The alluvium is grey in color with sand and intercalations.

Along Arjunanadhi and its tributaries, thin narrow strips of light colored alluvium are seen to occur in the upper reaches of the basin. Kankar formations are of secondary origin and they are mostly modules and intercalated with alluvial formations and soils. At places, a thin concretionary sheet of Kankar beds is found to occur in the stream and river courses. They occur as detached and scattered patches embedded with rock lumps, pebbles etc. The alluvial formation is confined only to the Vaippar river course. Red sandy loamy soils are found in the Western parts of the basin adjoining the hilly areas. The presence of ferromagnesium minerals in the parent rock has given rise to reddish color to the soil.

3.1.2.3 Structures

Geologic structures are formed due to tectonic activities during different geological periods. The structures play very important roles in the occurrence and distribution of groundwater, especially in hard rock areas. The Vaippar basin has been subjected to metamorphic activities and later cause the extensive intrusive phenomenon. A few lineaments are observed in this area which would have caused by the tectonic effects. The lineaments in NE-SW direction confirm the regional trend.

3.1.3 Geomorphology

Geomorphology deals with different land forms which are related to the occurrence and distribution of groundwater as well as the land use pattern of the basin. Geomorphology of a place also plays an important role in controlling infiltration and hence the surface runoff. The geomorphology of Vaippar basin is presented in Figure 3.5. Geology and geomorphology of a place can be relied upon for selecting a suitable location for water harvesting structure; surface or sub-surface. Three landforms have been delineated in Vaippar basin; namely denudational, fluvial and coastal landforms.

3.1.3.1 Denudational Landform

The denudational landforms include hills, mountains, peaks, ridges, inselbergs and pediments. They occur in the western parts of the basin around Sankarankovil, Sivagiri, Srivilliputtur and Rajapalayam areas. These landforms mainly represent the catchment areas and runoff zones in the basin. Pediments are generally less permeable and form poor potential zones. However, the pediments found in Vaippar basin are permeable in nature and occur throughout the basin perhaps indicating that they may be of recent origin. Shallow pediments occur along Vaippar and its tributaries. It is moderately permeable and forms poor to moderate potential zones.

3.1.3.2 Fluvial Landform

The Vaippar river and its tributaries have developed depositional landforms, such as bazada zones, valley fills buried pediments and alluvial plains. The bazada zones occur west of Puliyangudi, Sivagiri, Rajapalayam, Srivilliputhur and Watrap which are bordering the mountainous regions. It consists of colluvio-fluvial materials derived from the slopes of the hills and thickness varies from 3 m to 5 m. It is permeable, porous and unconsolidated which can serve as good recharge zone. The valley fill is developed in and around Watrap. It consists of colluvio-fluvial materials derived from the hill slopes of Periyar, Kovilar and the tributaries of Arjuna Nadhi. The thickness varies from 10 to 15 m form moderate to good potential zones. The buried pediments occur bordering the bazada zones between Puliyangudi and Rajapalayam. It may have thick overburden and soil cover from 5 m to 10 m and deep weathered mantle. These zones form moderate potential zones. The alluvial formation commences from the downstream side of Sattur and extends both sides of the river Vaippar, thickness ranging from 6 m to 15 m with highly porous and unconsolidated forming very good potential zones.

3.1.3.3 Coastal Landform

The coastal alluvium is restricted to a narrow stretch parallel to the coast consisting of fine sand and shell fragments. Sand ridges occur parallel to the coast consisting of fine sand and shell fragments. Sand ridges occur parallel to the coast as low elongated patches. They are highly porous and permeable and form moderate potential zones.

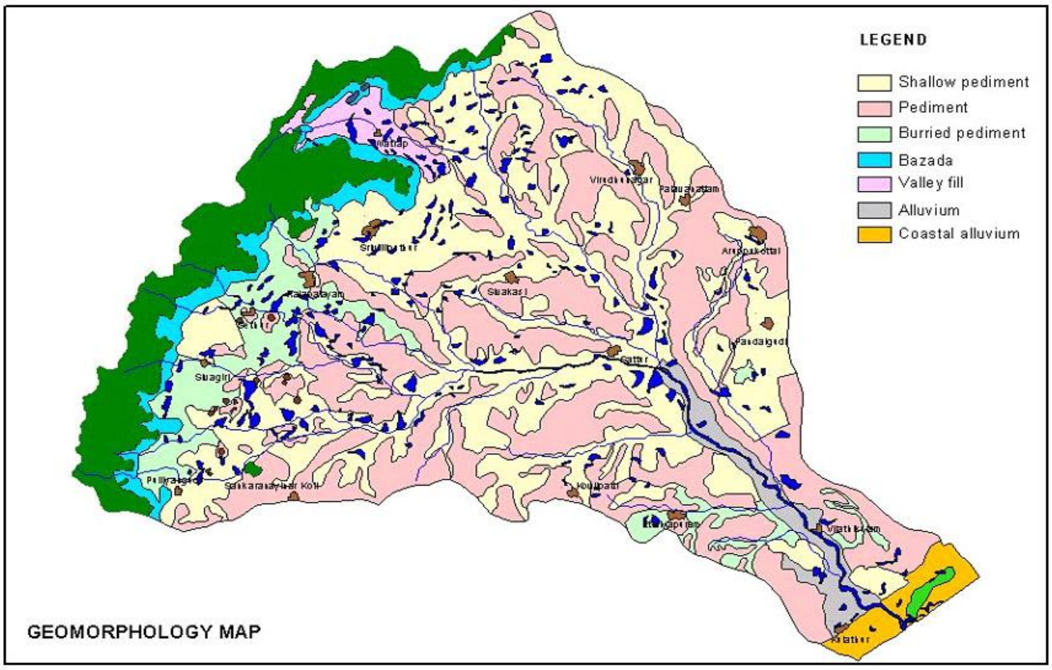

Figure 3.5 Geomorphology Map of Vaippar Basin

3.1.4 Hydrogeology

A study of the hydrogeology of a region will help to decide whether a place is suited for groundwater development or not. Higher groundwater extraction may mean higher recharge to the area and hence higher potential. Such an area can surely be considered for groundwater resources development through percolation ponds. The hydrogeological study of Vaippar basin involves collection and analysis of water level fluctuations, geophysical, aquifer performance and water quality data. The weathered zone in the western part of the area ranges from 10m to 25 m and in the Eastern and Northern parts from 20m to 40 m below ground level. The fractures and joints in the hard rock areas extend up to a depth of 45 m. Dug wells and bore wells are sunk in this basin mostly for irrigation purposes. The dug well yield about 0.615 ham. The yield of the bore wells yield ranges between 50 lpm and 150 lpm. The low yield in bore wells is due to the poor transmissivity of hard rock aquifers.

3.1.5 Land Use

The total area of the Vaippar basin is 5423 km^2 out of which hilly area covers 591 km^2, shrubland covers 2343 km^2, the tanks have an extent of 206 km^2. Sparse irrigation activity is carried out in 1108 km^2 and Intensive irrigation is carried out in 1124 km^2. In the sub-basins of Kalingalar, Deviar, Nagariar and Sevalperiyar, the area under forest fulfills the national norms of one-third of the geographical area should be under forest.

The higher percentage of barren land is found in Arjunanadhi and Kousiganadhi. In almost all the sub-basins of Vaippar basin, the percentage of land put to Non-agricultural use is more or less nearer to 15% and Sindapalli Uppodai is found to be more significant in this aspect. Increase in urbanization and industrialization results in the increasing trend of the area put to non-agricultural use. The land use map of the study basin is shown in Figure 3.6.

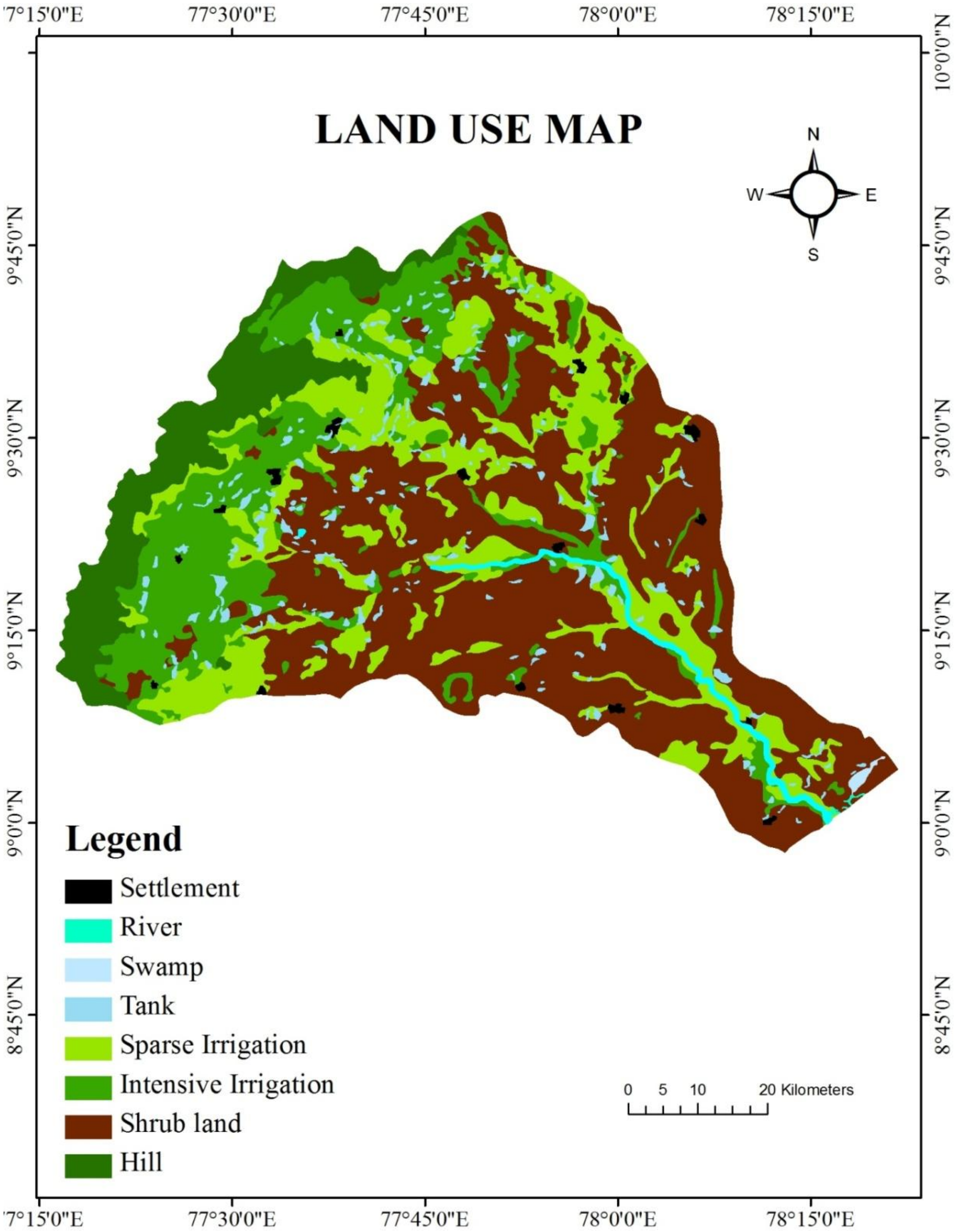

Figure 3.6 Land use Map of Vaippar basin

3.1.6 Climatic Condition

The Vaippar basin has a tropical climate. It has a hot summer and mild winter. Agro-climatically, the area falls under semi-arid regions. The climate of Vaippar basin is influenced by the monsoonal winds as in other parts of Tamilnadu. The monsoonal season is mainly responsible for most of the rains over the basin, with the Northeast monsoon accounting for the maximum amount of rainfall. Most of the agricultural activities are centered on this season between September and December. The Southwest monsoon during the months of June to September also produces a reasonable amount of rainfall which is quite useful for the rain-fed agriculture. Unfortunately, the basin falls in the rain shadow area of Western Ghats as far as Southwest monsoon is concerned. The winter (January to February) and summer (March to May) seasons rainfall may not be significant in producing any useful runoff but certainly helpful in maintaining the soil moisture in the basin. The ranges of some of the climatic factors are given below.

(I) **Temperature:** The temperature variation is from 20°C to 30°C in winter and 30°C to 40°C in summer.

(II) **Humidity:** The mean monthly humidity value of this basin area varies between 55% and 73%. Generally, the humidity is quite high during the monsoon season compared to the non- monsoon season.

(III) **Wind Velocity:** The average monthly wind velocity varies between 3.5 Kmph and 7.25 Kmph. The wind velocity is high during the months of June, July and August, mainly influenced by the Southwest monsoon winds.

(IV) **Sunshine:** The average sunshine in a month varies from 5.5 hrs to 8.5 hrs. The sunshine hours are generally high during months of January, February, March and April.

(V) **Evaporation and Evapotranspiration:** The water balance of an area is greatly influenced by evaporation and evapotranspiration. The Vaippar basin being in a tropically semi-arid region, the water losses from the irrigated fields are very high. Hence, it becomes very important to estimate the evaporation losses while doing the water balance analysis. The mean monthly potential evaporation ranges between 120mm and 235mm, whereas the average mean monthly potential evapotranspiration ranges between 125mm and 210 mm.

(VI) **Rainfall:** There are 15 rain gauge stations located within the basin with one more station at Kadayanallur just outside the boundary of the basin. The mean annual rainfall in the basin varies from 617 mm to 957 mm. There is a wide variation in the quantum of long-term annual rainfall. The rainfall contribution is slightly higher in the Northwestern parts of the basin. The long-term average annual rainfall of Watrap rain gauge station is 957mm which is higher than the state long-term average. Fairly good amount of rainfall has also been received at Srivilliputtur and Sivakasi areas where the long-term average rainfall works out to 872mm and 755 mm respectively. Progressively the rainfall decreases towards the south and eastern parts of the basin.

3.2 RAINFALL ANALYSIS

Fifteen rain gauge stations covering the Vaippar river basin have been identified and 39 years of rainfall data of each station were collected from State Statistical Department, Chennai. The daily rainfall values of each station are converted into monthly and yearly rainfall depths. The mean seasonal and yearly average values of each station were presented in Table.3.2 which is used to map the spatial variation of rainfall over the Vaippar basin. The yearly rainfall value is further analyzed for the frequency of occurrence.

Table 3.2 Seasonal and Annual average value of rainfall in each station

S.No.	Station Name	Seasonal Average (mm)				Annual Average (mm)
		Southwest	Northeast	Winter	Summer	
1	Aruppukottai	186.6	363.9	28.0	128.8	707.2
2	Sivagiri	99.7	477.8	70.8	176.0	824.3
3	Vilathikulam	99.2	351.2	31.4	80.3	562.0
4	Sankarankoil	68.1	412.7	46.3	123.8	650.9
5	Kovilpatti	153.7	413.2	37.2	141.9	746.0
6	Sathur	147.8	342.4	31.3	143.8	665.3
7	Virudhunagar	210.9	363.2	33.4	147.3	754.8
8	Srivilliputhur	158.5	441.5	41.7	181.7	823.5
9	Watrap	184.6	492.6	57.2	173.0	907.4
10	Sivakasi	155.0	368.3	33.1	138.4	694.8
11	Kavalur	175.4	332.8	36.8	122.4	667.5
12	Pilavukkal	167.0	439.1	73.6	158.3	837.9
13	Vembakottai	156.8	472.7	26.9	171.7	828.1
14	Vasudevanallur	71.2	502.7	64.4	140.5	778.8
15	Rajapalayam	112.6	484.6	60.0	184.4	841.6

3.2.1 Dependability Analysis of Rainfall

Rainfall is the primary hydrological input for agriculture, but rainfall in the semi-arid area is commonly characterized by extremely high spatial and temporal variability with an annual rainfall from 250 to 750 mm. The quantity and distribution pattern decides the availability of surface and groundwater potential. The dependability analysis of annual rainfall values of Vaippar basin is carried out in order to identify the dependable year and the corresponding value of annual rainfall. The 39 years of collected data are used in dependability analysis by the Weibull's method. The values of various dependable annual rainfall and dependability graph are presented in Table 3.3 and Figure 3.7.

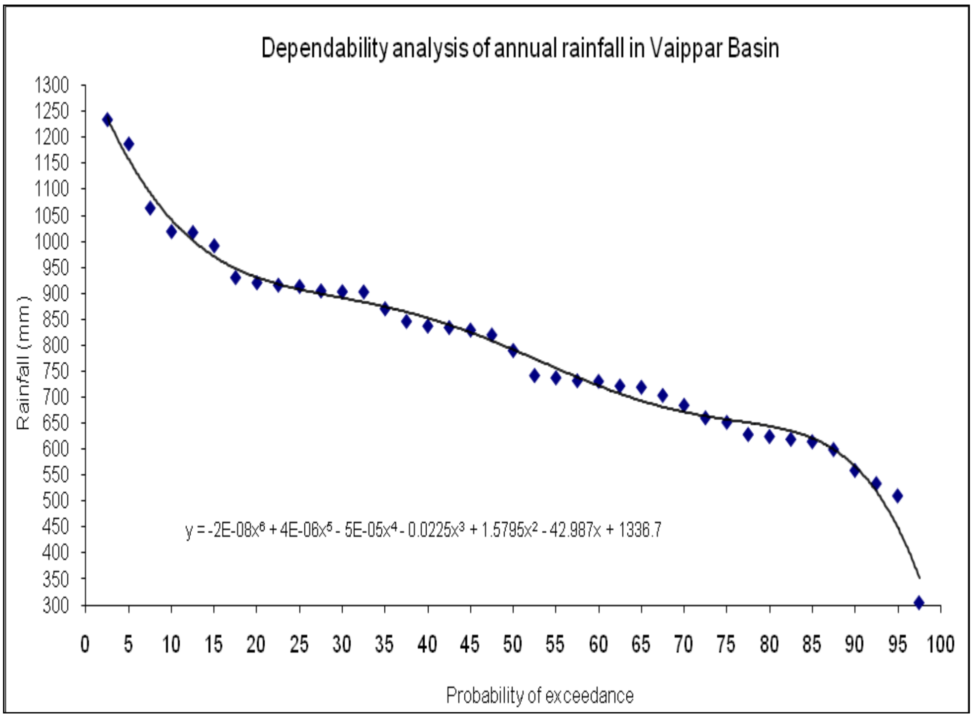

Figure 3.7 Dependability Analysis of Annual Rainfall in Vaippar basin

Table 3.3 Dependability analysis of rainfall in Vaippar basin

Sl.No.	Year	Annual Rainfall (mm)	Rank (m)	% P
1	1983-84	1235	1	2.50
2	1979-80	1188	2	5.00
3	2007-08	1065	3	7.50
4	1987-88	1020	4	10.00
5	2010-11	1018	5	12.50
6	1998-99	992	6	15.00
7	1997-98	931	7	17.50
8	1977-78	921	8	20.00
9	1989-90	917	9	22.50
10	2005-06	914	10	25.00
11	1999-00	905	11	27.50
12	1981-82	904	12	30.00
13	1993-94	904	13	32.50
14	2011-12	871	14	35.00
15	1973-74	847	15	37.50
16	1976-77	838	16	40.00
17	2008-09	835	17	42.50
18	2001-02	830	18	45.00
19	2004-05	821	19	47.50
20	1996-97	791	20	50.00
21	1984-85	743	21	52.50
22	1990-91	738	22	55.00
23	1985-86	732	23	57.50
24	2000-01	731	24	60.00
25	1992-93	723	25	62.50
26	2006-07	720	26	65.00
27	2002-03	704	27	67.50
28	1980-81	685	28	70.00
29	1988-89	661	29	72.50
30	1994-95	652	30	73.50
31	2003-04	629	31	75.50
32	1975-76	625	32	80.00
33	1978-79	620	33	82.50
34	1991-92	615	34	85.00
35	2009-10	600	35	87.50
36	1982-83	560	36	90.00
37	1974-75	534	37	92.50
38	1995-96	511	38	95.00
39	1986-87	305	39	97.50

The 50%, 75% and 90% dependable values of rainfall and its year of occurrence are presented in Table 3.4. Temporal distribution of annual rainfall and the frequency plot are presented in Figure 3.8 and 3.9. It was inferred that 50% dependable annual Rainfall value is 791mm and the corresponding return period is 2 years. Similarly the 75% & 90% dependable rainfall are 629 mm & 560 mm.

Table 3.4 Dependable rainfall values and its year of occurrence

Sl. No.	Year	% P	Annual Rainfall (mm)
1	1996-97	50 %	791
2	2003-04	75 %	629
3	1982-83	90 %	560

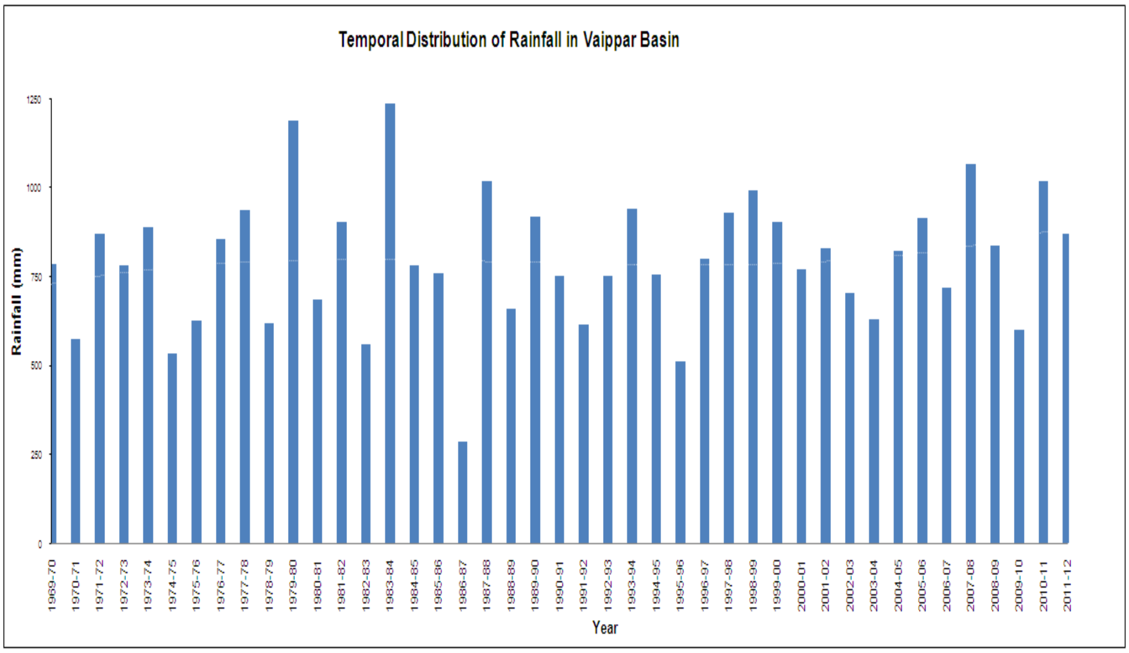

Figure 3.8 Temporal distributon of annual rainfall in Vaippar Basin

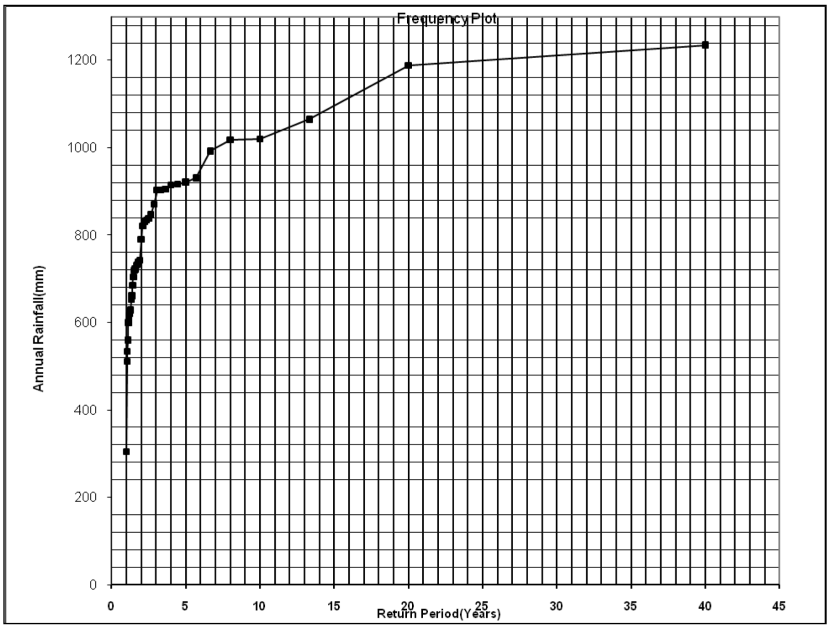

Figure 3.9 Frequency plot of annual rainfall values of Vaippar Basin

3.2.2 Spatial Variation of Rainfall in Vaippar Basin

The mean monthly, seasonal and annual rainfall values are calculated for each station. The calculated mean annual, seasonal and monthly values of rainfall for each station are entered in the GIS database. These attribute information along with the spatial location of each rain gauge are used to map the spatial variation of rainfall in the entire Vaippar basin. The spatial variations of annual as well as seasonal rainfall patterns are mapped using ArcGIS.

3.2.2.1 Spatial Pattern of Annual Rainfall

The annual rainfall in Vaippar Basin varies over the entire area. The preparation of spatial distribution map of annual rainfall was done using the Geostatistical methods in ArcGIS. The spatial analysis of rainfall for annual and various seasons was done for the 75% dependability rainfall year. The spatial pattern of annual rainfall in Vaippar basin is presented in Figure

3.10. The entire basin can be divided into three parts: the upper portion consists of hills and forest, the middle reach comprises of moderately sloped terrain with agricultural fields and the lower basin has flat topography. The upper part of the catchment (about 49%), which is covered with the Western Ghats and reserved forest, receives the maximum amount of rainfall. The middle portion of the basin (41%) gets moderate rainfall i.e. around the basin average value. The lower part (10%) receives much lesser rainfall compared to the basin average. The middle and lower portion makes the basin to fall into the semi-arid classification.

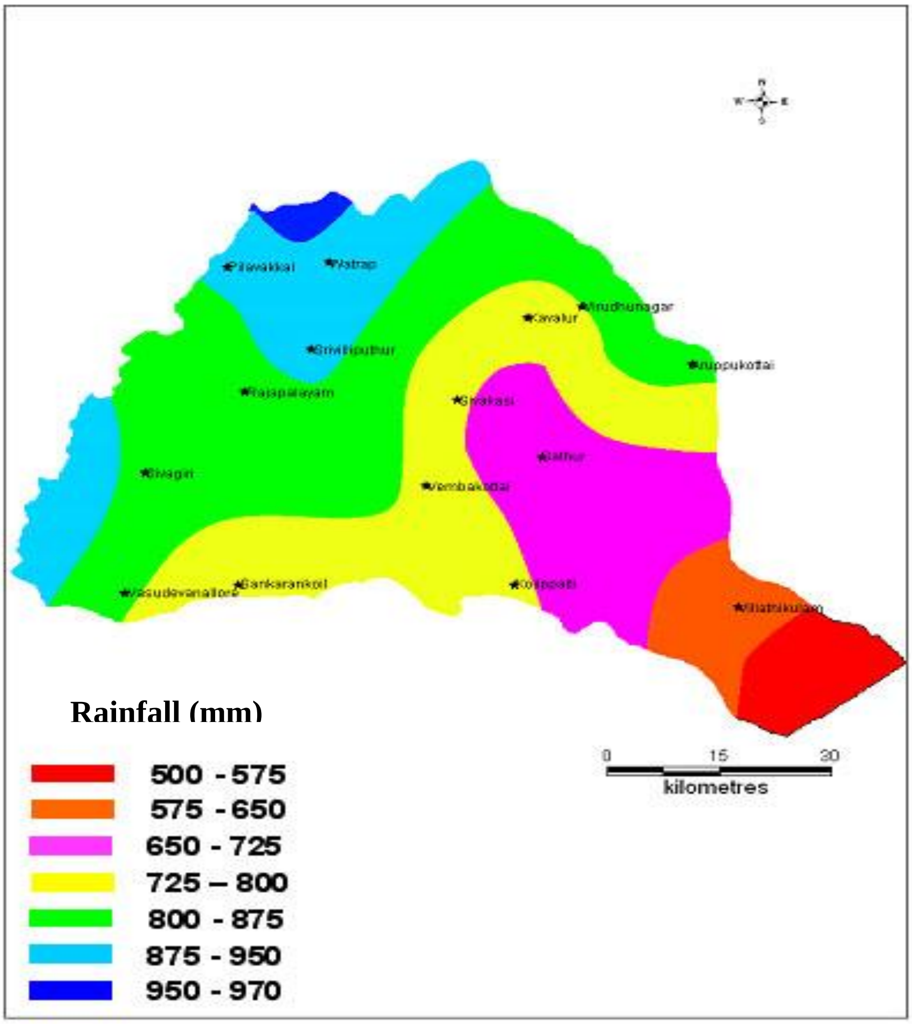

Figure 3.10 Spatial distribution of annual rainfall in Vaippar Basin

3.2.2.2 Spatial Pattern of Rainfall during Southwest Monsoon

The spatial pattern of South West Monsoon rainfall over entire Vaippar is presented in Figure 3.11 and it varies in the range of 70 mm to 250 mm. The upper portion of the basin gets maximum rainfall and lower part receives minimum. More particularly during the months of June, July the basin gets very less quantity of rainfall.

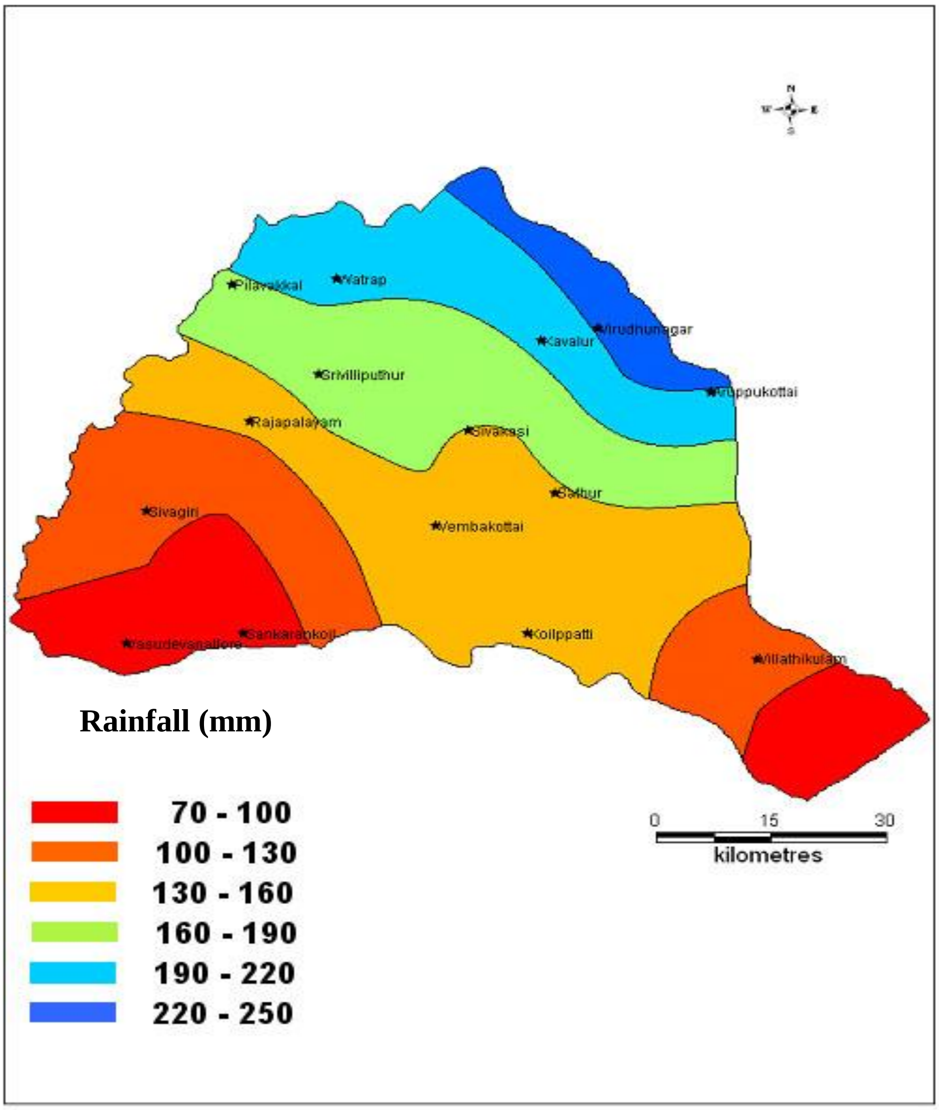

Figure 3.11 Spatial variation of Southwest Monsoon rainfall in Vaippar Basin

3.2.2.3 Spatial Variation of Northeast Monsoon Rainfall

The spatial variation of Northeast Monsoon rainfall in Vaippar basin is presented in Figure 3.12. The Vaippar basin gets a major portion of its rainfall during the Northeast Monsoon period. There is significant variation taking place in the rainfall values and it varies from 320 mm to 560 mm. The rain gauge stations Watrap, Sivagiri, Srivilliputtur receives the maximum amount of rainfall whereas the Sathur, Vilathikulam, Virudhunagar, Sivakasi areas receive low rainfall.

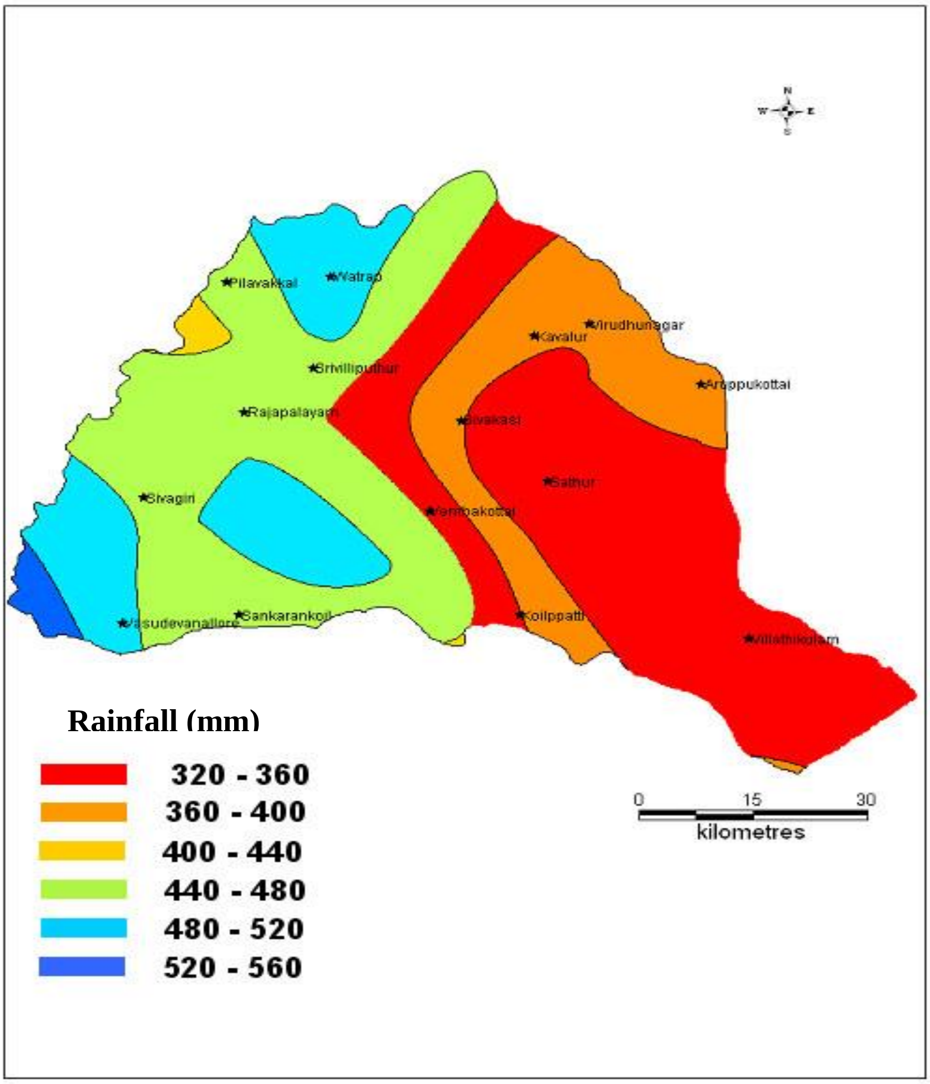

Figure 3.12 Spatial variation of Northeast Monsoon rainfall

3.2.2.4 Spatial Variation of Winter Rainfall

The winter rainfall map of Vaippar is given in Figure 3.13. During the winter period, the Vaippar basin receives very low rainfall. The order of rainfall during winter period is 25 mm to 95 mm. There is no significant variation of rainfall in the entire region. About 55% of the area receives very low rainfall (i.e. of the order of 25-40 mm).

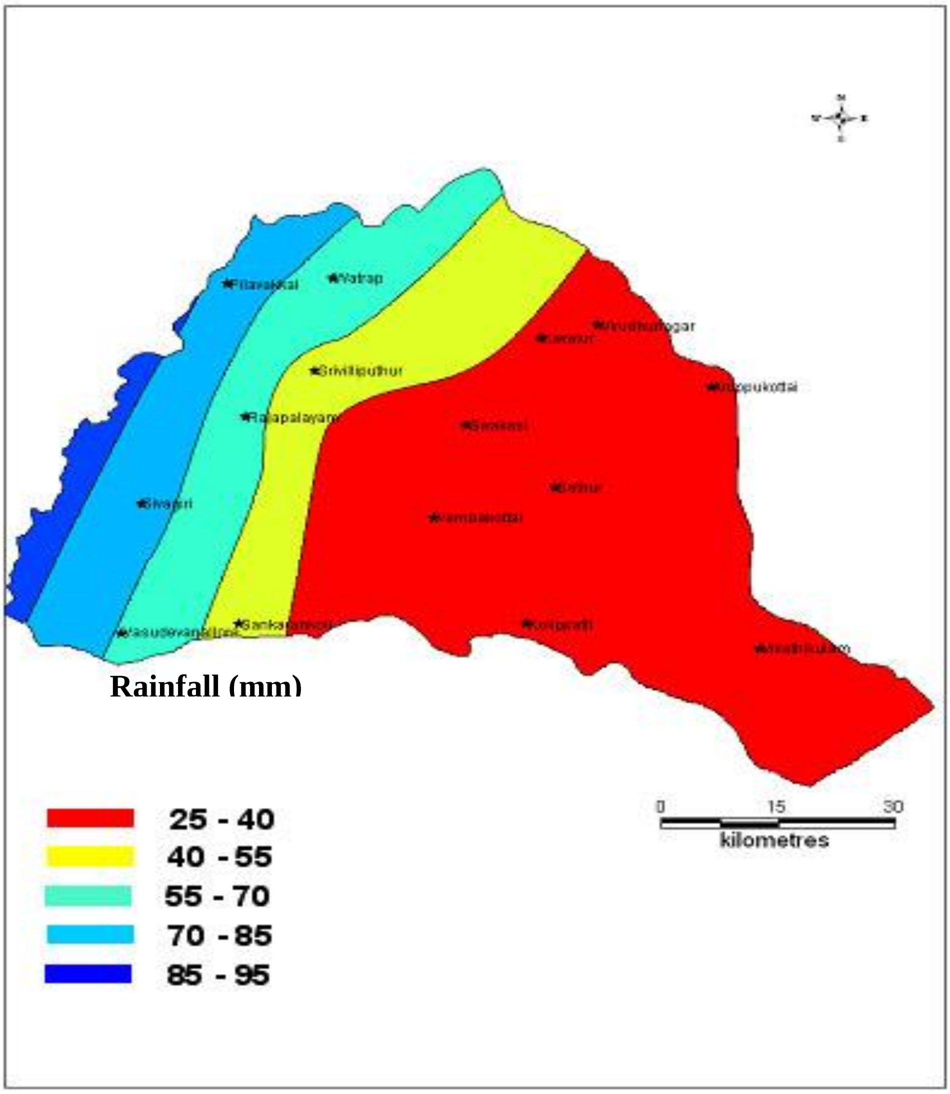

Figure 3.13 Spatial Variation of Winter rainfall in Vaippar Basin

3.2.2.5 Spatial Pattern of Summer Rainfall

Vaippar basin receives more rainfall during Summer compared to Winter. The spatial variation of rainfall during summer period is presented in Figure 3.14. The summer rainfall in Vaippar basin varies from 40mm to 200mm. More than 50% area receives rainfall above 130 mm. This makes a significant effect during the summer period.

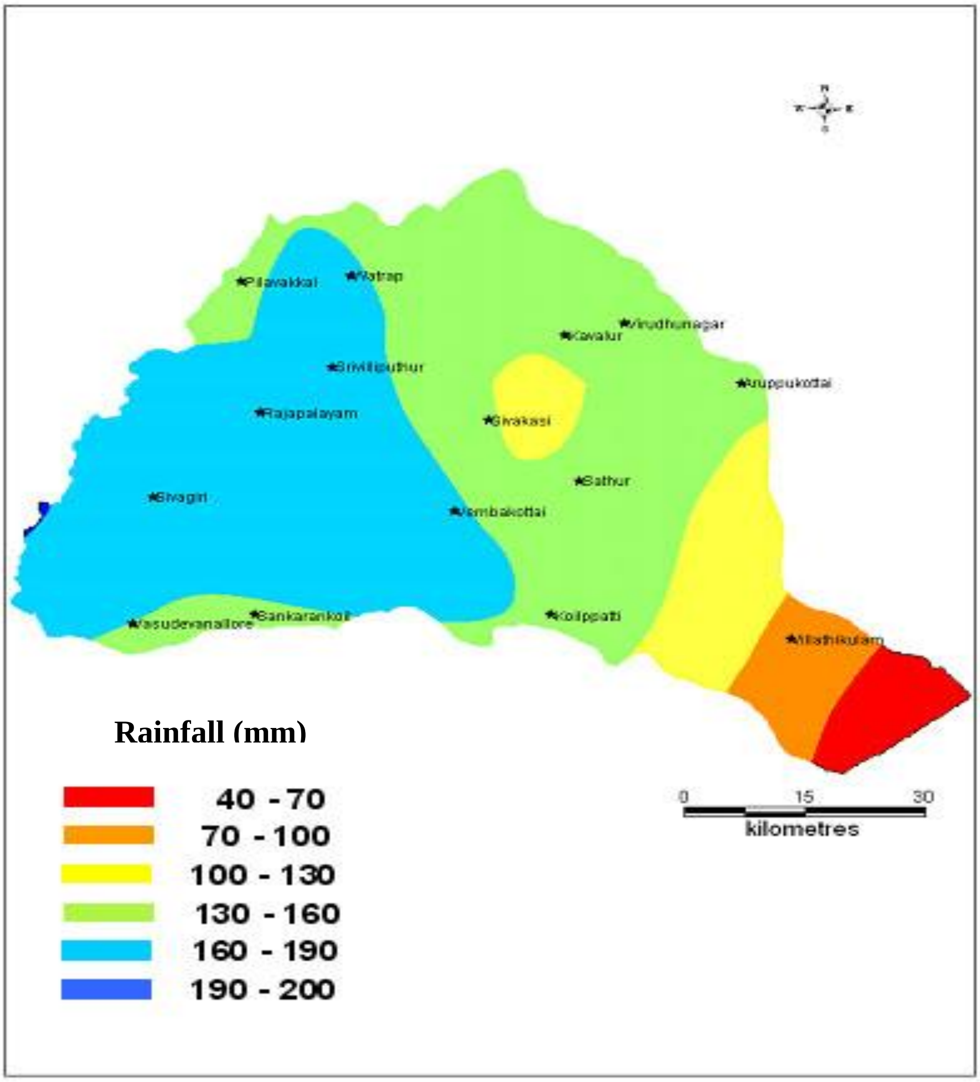

Figure 3.14 Spatial Variation of Summer Rainfall in Vaippar Basin

3.2.2.6 CROP SEASONAL ANALYSIS OF RAINFALL

In this basin three major crop seasons are practiced, which are:

(i) Samba Crop Season - 1st October to 12th February.

(ii) Kuruvai Crop Season -1st April to 14th July.

(iii) Navarai Crop Season -15th January to 29th April.

The daily rainfall data for 33 years for 16 rain gauge stations have been used for the analysis. Then the crop seasonal average values of rainfall of each station are calculated from the daily rainfall data and presented in Table 3.5. The average values are fed into GIS and spatial distribution of crop seasonal rainfall over the basin are analyzed.

Based on the irrigation water availability in canals, tanks and wells, the area under different crops vary. Major paddy cropping is confined to Samba season since Northeast monsoon coincides with it. The monsoon rain helps to build up storages in reservoirs, tanks, and recharging aquifers. After the harvest of main paddy crop during samba season, either Navarai paddy or other irrigated crops are raised according to the availability of surface and ground water. The crop seasonal analysis of rainfall will give a better picture of the spatial variation of rainfall over the basin level.

The samba crop season starts from 1st October and ends on 12th February. The analysis of rainfall distribution is carried out by considering 33 years of data. Figure 3.15. shows the spatial distribution of rainfall during samba crop season. The basin receives more than 50% of rainfall during the samba season. The average rainfall distribution in Vaippar basin during the samba season varies from 300 mm to 600 mm. The presence of Western Ghats makes the central and upper part of the basin to receive above normal rainfall. During the Samba season, Paddy is the main crop in the whole of Vaippar

Table 3.5 Crop Seasonal Variation of Rainfall in each Station

Sl. No.	Station	Crop Seasonal Rainfall (mm)		
		Kuruvai	Samba	Navarai
1	WATRAP	148	499	173
2	PILAVAKKAL	126	465	176
3	SIVAGIRI	150	500	202
4	ARUPPUKOTTAI	139	381	90
5	SRIVILLIPUTHUR	156	459	145
6	SATHUR	140	379	115
7	SIVAKASI	132	375	123
8	VIRUDHUNAGAR	148	381	117
9	KAVALUR	126	367	101
10	RAJAPALAYAM	134	501	153
11	VEMBAKOTTAI	162	484	132
12	KOVILPATTI	137	432	122
13	VILATHIKULAM	73	362	84
14	PERAIYUR	177	465	115
15	SANKARANKOIL	110	438	133
16	VASUDEVANALLUR	140	523	145

The Kuruvai crop season starts from 1st April and ends on 14th July. The basin receives nearly 25% of its rainfall during the Kuruvai season. The average rainfall distribution during the samba season varies from 25 mm to 200 mm. More than 60% of basin area receives an average rainfall of 100 mm to 125 mm. The lower part of the basin gets a very low amount of rainfall in comparison with the other parts of the basin. The spatial distribution of rainfall for Kuruvai crop season is given in Figure 3.16.

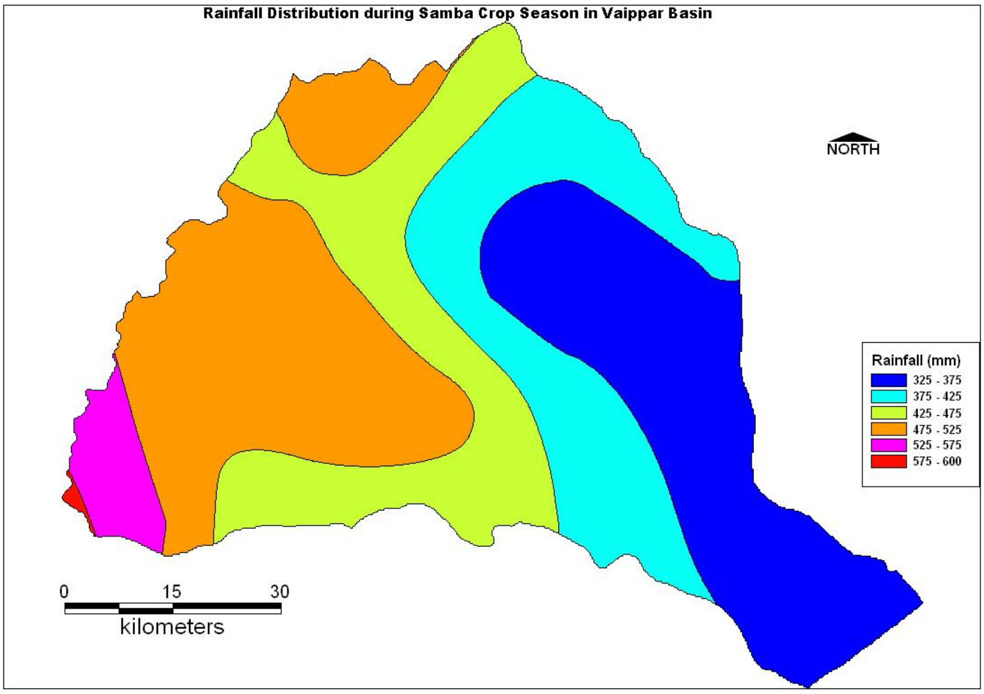

Figure 3.15 Spatial Variation of Rainfall during Samba Crop Season

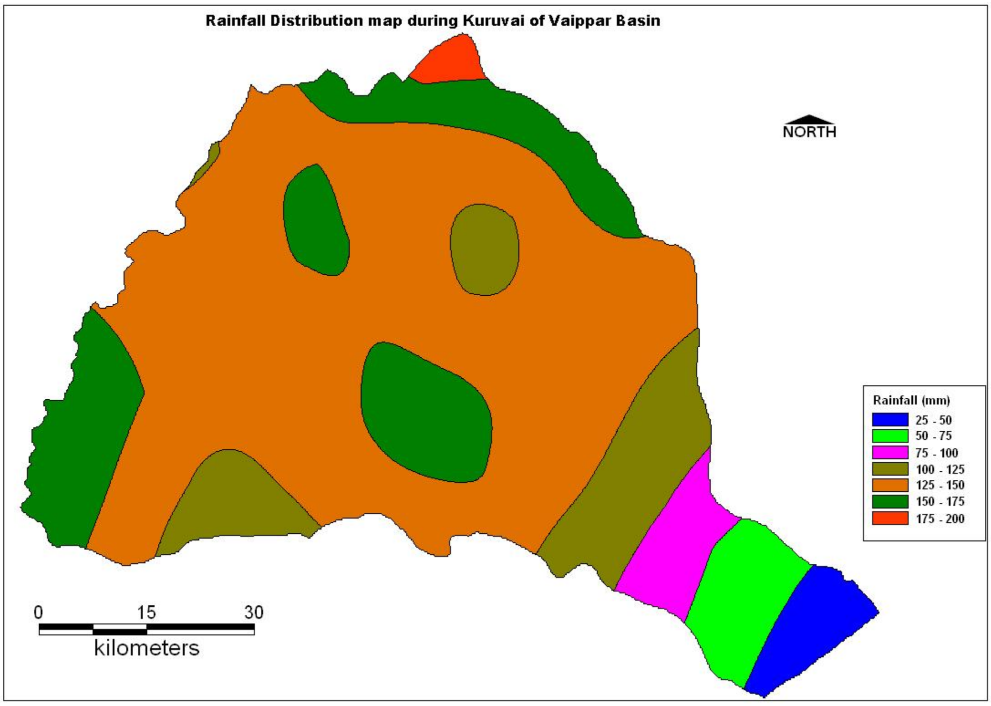

Figure 3.16 Spatial Variation of Rainfall during Kuruvai Crop Season

The Navarai crop season starts from 15th January and ends on 29th April. During Navarai season the basin receives little more rainfall in comparison with that of the Kuruvai season. The summer rainfall is the main contribution for the Navarai season. The average rainfall distribution during this season varies from 50 mm to 250 mm. The Navarai crop seasonal rainfall distribution is presented in Figure 3.17. More than 80% of basin area receives a rainfall more than 100 mm.

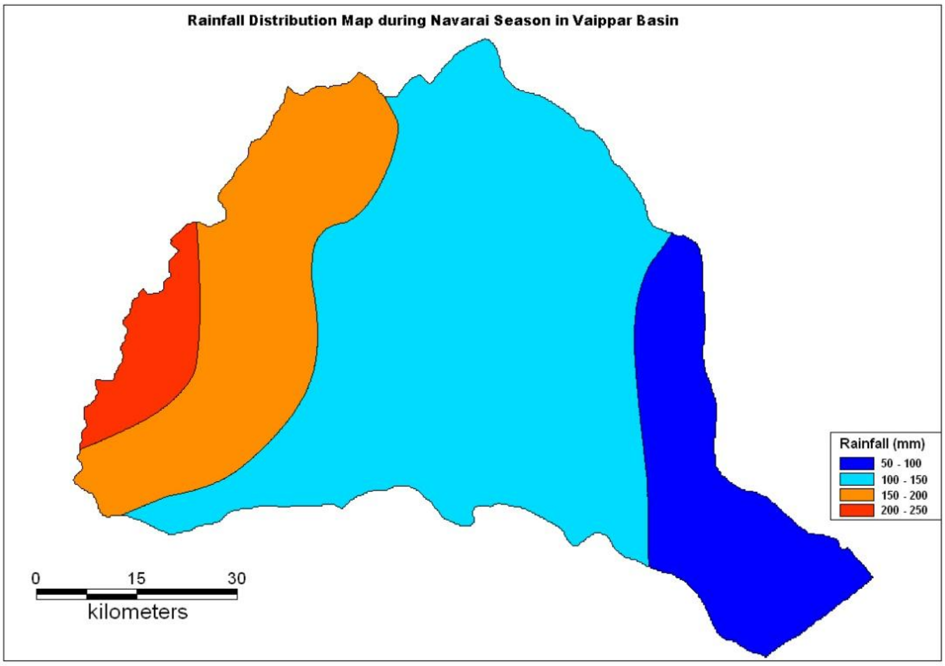

Figure 3.17 Spatial Variation of Rainfall during Navarai Crop Season

3.3 WATER RESOURCES POTENTIAL ASSESSMENT ON BASIN SCALE

The surface water potential estimation was carried out based on daily rainfall values for 75% dependable annual rainfall, which is occurred in 2003-04. In addition to that, the surface water potential estimation was also carried out for the minimum and maximum annual rainfall values occurred during the past 39 years. The basin level groundwater resources potential was estimated using the water table fluctuation method, one of the methods of GEC norms.

3.3.1 Estimation of Surface Runoff Using SCS NCRS Method

Rainfall excess forms the main input to arrive at the direct runoff. After flowing through the catchment, the excess rainfall becomes the direct runoff at the catchment outlet. It is defined as the difference between total rainfall and that lost to abstractions such as depression storage, interception, evaporation and infiltration (Chow, 1964). There are many methods for estimating the volume and time distribution of rainfall excess. The Soil Conservation Service (SCS) developed a comprehensive procedure called as runoff curve technique for calculating the abstractions and the rainfall excess. This method takes care of the heterogeneous nature of the catchment characteristics and antecedent soil moisture conditions over the catchment. The micro level changes of the catchment characteristics, such as the variations in soil and land use, which mainly controls the surface runoff generation, are easily handled by this technique. Typically, the way to account for this variation is to divide the watershed into smaller areas of “uniform” land use, land cover, and soil type combinations.

The rainfall-runoff relationship in this method is derived from the water balance equation and a proportionality relationship between retention and runoff. The SCS rainfall-runoff relationship is given by equation 3.1 (Novotny et al., 1994):

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \; for P > I_a \qquad (3.1)$$

Where P is the rainfall depth (mm).

Q is the depth of excess rainfall (mm).

I_a is the initial abstractions (mm).

S is the volume of total storage (mm).

Storage includes both the initial abstractions and total infiltration. The initial abstraction is a function of land use, treatment and condition, interception, infiltration, detention storage, and antecedent soil moisture (Novotny et al., 1994). The initial abstraction and the total storage are related in an empirical statistical equation which is given in equation 3.2.

$$I_a = \lambda S \qquad (3.2)$$

Where λ varies from 0.1 to 0.3

The storage S (in millimeters) is obtained using the Formula 3.3

$$S = \frac{25400}{CN} - 254 \qquad (3.3)$$

Where, CN is the curve number that can be obtained from standard tables for different combinations of land use and land cover, soil hydrologic group, soil treatment and condition. The hydrologic soil group reflects the soil's permeability and surface runoff potential. Following is a description of the four different hydrologic soil groups (Novotny et al., 1994):

1. Group A are soils with low total surface runoff potential due to their high infiltration rates. They consist mainly of excessively drained sands and gravels.

2. Group B are soils with low to moderate surface runoff potential. They have moderate infiltration rates and moderately fine to moderately coarse texture.

3. Group C are soils with moderate to high surface runoff potential. They have slow infiltration rates and moderately fine to fine textures.

4. Group D are soils with high surface runoff potential. They have very slow infiltration rates and consist chiefly of clay soils.

In the distributed Curve Number model, each polygon is assigned a CN that corresponds to its land use-land cover and soil hydrologic group. The degree of lumping is limited to each polygon size. The goal is to maintain the spatial variation in excess rainfall in this model. The basic approach is based on the assumption that variation in actual runoff from the CNII (base CN) value is due to the antecedent moisture condition (AMC) of the soil. Thus, the relationships between CNIII (AMC = III) and CNI (AMC = I) to CNII (AMC = II) are used to scale the storm CN.

The AMC = II represents the average case for annual floods which is an average of the conditions that have preceded the occurrence of the annual flood on numerous watersheds. AMC = I represents dry soils (though not to the wilting point), and AMC = III represents the conditions if heavy rainfall or light rainfall with low temperature occurred during the five days period prior to the given storm and soils, in this case, are nearly saturated. The transformation equation from CNII to CNI is given by equation 3.4 (Novotny et al., 1994)

$$CN\ (I) = \{\ 4.2\ CN(II) / [(10- (0.058\ CN\ II)]\ \} \qquad \text{...... (3.4)}$$

For the AMC I the above formula is used to transfer the CN II to CN I.
The transformation equation from CNII to CNIII is given by equation 3.5 (Novotny et al., 1994)

CN(III) = { [23 CN(II)] / [0+0.13 CN (II)] } ...... (3.5)

For the AMC III, the above formula is used to transfer the CN II to CN III. The AMC conditions with the soil moisture condition has been given in Table 3.6.

Table 3.6 SCS Soil moisture condition

AMC Condition	Soil Characteristics	Total day antecedent rainfall (mm)	
		Dormant Season	Growing Season
I	Soils are dry but not to wilting point; Satisfactory cultivation has taken place	< 13	< 36
II	Average condition	13 – 28	36 - 53
III	Heavy rainfall or light rainfall and low temperature have occurred within the last 5 days; Saturated soil	> 28	> 53

3.3.1.1 SCS-CN Equation for Indian Conditions

For use in Indian conditions in equation (3.2) λ = 0.1 and 0.3 subjects to certain constraints of soil type and AMC type has been recommended in equation 3.6 and 3.7 (K.Subramanya, 2009)

$$Q = \frac{(P - 0.1S)^2}{(P + 0.9S)} \; for P > 0.1S, \qquad (3.6)$$

Valid for Black soils under AMC of Type II and III

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \; for P > 0.3S, \qquad (3.7)$$

Valid for Black soils under AMC of Type I and for all other soils having AMC of types I, II and III. Runoff Curve Numbers [CN_{II}] for Hydrologic Soil Cover Complexes [Under AMC-II conditions] are given in Table 3.7.

Table 3.7 CN_{II} for Hydrologic Soil Cover Complexes [Under AMC-II conditions]

Land Use	Cover		Hydrologic soil Group			
	Treatment or practice	Hydrologic condition	A	B	C	D
Cultivated	Straight row		76	86	90	93
	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
		Good	62	71	77	81
	Bunded	Poor	67	75	81	83
		Good	59	69	76	79
	Paddy		95	95	95	95
Orchards	With understory cover		39	53	67	71
	Without understory cover		41	55	69	73
Forest	Dense		26	40	58	61
	Open		28	44	60	64
	Scrub		33	47	64	67
Pasture	Poor		68	79	86	89
	Fair		49	69	79	84
	Good		39	61	74	80
Wasteland			71	80	85	88
Roads (dirt)			73	83	88	90
Hard surface areas			77	86	91	93

The runoff potential was estimated using the Soil Conservation Service method with distributed CN. The land-soil map of the Vaippar basin was overlaid in the ArcGIS and the individual land-soil polygon was assigned a CN. Then the SCS method was used to find the runoff at each individual polygon hence the runoff has been estimated in a distributed manner throughout the basin**.**

3.3.1.2 Procedure for SCS NCRS method

1. The Soil, Land use, Thiessen polygon map of the Vaippar basin is overlaid in the ArcGIS. The area of the overlaid typical land-soil polygon has been calculated.

2. Then the attribute table has been transferred to the Visual Basic software and then the code has been written to found out the runoff at each and every typical Land-Soil polygon.

3. Each Land use-Soil polygon is assigned a unique CN that corresponds to the five-day antecedent moisture condition (AMC) of the particular Thiessen polygon.

4. Then the attribute table is linked to the ArcGIS to show the spatial variation of the surface runoff throughout the basin. The Figure 3.18 shows the overlaid layer of Land-Soil map.

3.3.2 Surface Water Potential for Vaippar Basin

The surface water potential for the Vaippar basin is estimated using SCS method for 75% dependability rainfall. The overlaid map of soil and land use gives the individual typical Land-Soil polygon. The area of the polygon is determined and then the attribute table is taken to the VisualBasic to calculate

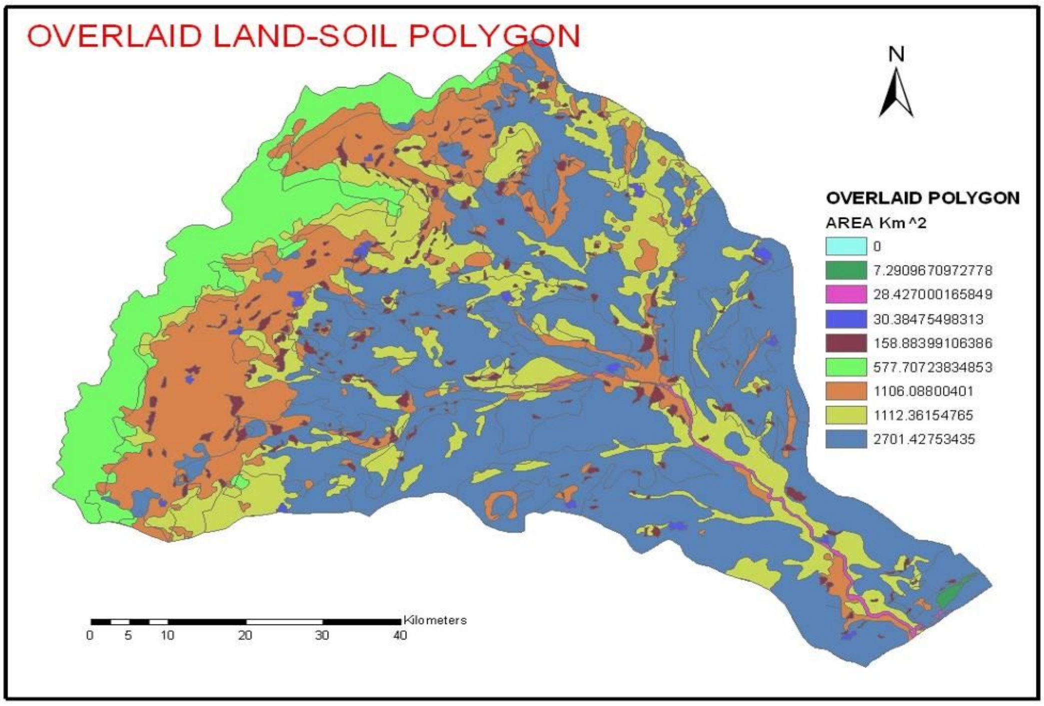

Figure 3.18 Map of overlaid land use and soil polygon

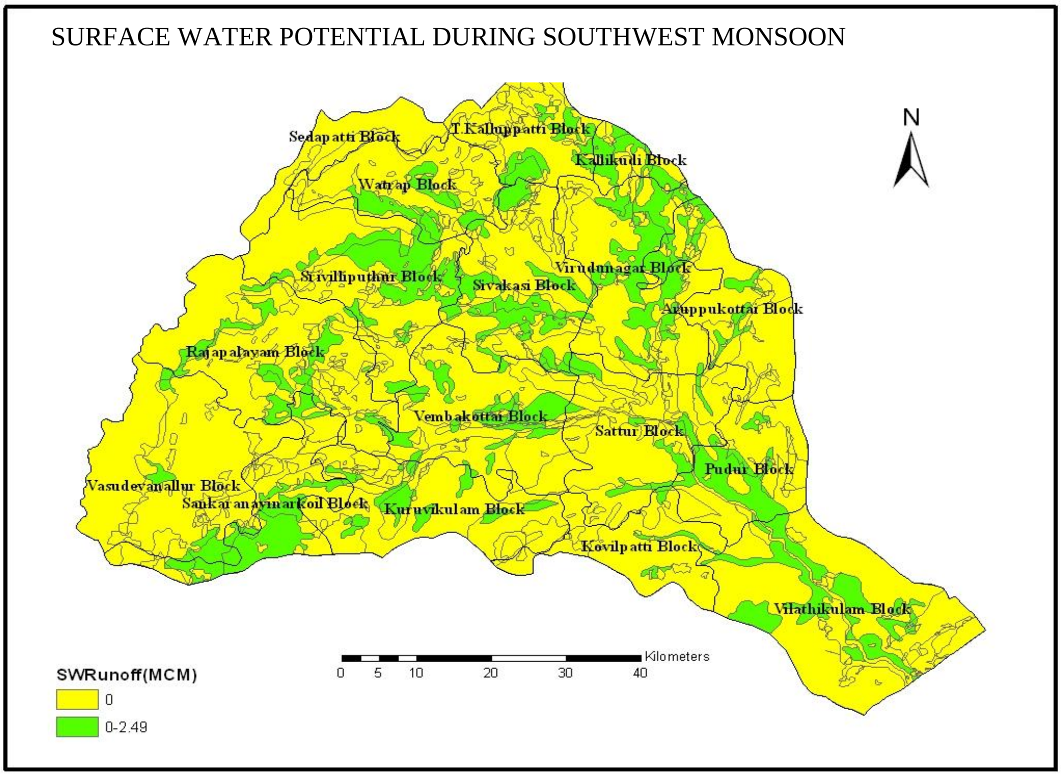

Figure 3.19 Spatial distribution of surface water potential during Southwest Monsoon

the runoff in each individual polygon. The calculated runoff is then linked to ArcGIS to represent the spatial variation of runoff. The spatial surface runoff variation for the seasons Southwest Monsoon, Northeast Monsoon, Winter and Summer are shown in Figure 3.19, 3.20, 3.21. 3.22 respectively for the 75% dependability rainfall year and the annual spatial variation of surface water potential for the year 2003-2004 is shown in Figure 3.23

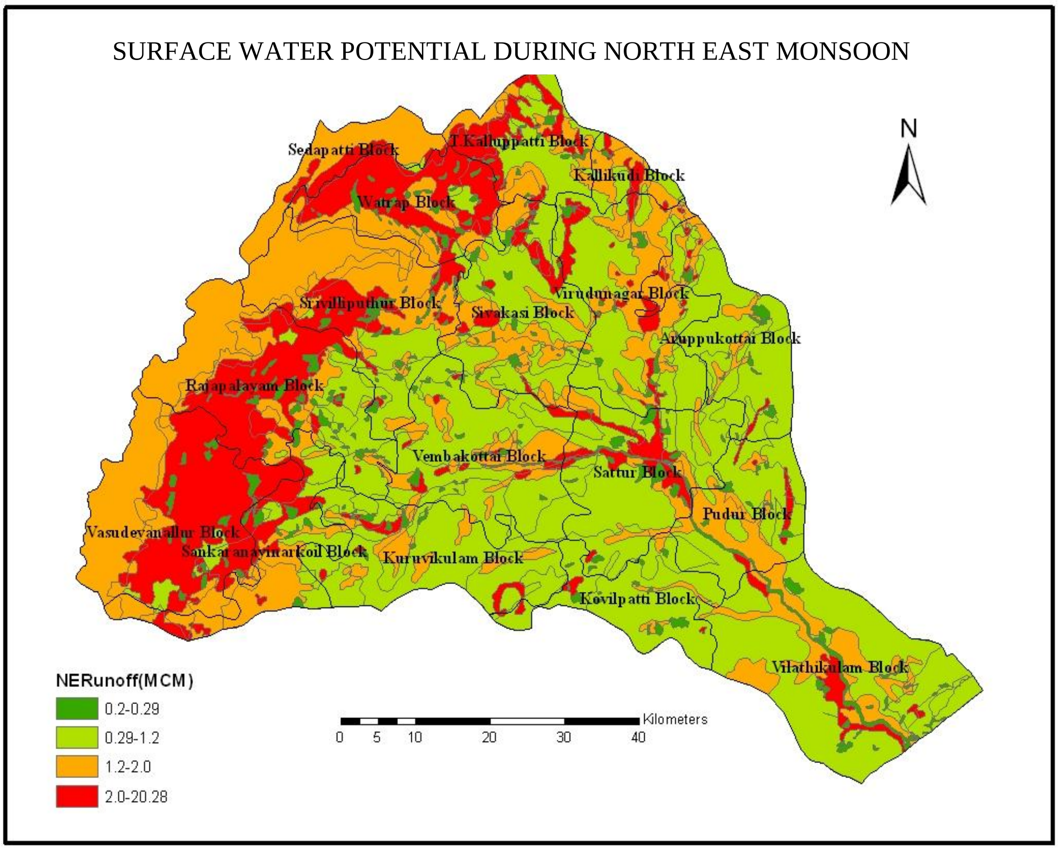

Figure 3.20 Spatial distribution of Runoff Potential during Northeast Monsoon

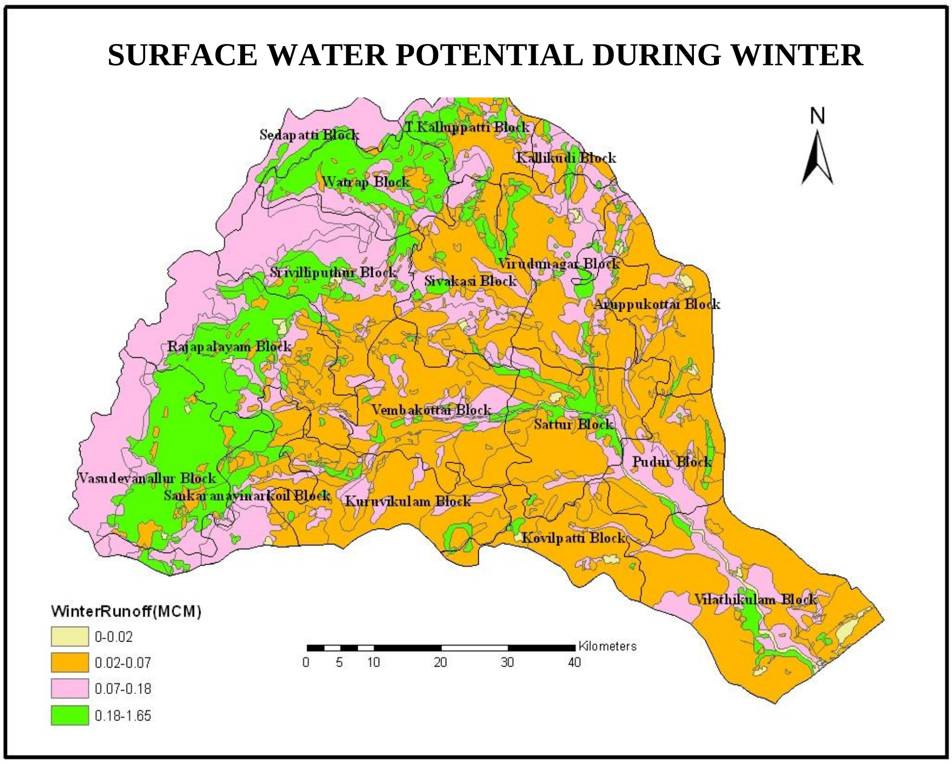

Figure 3.21 Spatial distribution of Runoff Potential during Winter season

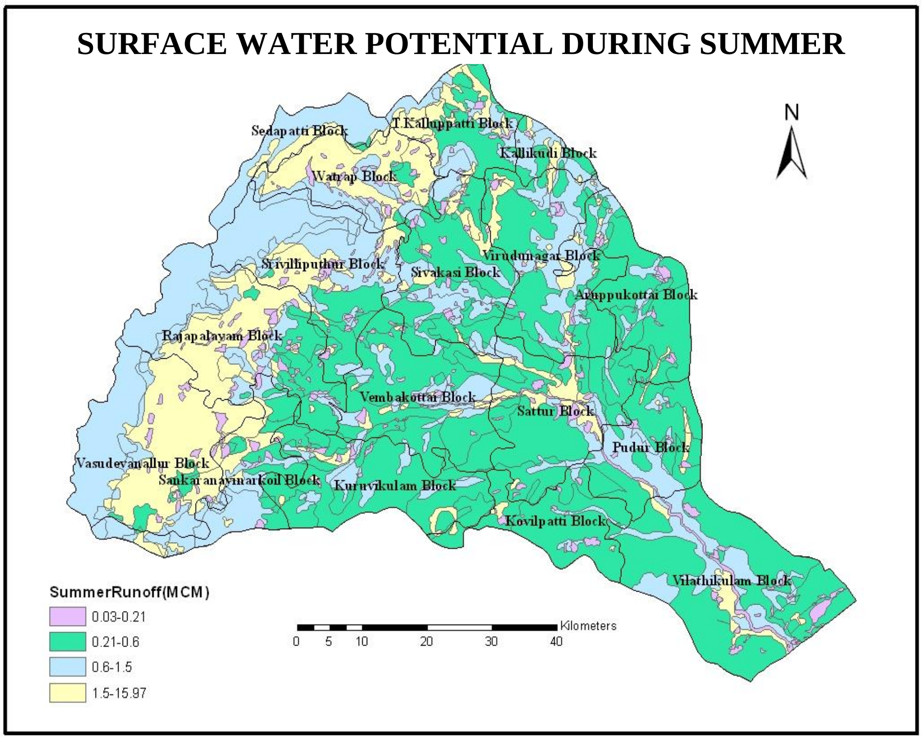

Figure 3.22 Spatial distribution of Runoff potential during Summer season

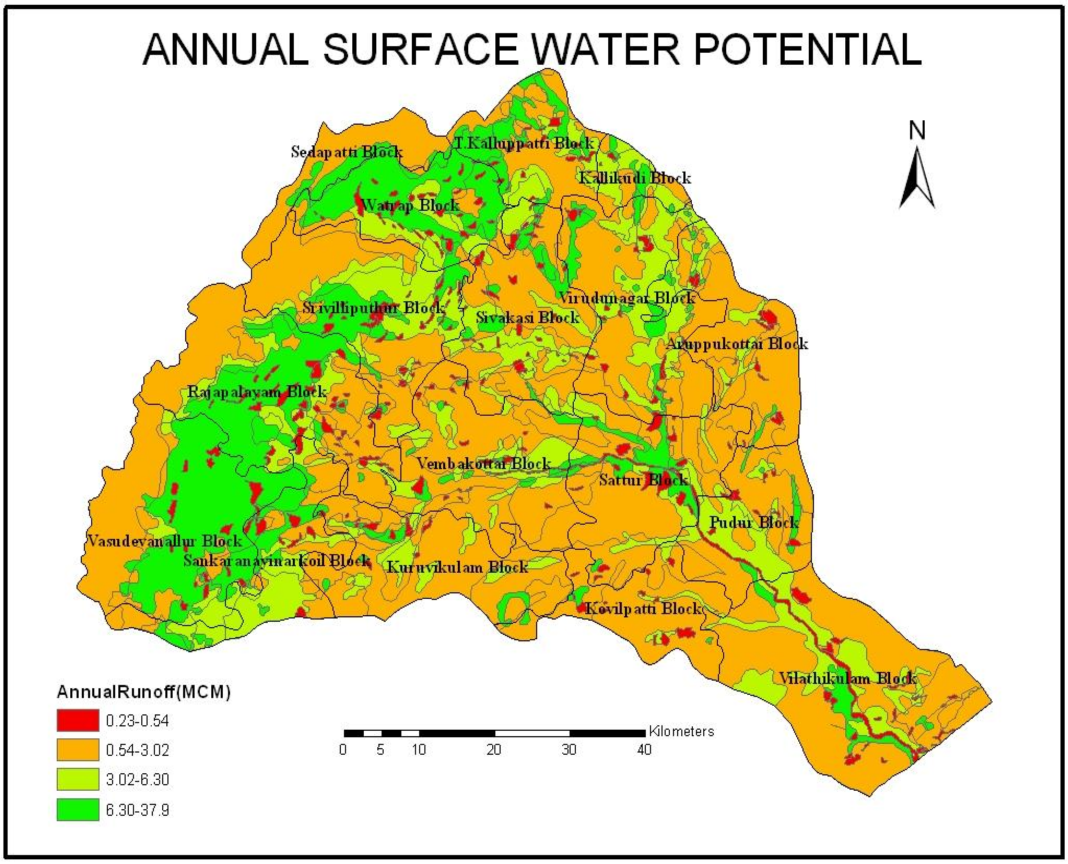

Figure 3.23 Spatial distribution of Annual surface water potential in 2003-2004

The following Table 3.8 shows the runoff distribution for various seasons with its contributing area. It is observed that surface runoff varies for different seasons. During Southwest monsoon most part of the Srivilliputtur block, Sivakasi block and Virudunagar block had received 2.49 MCM of surface water. During Northeast monsoon, most part of the Srivilliputtur, Vasudevanallur block and Watrap block had received a maximum of 20.27 MCM of surface water. All other parts of the basin had received 1.2 MCM of surface water.

Table 3.8 Surface Runoff Potential with its contributing area for different seasons

Seasons	Surface Water Potential (MCM)	Contributing Area in km^2
Southwest Monsoon	0	2857.89
	0.01 - 2.49	2465.57
Northeast Monsson	0.2 - 0.29	152.247
	0.29 - 1.2	774.267
	1.2 - 2.0	318.900
	2.0 - 20.28	3159.70
Winter	0 - 0.02	4700.06
	0.02 - 0.07	223.335
	0.07 - 0.18	146.422
	0.18 - 1.65	655.556
Summer	0.03 - 0.21	615.132
	0.21 - 0.6	607.794
	0.6 - 1.5	622.286
	1.5 - 15.97	2137.63
Total Annual Potential	0.23 - 0.54	201.63
	0.54 - 3.02	1121.78
	3.02 - 6.30	532.689
	6.30 - 37.9	3541.134

During Winter season most part of the Srivilliputtur block, Vasudevnallur block and Watrap block had received a maximum of 1.65 MCM. All other parts of the basin had received 0.07 MCM of surface water.

During summer season most parts of the Srivilliputtur, Vasudevnallur block and Watrap block had received a maximum of 15.97 MCM of surface water. All other parts of the basin had received 0.6 MCM of surface water. Table 3.9 shows the total runoff distribution during different seasons in the basin. It is observed that northeast monsoon has received a maximum of 584.149 MCM during 2003-2004. Southeast Monsoon receives 78.92 MCM whereas the basin receives a considerable amount during summer season i.e of 169.43 MCM.

Table 3.9 Surface Runoff Variation for different seasons

Area of Vaippar Basin (km^2)	Southwest monsoon runoff (MCM)	Northeast Runoff (MCM)	Winter Runoff (MCM)	Summer Runoff (MCM)	Annual Runoff (MCM)
5423	**78.921**	**584.149**	**5.96**	**169.437**	**838.467**

3.3.3 Groundwater Potential Estimation by Water Table Fluctuation Method

The basin level groundwater resources potential was estimated using ground water level fluctuation method, one of the methods recommended by Groundwater Estimation Committee (GEC). For this study eighty three observation wells were monitored in the Vaippar river basin and Thiessen polygons were constructed for these wells. The monthly water level data for the 75% dependable rainfall year and the fluctuation for each month of this 83 observation wells were calculated. With the influential area of each well, specific yield and fluctuations of each month were used to calculate the potential and change in storage over the entire basin. Water Table Fluctuation Method is used to find out the volume of groundwater.

The formula is given by equation 3.8

$$\text{Groundwater Volume} = S_y \times A \times h \qquad (3.8)$$

Where S_y is the specific yield of the aquifer medium; A is the Area of influence of the well; and H is the level difference between the successive months. The calculated monthly ground water potential variations of the wells for various seasons such as Southwest, Northeast, Winter and Summer are given in Figure 3.24, 3.25, 3.26 and 3.27.

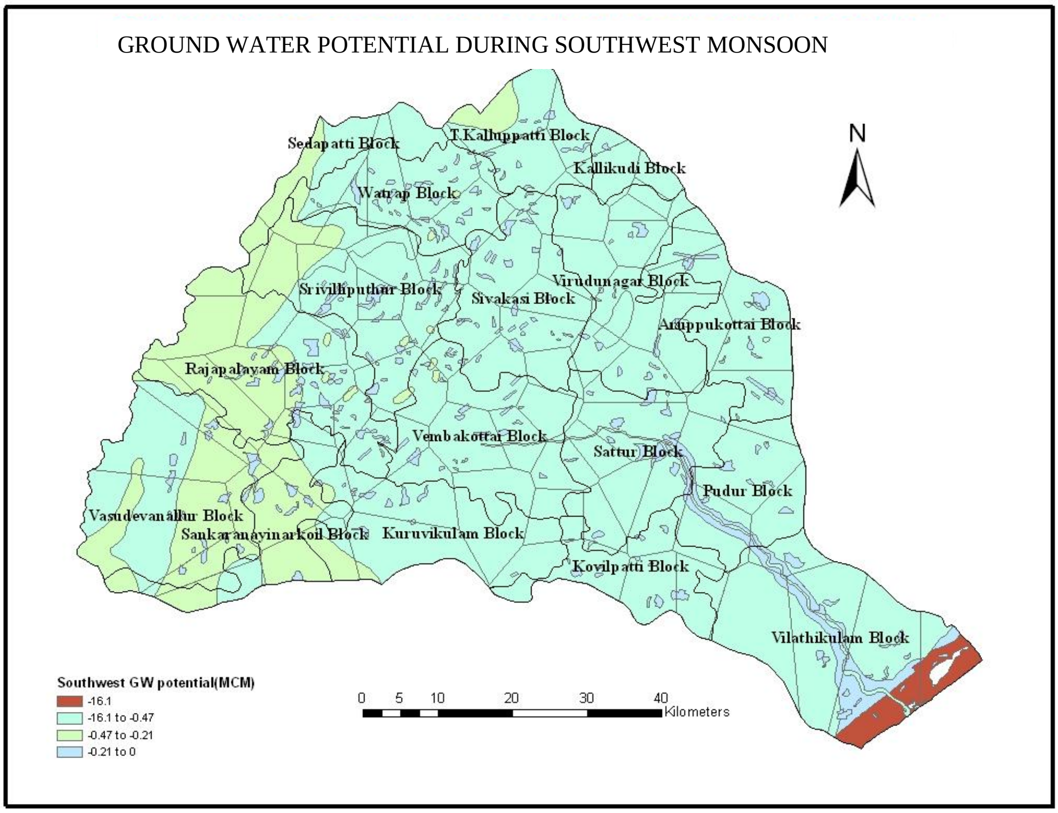

Figure 3.24 Groundwater Potential during Southwest Monsoon (2003-04)

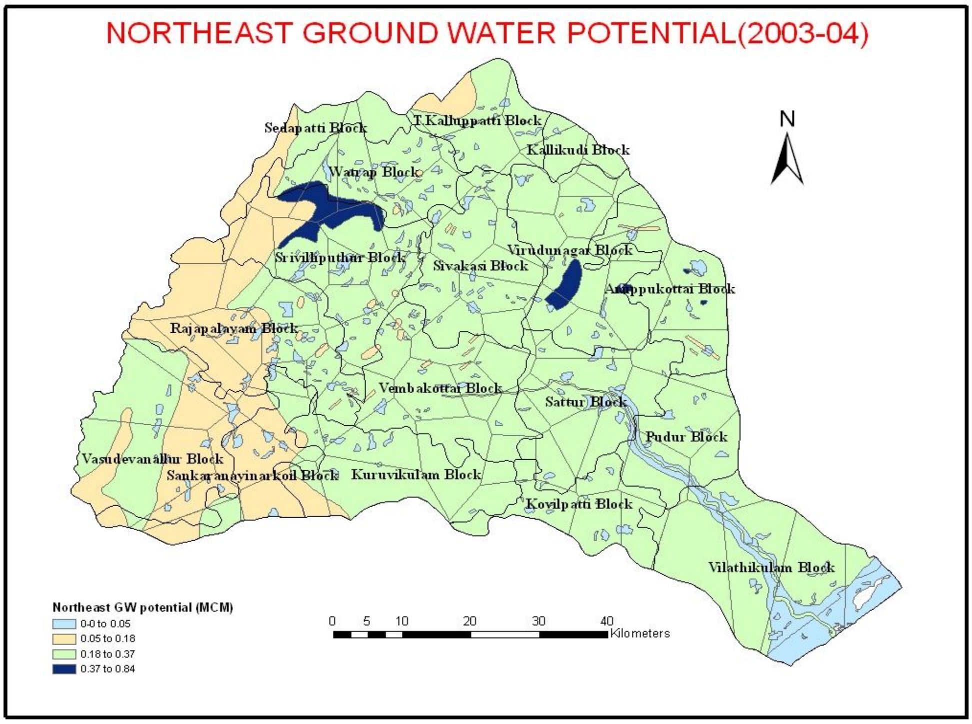

Figure 3.25 Groundwater Potential during Northeast Monsoon in 2003-04

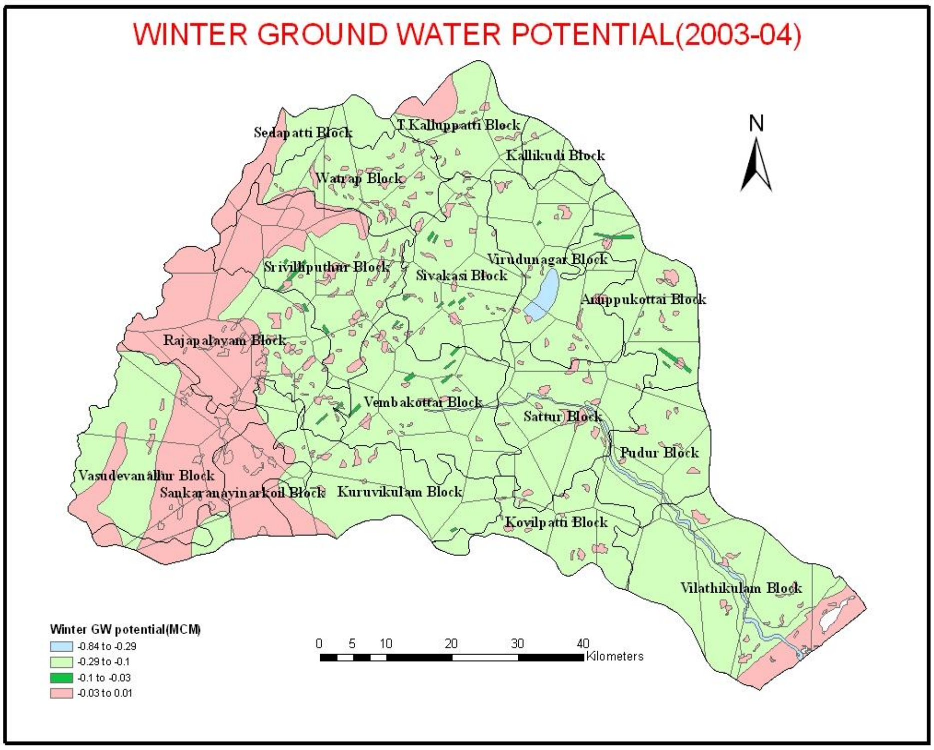

Figure 3.26 Groundwater Potential during Winter Season in 2003-04

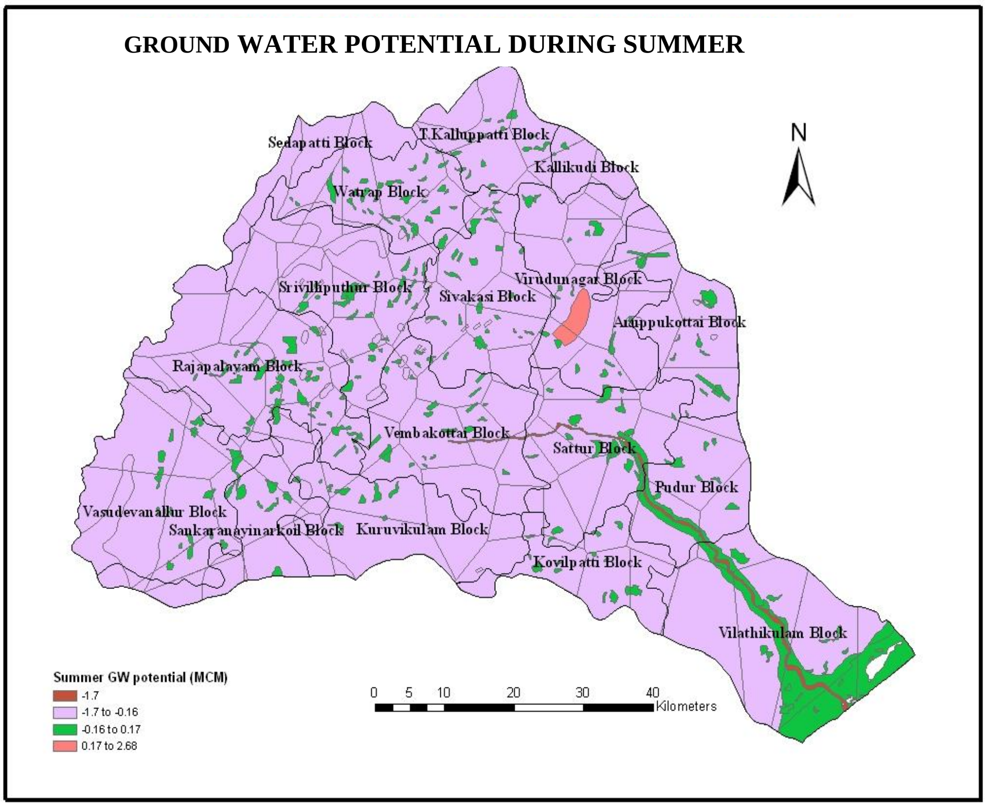

Figure 3.27 Groundwater potential during Summer Season in 2003-04

Through the analysis by groundwater fluctuation method, it was observed that during Northeast Monsoon the Rajapalyam block, Sankarankoil block and some parts of the Vasudevanallur and T.Kallupatti block has got 0.05 to 0.09 MCM of groundwater. Some parts of the Watrap and Virudunagar block has got 0.37 to 0.84 MCM of groundwater. As the basin receives most of its rainfall during Northeast monsoon, the groundwater potential is high due to recharge. During Southwest monsoon almost from all part of the basin shows negative value indicating that more discharge is taking place than recharge as rainfall in this season is very low. During winter season some small portion of the basin has the potential of 0.01 MCM of groundwater. During summer Virudhunagar block has got 0.17 to 2.68 MCM of groundwater potential and all other areas of the basin have negative value because of more extraction of ground water for agriculture and other purposes.

3.4 INFERENCES OF THE BASIN LEVEL STUDY

(i) Rainfall analysis inferred that 50% dependable annual value is 791mm and the corresponding return period is 2 years. Similarly the 75% & 90% dependable rainfall are found to be 629 mm & 560 mm. Vaippar basin receives significant amount of rainfall during Northeast Monsoon period followed by southwest and summer season receives more compared to Winter. In Northeast Monsoon period, spatial significant variation values are from 320 mm to 560 mm. The summer rainfall in Vaippar basin varies from 40 mm to 200 mm. More than 50% area receives rainfall above 130 mm.

(ii) Surface runoff potential assessment of the basin indicates that the annual surface runoff potential is found to be 838.467 MCM. And the surface runoff potential during Northeast Monsoon, Southwest, Summer and Winter are found to be 584.14 MCM, 78.921 MCM, 169.437 MCM and 5.96 MCM.

(iii) Ground water assessment by ground water fluctuation method reveals that the spatial potential variation in the Northeast monsoon varies from 0.05 to 0.84 MCM. As the basin receives most of its rainfall during Northeast monsoon, the ground water potential is high due to recharge. During Southwest monsoon almost from all part of the basin shows negative value indicating that more discharge is taking place than recharge as rainfall in this season is very low.

CHAPTER 4

EXPERIMENTAL SUB-BASIN AND DATABASE DEVELOPMENT

4.1 SUB-BASIN - SINDAPALLI UPPODAI

Sindapalli Uppodai sub-basin is selected as a study area for physically based Rainfall-Runoff modelling at the micro level. The entire sub-basin falls under the semi-arid classification. Sindapalli Uppodai receives drainage from its own catchment. Sindapalli sub-basin consists of 16 tanks, mainly used for irrigation purposes. The tanks are connected by a common drainage and forms cascade of tanks few of them are isolated tanks. The cascade of tanks connected together through the main course, called Sindapalli Uppodai, thereby forming a clustered tank catchment. The index map of Sindapalli Uppodai sub-basin is shown in Figure 4.1.

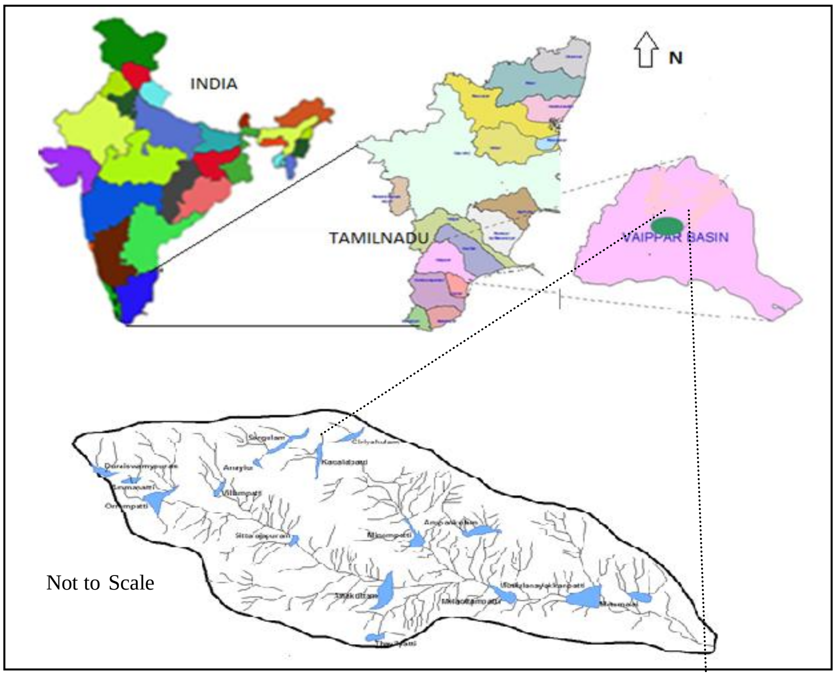

Figure 4.1 Index map of Sindapalli Uppodai sub-basin

The Sindapalli Uppodai sub-basin is a part of Vaippar basin and located between Taluks of Sivakasi and Sattur in Virudhunagar District, Tamil Nadu. The total geographical area of study area Sindapalli Uppodai is 142 km^2. The names of each tank in the tank cluster are given in Table 4.1. The maximum rainwater is collected and stored in these tanks and utilized for the needs of irrigation and drinking water demands through directly as well as recharging ground water aquifers. In the sub-basin, tank irrigation is followed in the vicinity of tanks and well irrigation is practiced in other areas. The Sindapalli Uppodai sub-basin falls in the SOI Toposheet Nos.58 G11 & 58 G15, which is collected from the Survey of India, Chennai.

Table 4.1 List of tanks in the tank cascaded sub-basin

Sl. No	**Tank Name**	**Sl. No.**	**Tank Name**
1	Duraiswamypuram	9	Anupankulam
2	Ammapatti	10	Melaottampatti
3	Oorampatti	11	Muthalanayakkanpatti
4	Villampatti	12	Mettamalai
5	Sittarajapuram	13	Anayiur
6	Anaikuttam	14	Sengulam
7	Minampatti	15	Kattalaipatti
8	Thayilpatti	16	Ciriyakulam

4.2 HYDROMETEOROLOGICAL CHARACTERISTICS

4.2.1 Climate

The climate of the region is semi- arid tropical monsoon type. It has a high mean temperature and a low degree of humidity. The temperatures range from 20°C to 37° C. April, May and June are the hottest months of the year.

4.2.2 Rainfall

Rainfall is the prime source for water. The quantity and distribution pattern decides the availability of surface and ground water potential in a region. The analysis of the spatial and temporal distribution of rainfall will be the initial work undertaken in any water resources estimation activity. Rain gauge placed at Sivakasi, Sattur and Vembakottai covers the entire Sindapalli Uppodai sub-basin. The daily rainfall data were collected for 77 years from State Statistical Department, Chennai. The daily rainfall is converted into monthly and yearly rainfall depths. The yearly rainfall values were presented in Table 4.2. Temporal distribution of rainfall is carried out to understand the variation of rainfall and presented in Figure 4.2. The average annual rainfall for Sindapalli Uppodai sub-basin is 758 mm. The yearly rainfall values were further analyzed for the frequency of occurrence.

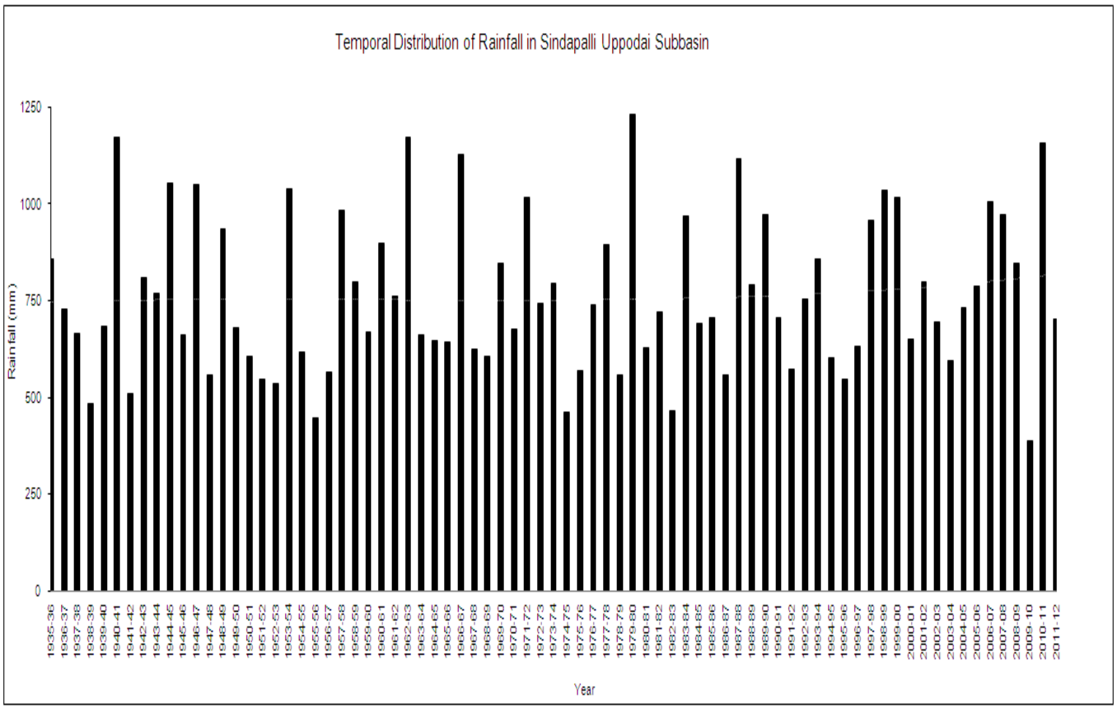

Figure 4.2 Temporal distribution of annual rainfall at Sindapalli Uppodai

Table 4.2 Annual Rainfall for Sindapalli Uppodai sub-basin

Sl. No.	Year	Rainfall (mm)	Sl. No.	Year	Rainfall (mm)
1	1935-36	857	40	1974-75	462
2	1936-37	728	41	1975-76	567
3	1937-38	664	42	1976-77	740
4	1938-39	482	43	1977-78	895
5	1939-40	684	44	1978-79	556
6	1940-41	1171	45	1979-80	1232
7	1941-42	509	46	1980-81	627
8	1942-43	807	47	1981-82	722
9	1943-44	768	48	1982-83	466
10	1944-45	1053	49	1983-84	967
11	1945-46	660	50	1984-85	691
12	1946-47	1050	51	1985-86	706
13	1947-48	557	52	1986-87	559
14	1948-49	935	53	1987-88	1114
15	1949-50	680	54	1988-89	791
16	1950-51	605	55	1989-90	973
17	1951-52	545	56	1990-91	704
18	1952-53	534	57	1991-92	571
19	1953-54	1039	58	1992-93	753
20	1954-55	618	59	1993-94	856
21	1955-56	445	60	1994-95	600
22	1956-57	566	61	1995-96	544
23	1957-58	983	62	1996-97	631
24	1958-59	799	63	1997-98	955
25	1959-60	667	64	1998-99	1036
26	1960-61	898	65	1999-00	1015
27	1961-62	760	66	2000-01	648
28	1962-63	1171	67	2001-02	799
29	1963-64	662	68	2002-03	696
30	1964-65	646	69	2003-04	594
31	1965-66	642	70	2004-05	730
32	1966-67	1125	71	2005-06	788
33	1967-68	625	72	2006-07	1003
34	1968-69	605	73	2007-08	973
35	1969-70	846	74	2008-09	846
36	1970-71	676	75	2009-10	386
37	1971-72	1017	76	2010-11	1156
38	1972-73	744	77	2011-12	700
39	1973-74	792			

4.2.3 Frequency Analysis of Rainfall

The dependability analysis of annual rainfall values of Sindapalli Uppodai sub-basin is carried out in order to identify the dependable year and the corresponding value of annual rainfall. The 77 years annual rainfall data are used in dependability analysis. Weibull's method was used to know the dependable rainfall. This formula is commonly used in hydrology and which avoids the difficulties

Weibul's formula: (T = (n+1)/m).

Where, T – be the return period for a particular rainfall (yrs);
m – be the rank of a particular annual rainfall;
n – be the total number of data available

Values of various dependable annual rainfall and dependability graph are presented in Table 4.3 and Figure 4.3. The 50%, 75% and 90% dependable values of rainfall and its year of occurrence are 722 mm in 1981-82, 606 mm in 1950-51 and 545 mm in 1995-96.

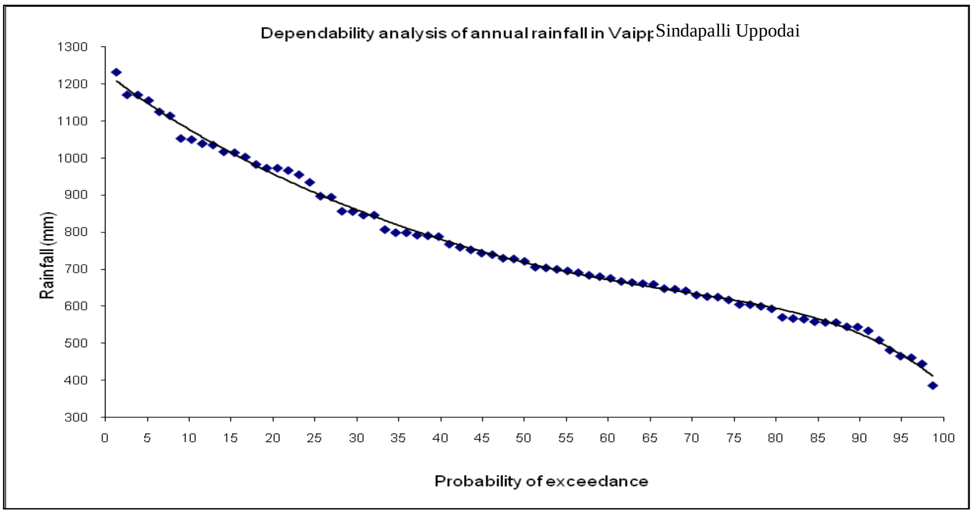

Figure 4.3 Dependability analysis of rainfall of Sindapalli Uppodai

Table 4.3 Dependability analysis of rainfall of the subbasin

Year	Annual Rainfall in mm	Rank	Probability in %	Return period T
1979-80	1233	1	1.28	78
1940-41	1171	2	2.56	39
1962-63	1171	3	3.85	26
2010-11	1156	4	5.13	20
1966-67	1126	5	6.41	16
1987-88	1115	6	7.69	13
1944-45	1054	7	8.97	11
1946-47	1051	8	10.26	10
1953-54	1040	9	11.54	9
1998-99	1036	10	12.82	8
1971-72	1018	11	14.10	7
1999-00	1015	12	15.38	7
2006-07	1004	13	16.67	6
1957-58	984	14	17.95	6
2007-08	974	15	19.23	5
1989-90	974	16	20.51	5
1983-84	967	17	21.79	5
1997-98	956	18	23.08	4
1948-49	935	19	24.36	4
1960-61	898	20	25.64	4
1977-78	895	21	26.92	4
1935-36	857	22	28.21	4
1993-94	856	23	29.49	3
1969-70	847	24	30.77	3
2008-09	847	25	32.05	3
1942-43	808	26	33.33	3
2001-02	800	27	34.62	3
1958-59	799	28	35.90	3
1973-74	793	29	37.18	3
1988-89	791	30	38.46	3
2005-06	789	31	39.74	3
1943-44	769	32	41.03	2
1961-62	760	33	42.31	2
1992-93	753	34	43.59	2
1972-73	744	35	44.87	2
1976-77	740	36	46.15	2
2004-05	731	37	47.44	2

1936-37	729	38	48.72	2
1981-82	722	39	50.00	2
1985-86	707	40	51.28	2
1990-91	705	41	52.56	2
2011-12	701	42	53.85	2
2002-03	696	43	55.13	2
1984-85	691	44	56.41	2
1939-40	685	45	57.69	2
1949-50	681	46	58.97	2
1970-71	676	47	60.26	2
1959-60	668	48	61.54	2
1937-38	665	49	62.82	2
1963-64	662	50	64.10	2
1945-46	660	51	65.38	2
2000-01	649	52	66.67	2
1964-65	647	53	67.95	1
1965-66	643	54	69.23	1
1996-97	631	55	70.51	1
1980-81	627	56	71.79	1
1967-68	626	57	73.08	1
1954-55	618	58	74.36	1
1950-51	606	59	75.64	1
1968-69	605	60	76.92	1
1994-95	601	61	78.21	1
2003-04	594	62	79.49	1
1991-92	571	63	80.77	1
1975-76	568	64	82.05	1
1956-57	566	65	83.33	1
1986-87	559	66	84.62	1
1947-48	557	67	85.90	1
1978-79	557	68	87.18	1
1951-52	546	69	88.46	1
1995-96	545	70	89.74	1
1952-53	535	71	91.03	1
1941-42	509	72	92.31	1
1938-39	483	73	93.59	1
1982-83	466	74	94.87	1
1974-75	462	75	96.15	1
1955-56	446	76	97.44	1
2009-10	387	77	98.72	1

For the rainfall-runoff modelling and groundwater dynamics study in this sub-basin three years of rainfall data are taken i.e from 2009 to 2011. In the water year, 2009 - 2010 (June 2009 to May 2010) the annual rainfall in the sub-basin is 387 mm having a probability of occurrence 98%, and is supposed to be the bad year with respect to rainfall. The annual rainfall in the year 2010- 2011 is 1156 mm having a probability of occurrence as 5% and is found to be a good year. The year 2011 – 2012 is an average year with the rainfall of 701 mm and the probability of rainfall occurrence is 53%.

4.3 DIGITAL ELEVATION MODEL

A topographic model (the DEM) can be constructed using topographic maps, aerial photographs, survey data obtained using conventional and/or GPS, or satellite photos. DEM software uses intelligent algorithms that model the topography, taking into account such simple things as flat water, and vertical cliffs. The elevation is found at certain points and a surface (the ground level) is fitted to the points. Once a DEM model is constructed for an area of interest, it can be used in hydrological modelling for carrying out the analysis.

The term Digital Elevation Model (DEM) is frequently used to refer to any digital representation of a topographic surface. However, most often it is used to refer specifically to a raster or regular grid of spot heights. The DEM is the simplest form of digital representation of topography. A variety of DEMs are available. The resolution, or the distance between adjacent grid points, is a critical parameter. The best resolution commonly available is 30 m, with a vertical resolution of 1 m. The coverage’s of the entire globe, including the ocean floor, can be obtained at various resolutions.

The elevation details of the study area were obtained from various sources such as contours and spot levels from SOI Toposheets, SRTM data, ASTER and Google Earth. Data collected from the above-mentioned sources were fed into the MapInfo GIS Software and the spatial variation of the elevation of that area was created. This will form the basic data source for the creation of DEM of the study area as well as the basin delineation. The spatial variation of elevation of Sindapalli Uppodai Sub-basin was developed with the capabilities of GIS. This spatial variation of elevation is used for the development of the 3-D representation of elevation known as Digital Elevation Model (DEM). The DEM for Sindapalli Uppodai Sub-basin was developed and presented in Figure 4.4.

4.4 DRAINAGE PATTERN

Drainage is the path connecting series of lowest points in the locality chosen by the water to flow. Drainage pattern offers knowledge on spatial extent or distribution of streams and water bodies in the study area through which general hydrology is ascertained and in-turn boundary of sub-watersheds or watershed is also being demarcated. The drainage patterns are controlled by factors such as slope, climate, and vegetation etc and it was developed in ArcGIS by using the SRTM data and toposheets. The drainage network of the tank cascaded Sindapalli Uppodai sub-basin is shown in Figure 4.5 below.

4.5 TANK DETAILS OF STUDY BASIN

The 16 tanks that form the tank cascades in Sindapalli Uppodai were identified from the SOI Toposheets. The manner in which they have

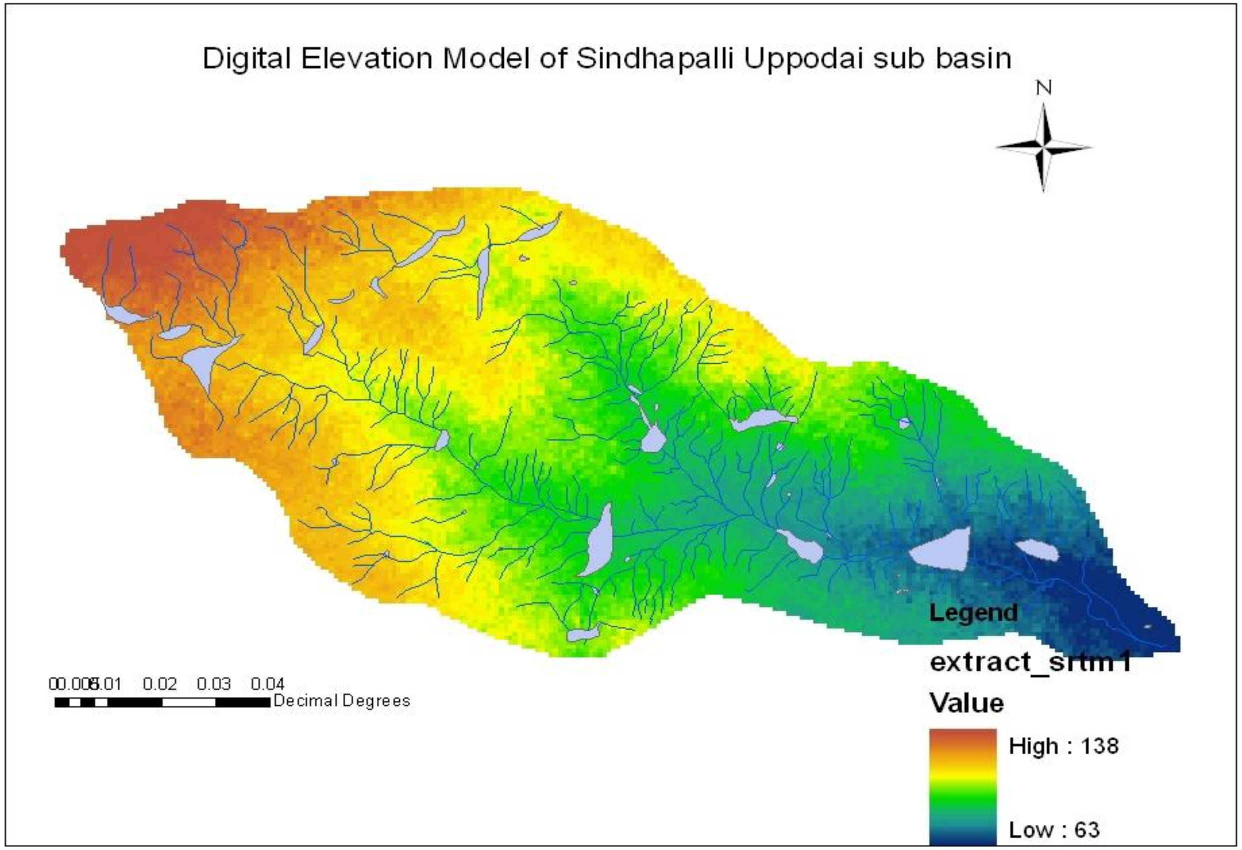

Figure 4.4 Digital Elevation Model (DEM) of Sindapalli Uppodai Sub-basin

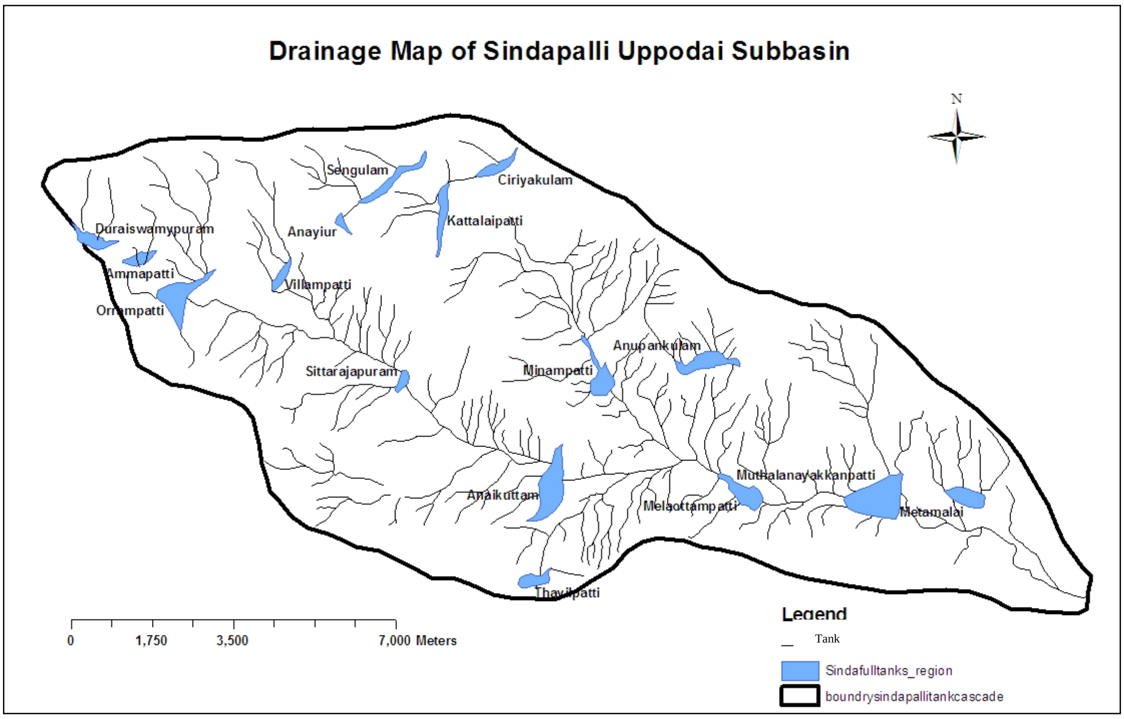

Figure 4.5 Drainage map of Sindapalli Uppodai sub-basin

connected, and their locations are also obtained. By making frequent field visits to the study area, the other details such as number and nature of outlet arrangements, land use pattern in catchment and command areas information's were collected. Field verification of inlet channels and others have been made during the field visit. The description of 16 tanks of Sindapalli Uppodai, selected for this study, including catchment area, water spread area, number of inlet channels and outflow arrangements, etc are given below

The Duraiswamypuram tank is situated in the uppermost part of Sindapalli Uppodai sub-basin. The entire catchment area falls under free catchment category with an area of about 2.92 km^2 and has the water spread area of about 0.2208 km^2. The land use pattern in the catchment area is of mainly agricultural and barren lands. Most parts of the catchment area is covered with red soil. Water enters the tank from North to South direction. It has two inlet channels, two sluices and a surplus weir. Maize, banana, and paddy are the cropping pattern followed in the command area of Durisamipuam tank. The length of the weir is about 17.2 m and the surplus joins the Ammapatti tank.

The Ammapatti tank is the second tank, which has the water spread area of about 0.1293 km^2 and catchment area of about 1.44 km^2. Water drains from North to South direction through two inlet channels. A stepped weir is constructed in North-East portion and the surplus course is connected with Oorampatti tank. Paddy and Maize are the main crops cultivated in the command area. The Ammapatti and Maniampatti are two villages situated very nearer to the bund of the tank.

The Oorampatti tank has one of the largest water spread area of about 0.464 km^2 and catchment area of about 8.28 km^2. The Oorampatti tank has four inlet channels. The surplus course joins with the same drained from Villampatti tank near Maranari Village. There are two supply sluices available for irrigation release. Out of which, one supply slice is in functioning condition.

The Villampatti tank is the fourth tank with a free catchment of about 3.68 km^2 and water spread area of about 0.113 km^2. The Villampatti tank has three inlet channels. The surplus from Villampatti tank is termed as Sindapalli Uppodai. This tank consists of one tank sluice, which is in good condition, used to release water to the command area. In the vicinity of Villampatti tank, significant areas are under cultivation. This tank plays a vital role in uplifting the agricultural activities in this area.

The Sitturajapuram tank is formed at the junction of Sindapalli Uppodai and local drainage by the construction of 2.25 m height and 58.4 m length weir, which has the water spread area of about 0.1335km^2 and free catchment area of about 15.09 km^2. There are two supply sluices which are not functioning since there is no agricultural activity is carried out now a day. This tank water is mainly used for augmenting the groundwater. Near the bund, one pumping station was constructed by Tamil Nadu Water Supply and Drainage Board in order to supply the drinking water to Sivakasi area.

The Anaikuttam tank is an important tank of this subbasin. The Anaikuttam tank is a tank with a maximum water spread area of about 0.578km^2 and free catchment area of about 19.65km^2. The Anaikuttam tank has three inlet channels. The Anaikuttam tank has the largest catchment area as compared with other tanks. There are four tank sluices are available out of which three of them used for irrigation release. The rectangular Weir type surplus arrangement, having length 117 m, was constructed for releasing excess water. The surplus course joins with Melottampatti tank.

Minampatti is located very near to Sivakasi town. The maximum water spread area of Minampatti tank is 0.1 km^2 and has a free catchment area of 17.519 km^2. The catchment area of the Minampatti tank comprises of both urban and barren land use patterns. In the vicinity of the tank, the agricultural activities are intensive. The surplus water is spilled using 55 m length surplus weir. Presently the tank receives urban sewage of entire Sivakasi Town. The drainage pattern is from North-West to East direction. The excess water after spilling out joins with Sindapalli Uppodai and reaches the Melottampatti tank at the downstream side.

Thayilpatti tank is situated in the urbanized area of Kottaiyur Village of Sivakasi Taluk. The catchment area of Thayilpatti comprises of agricultural and urbanized land use pattern. The drainage pattern to the Thayilpatti tank is from South to North direction. The water drains to the Thayilpatti tank through the three pipe culverts, one box culvert and one earthen channel that makes a total of five inlet courses, which draws water from the catchment and feeds the tank. The excess water drains out from the tank through the surplus weir of 12m length and 1.8m height, which is situated in the Northeast corner. The surplus joins the Sindapalli Uppodai at the downstream side of the Anaikuttam Tank.

Anupankulam tank is situated on the northern side of the sub-basin. The entire catchment falls under free catchment category having a geographical area of 5.77 km^2. The catchment area comprises of agricultural land use. The drainage pattern is from North to South towards Anupankulam tank. There are two major inlet channels and five minor inlet channels available. There is no direct sluice release from this tank since both sluices are in damaged condition. The tank serves as a major ground water recharging structure. The groundwater is pumped from an open well nearby the tank area and supplied to Sivakasi town through lorry. The surplus water joins the Melottampatti tank.

Melottampatti tank is one of the important tank contributing for irrigation purpose. It is formed in line with Sindapalli Uppodai mainstream. It has a water spread area of 0.294 km^2 and free catchment area of 17.348 km^2. It receives surplus water from four upper tanks namely Anaikuttam, Minampatti, Thayilpatti and Anupankulam. Among these tanks, Minampatti and Anaikuttam contribute more. The surplus water discharges to Muthalanayickanpatti tank through a 120 m length broad crested rectangular weir. Out of three tank sluices in this tank, two sluices are functioning properly.

Muthalanayakkapatti tank is also an important tank in this Sindapalli Uppodai sub-basin. It has a water spread area of 0.291km^2 and free catchment area of 18.43 km^2. It also receives surplus water from Melottampatti tank. Water drains into the tank from North to South direction. Water is supplied to the command area through two tank sluices present in the tank bund. The surplus water joins the main stream through an 115 m length rectangular weir.

Mettamalai tank is the last tank in this cluster. The water spread area of the tank is 0.127 km^2. The entire catchment falls in free catchment category having a geographical area of 3.363 km^2. There are two inlet channels are available to drain the water from its catchment. The drainage pattern for this tank is also from North to South. The surplus water drains through a 25 m rectangular weir and joins the stream. The tank supply sluices are in damaged condition and hence the irrigation activity is carried out with the help of wells situated in the command area.

Anayiur tank is one of a small tank both in terms of water spread and capacity. It has a catchment area of 2.037 km^2 and water spread area of 0.158 km^2. The drainage pattern is from West to North direction. There is no supply sluice for irrigation release since the existing one is in damaged condition. It is used to recharge the groundwater status of surrounding area. The surplus will join the Sengulam tank at the downstream side.

Sengulam tank is situated on the Northern side of the sub-basin. The drainage pattern is from North West to South East direction. It is located at starting point of urbanized area. It has water spread area of 0.228 km^2 and free catchment area of 4.602 km^2. There is no direct irrigation release from this tank. The surplus weir is also damaged and now it is completely replaced with bund. Hence no spilling is also allowed from this tank.

Kattalaipatti tank situated at starting point of Sivakasi town. Drainage flows from West to East direction. The catchment area is 3.709 km^2 and water spread area is 0.252 km^2. There is no direct irrigation release from this tank. Agricultural activities area carried only on some parts of the catchment. The length of surplus weir situated on the Northern part is 12 m. No supply sluices are present. The stored water is mainly useful for recharging the groundwater level. The surplus from this tank will contribute to Ciriyakulam tank located on the downstream side.

Siriyakulam tank is located in the Northern part of the sub-basin and urbanized catchment. The water spread area is 0.131 km^2 and catchment area is 1.208 km^2. Since this tank is situated in the completely urban area, sewage from the surrounding area was kept stored here. This tank has no command area as well as a surplus weir. Some of the tank pictures are shown in Figure 4.6.

4.6 DATABASE DEVELOPMENT

The study of hydrological modelling using physically based model and land evaluation for crop suitability assessment requires extensive field work and a GIS database of inter-related information in the form of spatial maps and attribute data. As this study requires voluminous spatial and non-spatial data, it involves with a large number of both primary and secondary data collection, analysis and GIS database development. A scientific database is one of the basic requirements of any modelling process. Both spatial and attribute data are required to create the GIS database. The database consists of physical, meteorological and hydrological characteristics of the sub-basin and is collected through field observation, questionnaire survey and from various departments both in the form of paper maps, charts and tables. ArcGIS software was used in preparing the GIS database.

Muthalanayakkanpatti tank

Minampatti tank

Melottampatti tank

Ammapatti tank

Thayilpatti tank

Sittarajapuram tank

Figure 4.6 Pictures of study tanks in the Sindapalli Uppodai sub-basin

4.6.1 Secondary Data Collection

Secondary data pertaining to the Sindapalli Uppodai such as Toposheets, watershed maps, Remote sensing data, geology, geomorphology, population data, soil and crop information were collected from various departments. Daily rainfall data, pumping test data, climatological data and Lithology of the area were also collected. The details of the type of secondary data collected with the source are given in Table 4.4.

Toposheets, ASTER data were used for the preparation of drainage map. This map helps in defining the boundary of the study sub-basin. Thematic maps of geology, geomorphology and soil map help in setting up the database of the unsaturated and saturated zone of the physically based model. Distributed land use map and degraded land maps were prepared using Remote sensing data.

Climatological data and crop details were used in building up the unsaturated zone of the MIKE SHE model for Evapotranspiration (ET) calculation and for defining crop parameter details. Soil information regarding the soil series types of the sub-basin was obtained from Tamil Nadu Agricultural University, which provides information regarding the depth of soil profile and other properties like texture, rootable depth, organic matter content and salinity.

The study area consists of nineteen type of soil series. This helps in developing the unsaturated zone database for MIKE SHE. Using GIS, the spatial variation of soil cover over the sub-basin were prepared for various properties.

Table 4.4 Secondary data collection with the source

Sl. No.	Secondary Data	Source
1	Toposheets 1:2,50,000 1:50,000 - 1:25,000	Survey of India, Guindy, Chennai
2	Remote sensing data RESOURCESAT LISS IV	National Remote Sensing Agency (Hyderabad)
3	ASTER data	Advanced Spaceborne Thermal Emission and Reflection
4	Daily rainfall data for 38 years	Indian Meteorological Department State Statistical Department, Chennai
5	Thematic maps like Geology, Geomorphology, Soil etc.	Surface and Ground Water Data Centre and Institute of Water Studies, Taramani
6	Piezometric level data, Watershed maps	Institute for Water Studies, PWD, Chennai
7	Lithology of the area	Central Ground Water Board, Chennai
8	Climatological data from Kavalur station	Kavalur Meteorological Station, PWD Virudhunagar.
9	Agricultural practices and Crop information	Agriculture and Agriculture Engineering Department
10	Tank details and Hydraulic particulars of each tank	Public Works Department, Virudhunagar and field investigation.
11	Village and Population data	Directorate of Statistics, Collectorate office, Virudhunagar district
12	Specific yield	Pumping test data from INCID Research Project, Centre for Water Resources.
13	Soil Information comprising series type, depth, texture, organic matter content etc	Tamil Nadu Agricultural University, Coimbatore.

4.6.2 Primary Data Collection

The study of water resource potential assessment and rainfall runoff modelling using the physically based model of Sindapalli uppodai subbasin requires extensive field work, a large number of both primary and secondary data collection and analysis, GIS database development. A scientific database is one of the basic requirements of any modelling process. Both spatial and attribute data are needed to create the GIS database. The database consists of physical, meteorological, and hydrologic characteristics of the basin and which are collected in various departments both in the form of paper maps and tables. Arc GIS 9.0 and Map Info 6.0 both used in preparing the GIS database required to do this research project.

4.6.2.1 Tank Capacity Survey using GPS

The capacity of each tank at different elevations will be the prime factor in determining the water availability as well as volume of water reached during a particular rainfall event. First of all, scales were drawn on the surplus weir and tank sluices to measure the stage on the tank. The capacity survey of each tank is carried out by using GPS as well as conventional engineering survey instruments. GPS system receives information with the help of satellites revolving around the globe. Elevation data of tank bed were obtained with the help of Differential GPS system. After that elevation contours of tank bed were developed at 0.1 m contour interval. With the capabilities of GIS, areas between two contour intervals were calculated and similar contour interval areas were added as shown in Figure 4.7 for Ammapatti tank. Contour areas were grouped resulting water spread area at a particular stage. From the tank stage and corresponding water spread area, the tank volume was calculated and a graph was plotted, known as Stage Vs Capacity Curve, for all the sixteen tanks. The developed Stage Vs Capacity curves for six of the tanks were presented in Figure 4.8.

4.6.2.2 Tank Particulars

Details of hydraulic particulars of the tank were obtained with the help of site investigation, ground survey, GPS & GIS techniques and presented in Table 4.5.

Table 4.5 Tank Particulars of Sindapalli Uppodai Sub-basin

Sl. No.	Tank	Catchment Area (km^2)	Water spread Area (km^2)	Capacity (Mm^3)	Type of Weir	Length of Weir (m)	No. of Sluice
1	Duraiswamypuram	2.583	0.189	0.558	Rectangular	17.2	2
2	Ammapatti	1.911	0.108	0.267	Stepped	19.6	2
3	Oorampatti	6.667	0.481	1.093	Rectangular	26.6	1
4	Villampatti	4.062	0.163	0.312	Stepped	43.9	1
5	Sittarajapuram	15.436	0.072	0.219	Rectangular	58.4	1
6	Anaikuttam	13.743	0.252	1.444	Rectangular	117.0	2
7	Minampatti	17.519	0.100	0.189	Rectangular	55.0	1
8	Thayilpatti	3.349	0.191	0.313	Rectangular	17.0	0
9	Anupankulam	5.770	0.335	0.842	Rectangular	25.0	2
10	Melaottampatti	17.348	0.294	0.735	Rectangular	120.0	3
11	Muthalanayakkanpatti	18.430	0.291	1.365	Rectangular	115.0	2
12	Mettamalai	3.363	0.126	0.228	Rectangular	25.0	1
13	Anayiur	2.037	0.158	0.190	***	***	1
14	Sengulam	4.602	0.228	0.486	***	***	2
15	Kattalaipatti	3.709	0.252	0.577	Rectangular	12.0	0
16	Ciriyakulam	1.208	0.131	0.238	***	***	0

Total overland tank storage capacity = 9.056 MCM

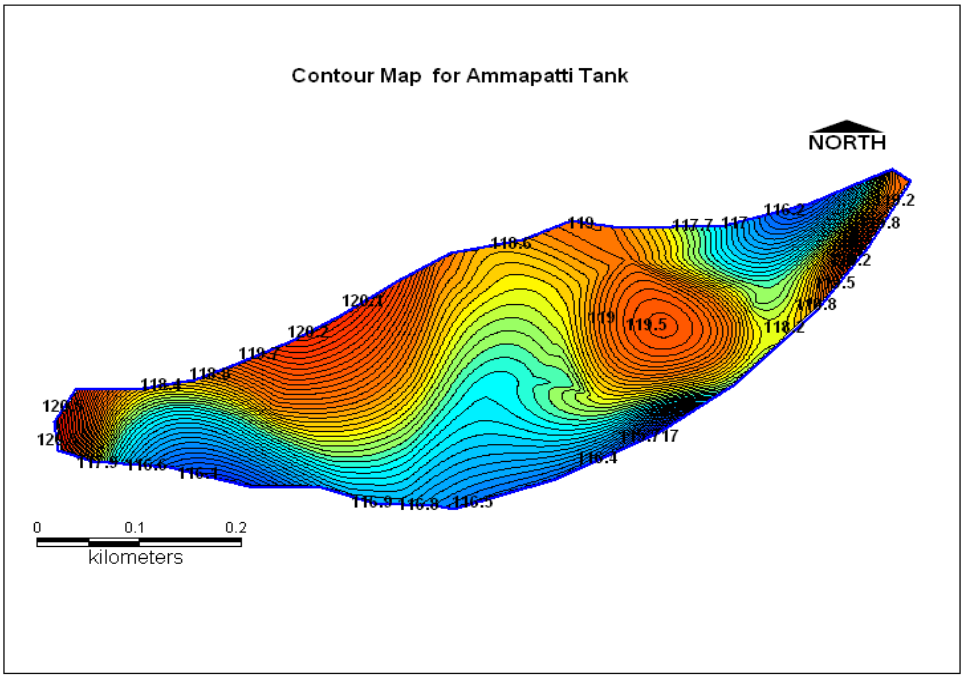

Figure 4.7 Contour Map of Ammapatti Tank

4.6.2.3 Stage Vs Discharge Curves

`The discharge through surplus weir depends upon length of the weir, head over the crest, the width of weir, the material used for the construction. All the above data were obtained for each tank surplus weir during the data collection phase. The discharge through weir is calculated using the formula

$$Q = 2/3\ C_d\ (\sqrt{2}g)\ L_{eff}\ H^{3/2} \qquad \text{-------} \ (4.1)$$

Where, Q – discharge over surplus weir (m^3/s);

C_d – coefficient of discharge;

L_{eff} – effective length of the weir (m); and H – head over crest (m)

The effective length of the weir is calculated with the consideration of end contractions taking place at both ends. According to Francis the effect

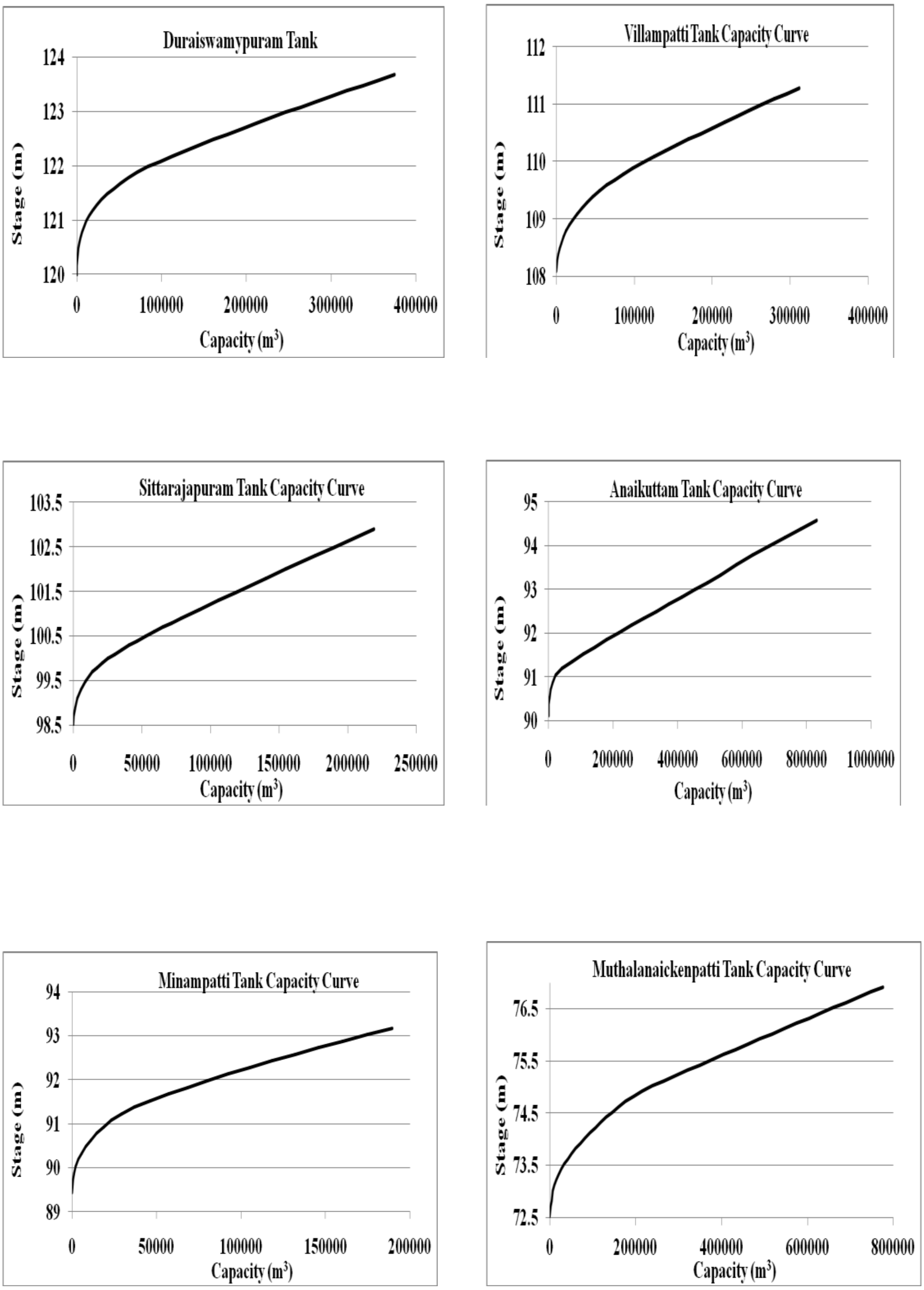

Figure 4.8 Stage Vs Capacity curve of the irrigation tanks

of end contractions will be 0.1 times the head over crest for each end. Hence, the effective length of weir is obtained by,

$$L_{eff} = L - (n*0.1*H) \quad \text{-------} \quad (4.2)$$

Where, L –actual length of weir (m);
n –number of end contractions

Then by considering stage and corresponding discharge the Stage Vs Discharge Curve for tank surplus weir was developed for each tank and curves for three tanks were presented in Figure 4.9. This Stage Vs Discharge curve was used to estimate the change in storage and outflow hydrograph at the end of tank routing.

4.6.2.4 Tank Water level data

Measurement of water level or stage of the tank can be made through scales which are drawn permanently from the deepest points of sluices, weirs and culverts by paint using a calibrated scale as given in Figure 3.8. Measurement of levels from a permanently drawn scale results in the accurate estimation of water level data. For each of its stage or water level, the corresponding water spread area and the tank volume can be calculated from the contour map of the tank. Scales were drawn in the deepest sluices, weir and culverts in order to measure the tank water level, to determine the water stored in the tanks, and to calculate the surplus taken place from each tank. The water level in each tank is monitored in tanks on weekly basis from 2008 to 2011. Scales were drawn by paint with the calibration as shown in Figure 4.10.

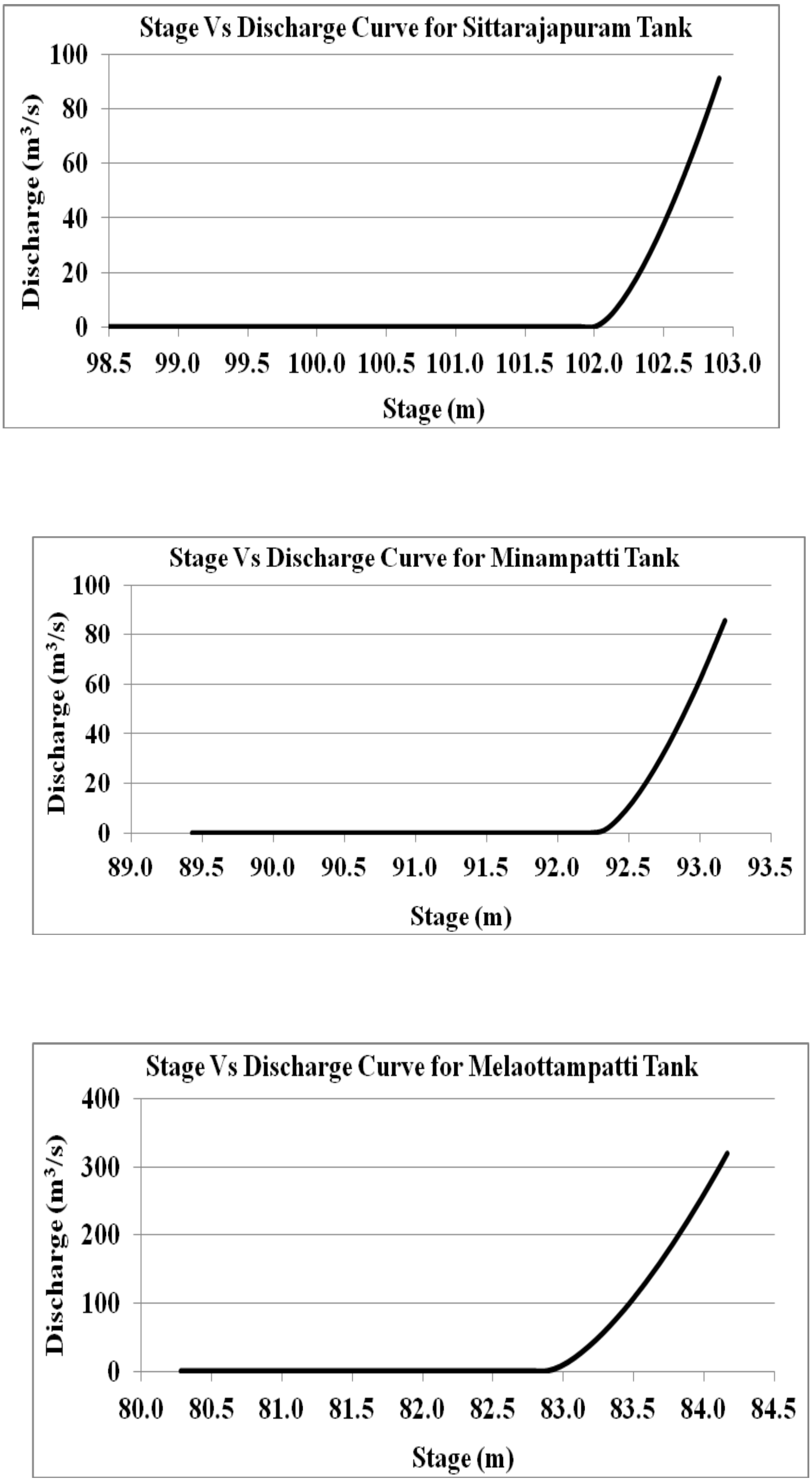

Figure 4.9 Stage Vs Discharge Curve of tank surplus weirs

Figure 4.10 Scales drawn in the sluices, culverts and weirs

4.6.2.5 Soil Mapping

Soil texture is a soil property used to describe the relative proportion of different grain sizes of mineral particles in a soil. Particles are grouped according to their size into what are called soil separates. These separates are typically named clay, silt, and sand. Classifications are typically named for the primary constituent particle size or a combination of the most abundant particles sizes. A fourth term, loam, is used to describe a roughly equal concentration of sand, silt, and clay and leads to the naming of even more classifications. Determining the soil textures is often aided with the use of a soil texture triangle. Soil texture triangle, showing the 12 major textural classes, and particle size scales as defined by the USDA.

To know the distribution of soil within the study area, soil samples from various points were collected. To understand the spatial distribution of soils, samples were collected from 52 points covering the entire Sindapalli Uppodai sub-basin. This is used to prepare the soil map of the study area by considering the variation of soil from closer samples. Textural analysis of soil was carried out for the samples collected and for this, a wet analysis method was adopted. Based on the textural classifications the type of soil was identified. Soil map of Sindapalli Uppodai sub-basin is prepared with the help of GIS. This will give the spatial distribution of soils in the study area.

4.6.2.5.1 Wet Analysis of Soil

The collection of soil was carried out with the help of Core Cutter. The collected soil samples were air dried separately and further used to carry out textural classification. A 10 g sample of the air-dried soil was placed in a small beaker. A pinch of Sodium Hexa Meta Phosphate, a dispersing agent is added to isolate the clay particles bonding together or with the other size fractions a small quantity of de-ionized. Water is added to the beaker and kept for a few minutes the soil sample is then poured on to a 230 ASTM mesh and washed using small quantities of water, in such a way the washings were collected carefully in a container kept underneath.

After the soil was thoroughly washed the contents of the lower container are transferred to a 1000 ml measuring jar and made up to 1000 ml be adding de-ionized water. Time is noted as soon as the agitation is stopped and a 20 ml sample of the suspension is pipetted into 50 ml beaker (A) after exactly 123 minutes the pipette should be in the centre of the jar and inserted to in such a way that its tip is between the graduation makes as 500 to 600 ml on the jar, at the time of extracting the suspension. The soil sample retained on the mesh is transferred fully into another 50 ml beaker (B). The beakers containing the soil sample and the sample of suspension are dried in an oven and weight of the dried in each of them is taken. After obtaining these details the values were fed into soil texture triangle to identify the soil type and results were presented in Table 4.6 with its soil sample location information. The soil texture and series information are then verified with the data obtained from Tamilnadu Agricultural University.

4.6.2.5.2 Soil Mapping using GIS

The soil testing results give the type of soil present at a particular location. These data were fed into GIS to know the spatial variation of soil over the Sindapalli Uppodai sub-basin. The spatial soil distribution map with its soil series was developed and presented in Figure 4.11. After creating the soil map, the extent of each soil type was calculated with the capabilities of GIS. The spatial distribution of soil and land use collectively applied to estimate the curve number value of a particular area.

Table 4.6 Location of Soil Sampling site & its Soil type

Sl. No.	Sample Labels (based on locations)	Type	Sl. No.	Sample Labels (based on locations)	Type
1	Muthu firework	Sandy Loam	27	30 Muthalanaicken Catchment	Sandy Loam
2	Duraiswamypurm end	Sandy Loam	28	24 Melottampatti	Sandy Loam
3	V4 Periyapottalpatti	Sandy Loam	29	Sengulam Command	Silt Loam
4	V5 Villampatti command	Sandy Loam	30	32 Chinnakamanpatti	Silt Loam
5	V2 Villampatti catchment	Sandy Loam	31	1 Visvanatham sivan koil	Silt Loam
6	Near Duraiswamypurm surplus	Silt Loam	32	Podureddypatti	Sandy Loam
7	Minampatti left bank surplus	Silt Loam	33	Kattalaipatti	Silt Loam
8	20 Metamalai catchment	Sandy Loam	34	V3 Periyapottalpatti	Silt Loam
9	18 Anupankulam command	Silt Loam	35	11 Ammapatti	Sandy Loam
10	5 Anaikuttam upstream	Loamy Sand	36	Duraiswamypuram command	Sandy Loam
11	10 Ammapatti command	Sandy Loam	37	28 Muthalanaickkenpatti	Silt Loam
12	3 Annaikuttam agri field	Sandy Loam	38	Sengulam command	Sandy Loam
13	6 Near Causeway	Sandy Loam	39	1 Near Drip Field	Silt Loam
14	4 Annaikuttam near surplus	Sandy Loam	40	2 Munkundanpatti	Silt Loam
15	Villampatti catchment interior	Sandy Loam	41	3 Sitturajapuram	Silt Loam
16	12 Oorampatti catchment	Sandy Loam	42	4 Oorampatti Railway Line	Sandy Loam
17	Anaiyur command	Sandy Loam	43	Oorampatti Catchment Interiar	Silt Loam
18	Anupankulam Catchment	Silt Loam	44	Duraiswamypuram Catchment	Sandy Loam
19	V 8 Anaiyur Catchment	Loamy Sand	45	7 Ayyanar Colony	Silt Loam
20	Maranari	Sandy Loam	46	8 Peranayickenpatti Junction	Silt Loam
21	16 Minampatti command	Silt Loam	47	9 Chinnakamanpatti interior	Silt Loam
22	17 Minampatti command	Sandy Loam	48	10 Perapatti	Silt Loam
23	V 0 – Poolavoorani	Silt Loam	49	11 Parapatti	Silt Loam
24	V 7 Anaiyur bus stand	Silt Loam	50	Sivakasi to Thiruthangal Road	Silt Loam
25	26 Melaottampatti	Silt Loam	51	Metamalai command area	Sandy Loam
26	Thayilpatti catchment bus stand	Silt Loam	52	Sindapalli	Sandy Loam

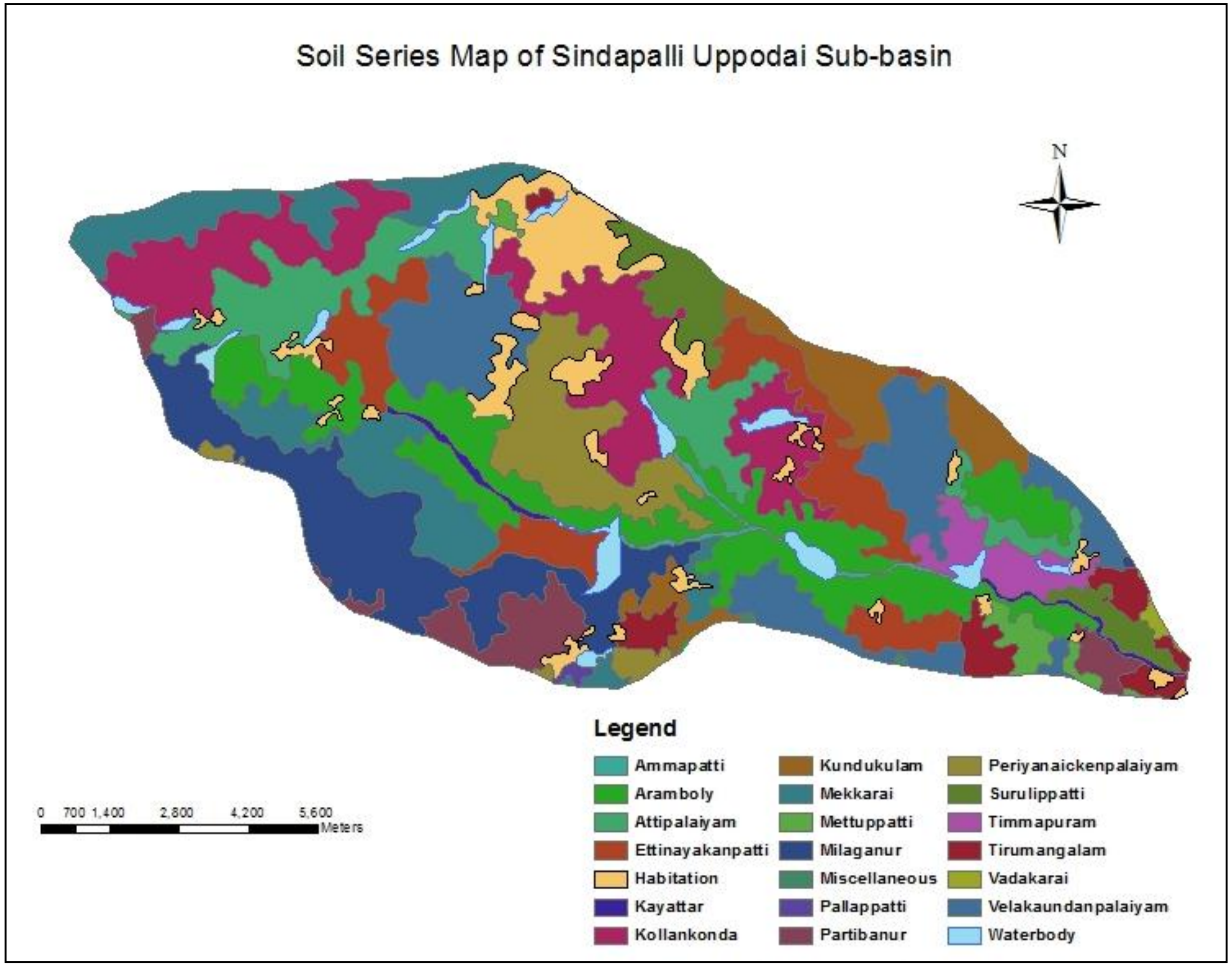

Figure 4.11 Soil Distribution Map of Sindapalli Uppodai Sub-basin

4.6.2.6 Land Use Mapping

The land use pattern of catchment plays a vital role in determining the runoff generation both in terms of volume and time. Land use map of the Sindapalli Uppodai sub-basin was created with the help of high-resolution Resourcesat data. First of all, various land use classification were based on supervised classification with the ground ruth verification data. Based on the land use type the entire region was classified into five categories. The geographical area of each land use pattern was calculated with the help of GIS software. The land use distribution of the sub-basin was given in Table 4.7.

Table 4.7 Land Use type in Sindapalli Uppodai Sub-basin

Sl. No	Land Use Type	Area (km^2)	%
1	Barren	14.619	10.47
2	Building and Industrial	27.900	19.89
3	Shrub land	78.995	55.18
4	Agriculture	16.832	11.77
5	Water bodies	3.766	2.69
Total		**142.112**	**100.00**

Out of five classifications, shrubland consists of dense bushes and sparse bushes contribute around 55 % of a total area covering most of the sub-basin. Residential and industrial buildings type of land use covers about 19% area. Water bodies such as lakes and small pond occupy about 2.7 % of total sub-basin area. The agricultural practice was classified into the Intensive Agricultural area and Non-Intensive Agricultural area. Since the Sindapalli Uppodai sub-basin receives less rainfall, the agricultural activities were taking place only in the vicinity of the tank (both catchment and command areas) and their total area was around 12%. The spatial distribution of land use pattern over the Sindapalli Uppodai sub-basin was developed using GIS and presented in Figure 4.12. Sub-catchment vice land use distribution was also digitized. This was used to estimate the SCS Curve Number (SCS-CN) for the corresponding tank catchment.

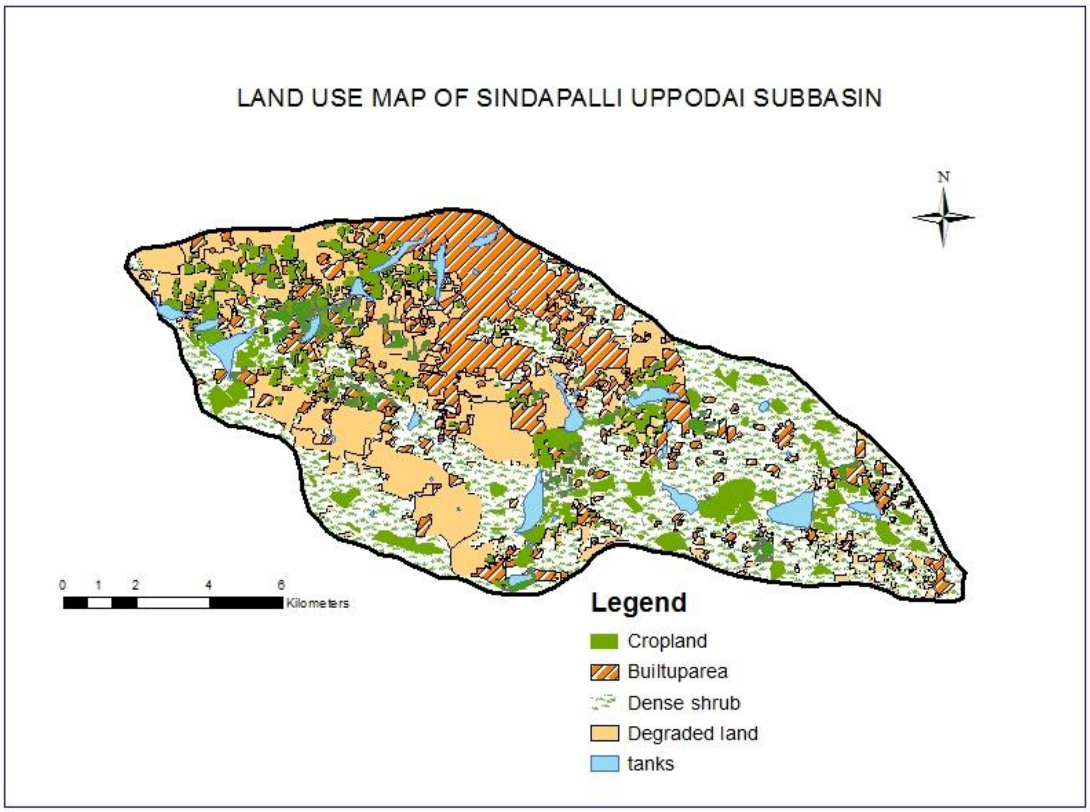

Figure 4.12 Land Use Map of Sindapalli Uppodai Sub-basin

4.6.2.7 Pumping Test Conducted

Pumping test was done for determining the discharge rate of the aquifer. The long duration pumping in the hard rock aquifer is difficult to perform like the alluvial confined aquifer. So, constant discharge pumping rate is considered by the preliminary test in the study area. The time and discharge are fixed as 100-130 minutes and 200-230 lpm respectively based on the availability of water in the well. During the preliminary investigation, two location were finalized namely Vettrilaioorani and Oorampatti. The equipments like pressure gauge and Water flow meter were purchased for conductance of pumping test in the field as shown in the Figure 4.13.

The procedures for the pumping test are as follows

i. Water is pumped from the dug well at a constant discharge for certain time.

ii. The effect of pumping i.e. drawdown is measured in the pumping dug well.

iii. Recovery is measured after the pumping is stopped.Recovery and drawdown are analyzed by the applicable method.

To calculate the Specific Yield (S_y) is given in Eqn 4.3.

$$s_y = \left(\frac{v_y}{v_b} \right) \times 100 \qquad \text{---- (4.3)}$$

Where; V_y is Volume of water drained out,

V_b is The total volume of aquifer material dewatered,

S_y is Specific Yield

Estimation of specific yield is calculated by pumping test in the study area. From the test, Specific yield value was calculated for computation of rainfall recharge in water level fluctuation method. One such test conducted in Oorampatti is presented here.


Figure 4.13 Photographs of Pumping test conducted in the field

i. Location: Oorampatti
ii. Constant Discharge: 500 lpm
iii. Static Water Level: 4.12m.
iv. Dimension of well: 7.5m x 7.5m

The recording since pumping started and the recordings since pumping stopped are given in Table 4.8.

Specific Yield (S_y) for Oorampatti is calculated as

$$S_y = (75/294.18) \times 100 = 25\ \%$$

Table 4.8 Recordings since Pumping started and pumping stopped

Time (min)	Depth of Measuring (m)	Observed Drawdown (m)
0	4.12	0
1	4.12	0
2	4.13	0.01
3	4.14	0.02
4	4.16	0.04
5	4.17	0.05
6	4.19	0.07
7	4.21	0.09
8	4.22	0.1
9	4.23	0.11
10	4.24	0.12
12	4.27	0.15
14	4.29	0.17
16	4.31	0.19
18	4.33	0.21
20	4.35	0.24
24	4.38	0.26
28	4.41	0.29
32	4.44	0.32
36	4.48	0.36
40	4.51	0.39
45	4.54	0.42
50	4.57	0.45
60	4.62	0.5
70	4.68	0.53
90	4.8	0.68
110	4.93	0.81
130	5.07	0.95
150	5.23	1.01

Time (min)	Depth of Measuring (m)	Residual Drawdown (m)
0	5.23	1.01
1	5.22	1
2	5.21	0.99
3	5.2	0.98
4	5.19	0.97
5	5.18	0.96
6	5.18	0.96
7	5.17	0.95
8	5.16	0.94
9	5.15	0.92
10	5.14	0.93
12	5.11	0.9
14	5.08	0.87
16	5.05	0.84
18	5.02	0.81
20	4.99	0.78
24	4.95	0.74
28	4.91	0.7
32	4.87	0.66
36	4.82	0.61
40	4.77	0.56
45	4.72	0.51
50	4.67	0.46
60	4.61	0.4
70	4.56	0.35
90	4.49	0.28
110	4.4	0.19
130	4.31	0.12
150	4.2	0.02

4.6.2.8 Geophysical Survey

A geophysical survey was carried out to find the lithology or hydrogeologic characteristics of the study area. Among various geophysical methods, Electrical Resistivity method was chosen because of easy in operation. In this method, the electrical current is introduced into the ground by two or more current electrodes and a potential difference is measured between two points suitably placed with respect to the current electrode. In this study vertical Electrical sounding is carried out to find out different layers in the aquifer using Schlumberger array electrode arrangement.

An electrical resistivity survey was conducted at nine locations in the study area. The places covered are Duraisamypuram, oorampatti, Thulukampatti, Alamartupatti, Muthalnayakanpatti, Melottampatti, Vetrilaioorani, Rediapatti, Venkatachalapuram. The resistivity survey carried in the study area is shown in Figure 4.14.

Geologically the area is formed by hard crystalline of lava solidified mainly of sedimentary and metamorphism rock structure. During the field visit, it was found that the major part of the study area is covered by gneissic groups of rocks. The sub-basin is underlined by both porous and fissured formations, unconsolidated and semi-consolidated formations. Granitic- Gneiss rocks constitute most in the aquifer systems of the sub-basin. From the investigation in the observation wells, it was found that the aquifer formation is highly porous, fractures and fissured and the picture of some of the observation wells are shown in Figure 4.15

Figure 4.14 Photographs of Resistivity Survey carried in the study area

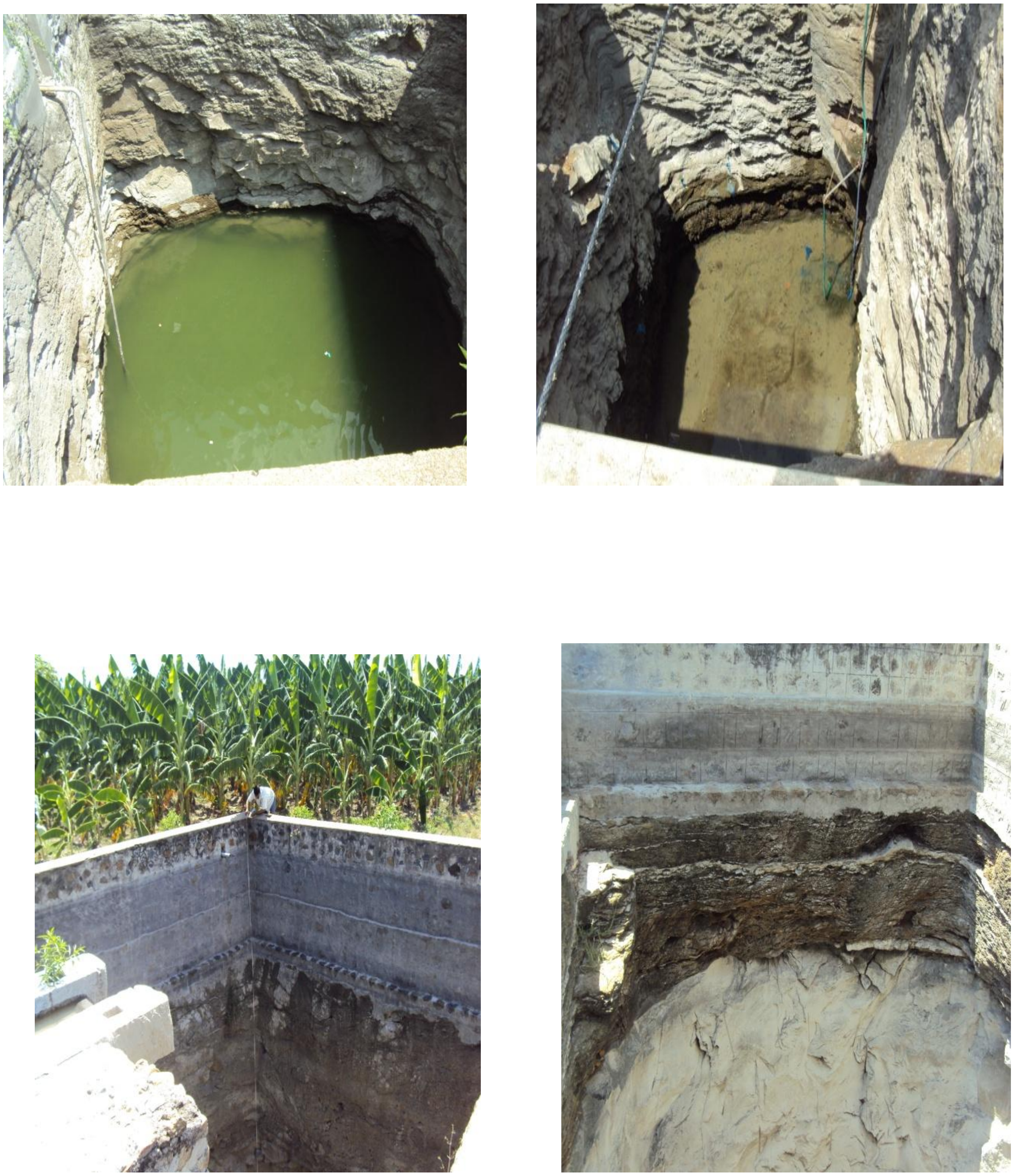

Figure 4.15 Picture of observation wells in the study area

4.6.2.9 Well Inventory Survey

Well Inventory Survey has been done for identifying the tube wells and open wells in the study area. It has been done with the help of CARTOSAT Remote sensing data, Google Earth and field survey. The identified open wells and tube wells are then mapped in GIS which is shown in Figure 4.16.

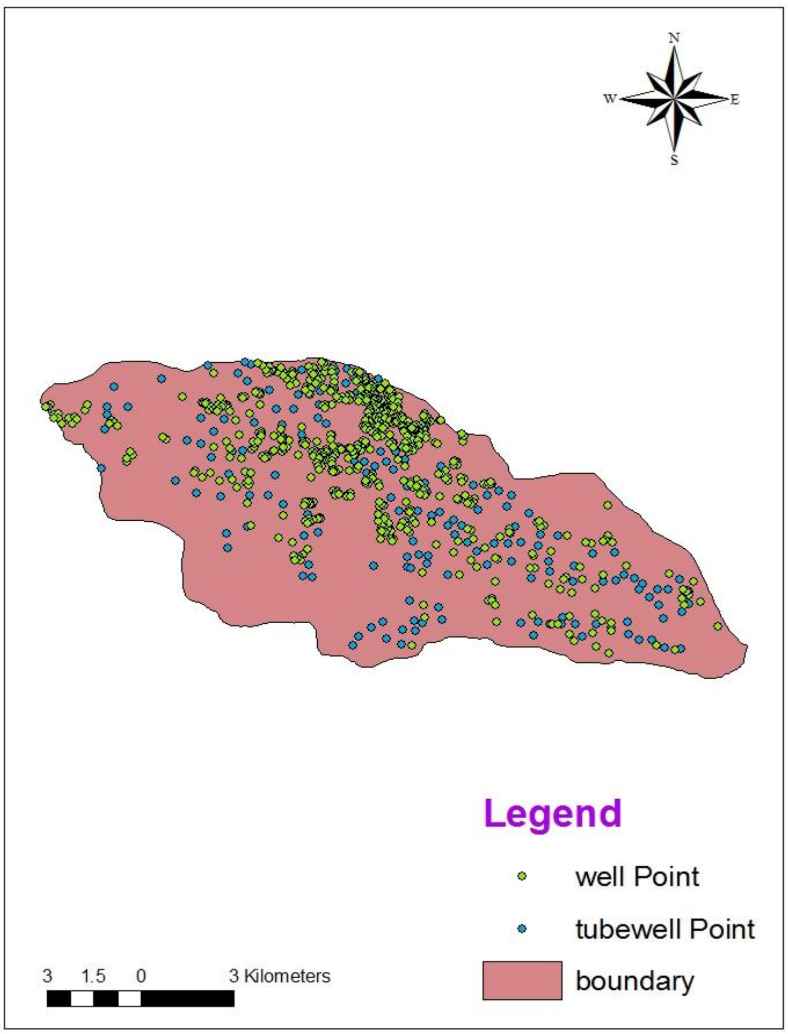

Figure 4.16 Location of tubewell and open well in the study area

4.6.2.10 Observation and pumping wells water level data

The collection of water-level data over one or more decades is required to compile a hydrologic record that encompasses the potential range of water-level fluctuations in an observation well and to track trends over time. Within the sub-basin, 71 number of both pumping and observation wells were identified for the monitoring of groundwater levels. Weekly water level observations are made in these wells during every week to access the elevation of the existing water table in different areas of the sub-basin.

The water levels are observed to monitor periodic water level changes, fluctuations due to recharge and discharge conditions. The selected groundwater wells are connected with respect to MSL of the ground level of each well using the GPS data. Of the 71 wells selected in which 14 wells are observation wells and 57 wells are pumping wells. The weekly ground water levels were collected from October 2008 to March 2012 and database were created in GIS. Well location map of the selected 71 wells for measuring the water level data in the study area is shown in the Figure 4.17.

4.7 SUMMARY

Rainfall-Runoff modelling involves various data of both spatial and tabular form pertaining to the catchment. In this study, both primary and secondary data required for the rainfall-runoff modelling were collected and a GIS database was created for Sindapalli Uppodai sub-basin

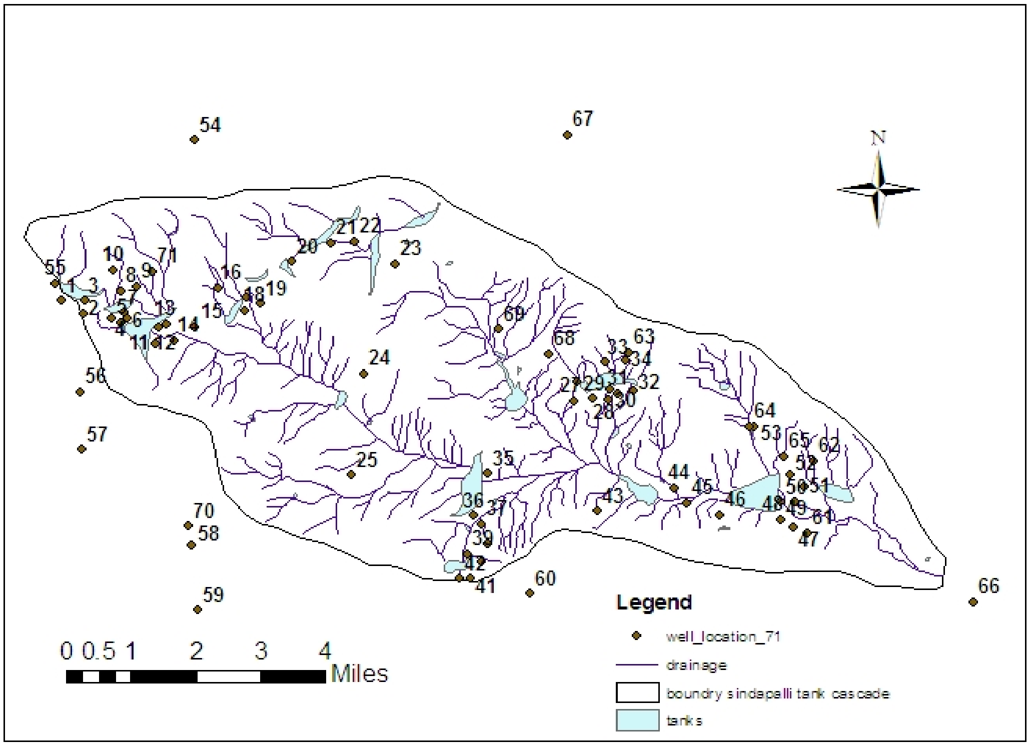

Figure 4.17 Well location map of Sindapalli Uppodai sub-basin

with the capabilities of GIS. With the usage of GIS, storage, retrieving, mapping of data were made easy. The conversion of point data into spatial data helped to know the variation over the entire study area. These data were used to carry out the overland flow analysis and surface and ground water interaction using MIKE SHE model. Hence, the parameter estimation for runoff routing and tank yield estimation will be easy and accurate. The developed GIS database for Sindapalli Uppodai can be used for building up the MIKE SHE model for integrated surface and groundwater analysis of the tank cascaded catchment in a distributed manner.

CHAPTER 5

GROUND WATER RESOURCE ESTIMATION FOR THE SUB-BASIN- SINDHAPALLI UPPODAI

5.1 METHODOLOGY FOR GROUNDWATER RESOURCE ESTIMATION

The Groundwater Estimation Committee (GEC) was constituted by the Government of India in 1982 to recommend methodologies for estimation of the groundwater resource potential in India. Groundwater assessment is done based on the watershed approach by using Groundwater Estimation Committee (GEC-1997) norms to find the groundwater potential. It was recommended by the committee that the groundwater recharge should be estimated based on groundwater level fluctuation method and Rainfall Infiltration factor method**.** Availability of adequate data is the key to the realistic estimation of groundwater resources. The following data elements are required for each assessment unit in the estimation of groundwater resources using the existing methodology:-

i. Rainfall data: Normal rainfall for the assessment year during monsoon and non-monsoon seasons. These data are being collected State Revenue Department.

ii. Water level data: Pre and post-monsoon water levels from the observation wells for two subsequent calendar years from 2009 and 2010.These data are being obtained by weekly monitoring in the study area periodically.

iii. Cropping Pattern Data: Paddy and non-paddy areas irrigated by different sources. This data is collected from Agriculture Department and State Administration.

iv. Tanks and Ponds data: Name of the tank, water spread area, number of day's water is available in the tanks season wise.

v. Groundwater draft: For estimating groundwater withdrawals, the number of each type of wells operating in the area, their corresponding running hours each month and discharge are required. If a complete inventory of wells is not available, then this can be obtained by carrying out sample surveys.

vi. Aquifer parameters: Data regarding the storage coefficient and transmissivity are required at a sufficient number of locations in the study area.

vii. Population data: Population and growth rate. These data are collected from Census Department and Director of Statistics, Virudhunagar District.

viii. Spatial Data of assessment units: Assessment unit location, command, non-command are derived from the CARTOSAT and RESOURCESAT imagery. The methodology for groundwater resource estimation is given in Figure 5.1

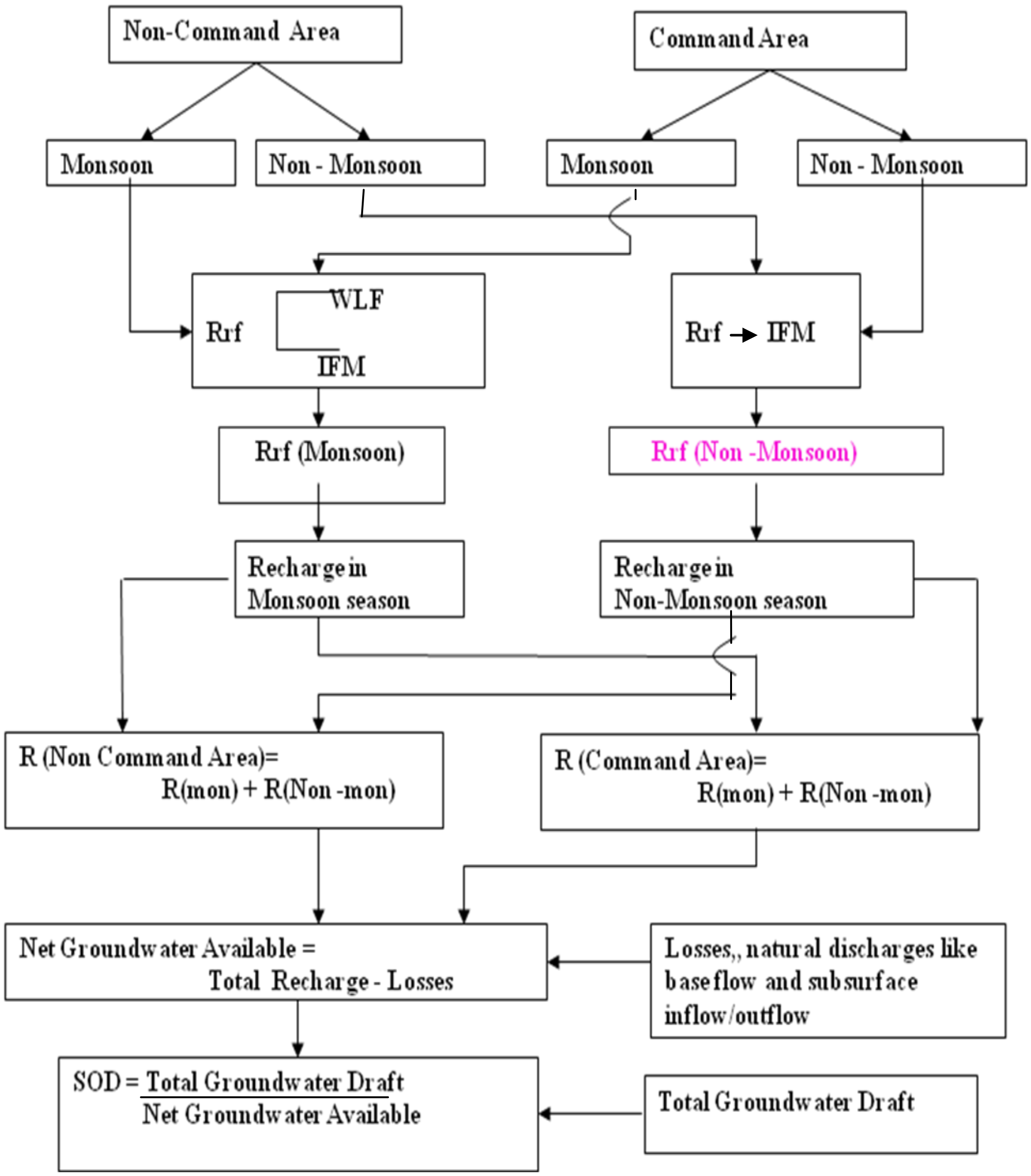

Figure 5.1 Methodology for Groundwater Resource Estimation

5.2. ESTIMATION OF GROUNDWATER RECHARGE FROM RAINFALL

Watershed with well defined hydro-geological boundaries is an appropriate hydrological unit for groundwater resource estimation. In hard rock areas, the hydrogeological and hydrological units normally coincide, which may not be the case in alluvial areas where the aquifers traverse the basin boundaries. In the present study, a unit for groundwater recharge assessment is the tank catchments. GEC 1997 has recommended for the delineation of subareas in the unit based on panchayat or village in each tank system. Groundwater recharge assessment is to be made separately for the non-command and command areas in the unit. For each of these sub-areas, recharge in the monsoon season and the non-monsoon season is to be estimated separately. For most parts of the country receiving the main rainfall from Southwest monsoon, the monsoon season would pertain to Samba period of cultivation. But in the Tamilnadu, the primary monsoon season is the Northeast monsoon, so the period of monsoon season is considered for the present study. Groundwater recharge from rainfall is estimated for monsoon and non-monsoon seasons separately. Rainfall recharge during monsoon season is estimated using two methods

i. Rainfall Infiltration Factor Method (RIF).
ii. Water level fluctuation Method.

5.2.1 Rainfall Infiltration Factor Method

This method estimate based on the formula given in Eqn 5.1.

$$R_{rf} = f \times A \times NormalMonsoon \qquad \text{… (5.1)}$$

Where, f = Rainfall Infiltration Factor

A = Area of computation for recharge.

The Rainfall Infiltration Factor (f) for the given unit depends only on the following factors;

i. Type of terrain.

ii. In the case of hard rock terrain, the rock type.

The Rainfall Infiltration Factor may be used for both monsoon and non-monsoon rainfall, with the condition that the recharge due to non-monsoon rainfall may be taken as zero if the normal rainfall during the non-monsoon season is less than 10% of normal annual rainfall. In using the method based on the specified norms, recharge due to both monsoon and non-monsoon rainfall is estimated for normal rainfall, based on recent 30 years climate data. It is necessary to have adequately spaced rain gauge stations within and outside the unit taken up for recharge computation. While adopting this method due weightage should be given to the nearby rain gauge stations.

5.2.2 Water Level Fluctuation Method

The groundwater level fluctuation method is to be used for recharge assessment in the monsoon season. For non-command areas, recharge in the non-monsoon season is a small component and may be estimated empirically, as described subsequently. Estimate specific yield from long duration pumping tests or based on norms for the particular hydro-geological area, and use this value of specific yield in the groundwater balance equation for the monsoon season to estimate recharge. Once specific yield value is determined, the recharge in the monsoon season can be calculated from Eqn 5.2.

$$R = h \times A \times S_y + D_g$$

--- (5.2)

Where, h = Rise in water level in the monsoon season,

A = Area for computation of recharge,

D_g = Groundwater draft for all uses,

S_y = Specific yield,

R = Possible Recharge.

The possible recharge in the above equation gives the available recharge from rainfall and other sources for the particular monsoon season is given by Eqn 5.3 & 5.4.

$$R_{rf} = R - R_{gw} - R_{wc} - R_t \quad \text{..... (5.3)}$$

$$R_{rf} = h \times S_y \times A + D_g - R_{gw} - R_{wc} - R_t \quad \text{.... (5.4)}$$

Where; R_{rf} = Recharge from rainfall

R_{gw} = Recharge from ground water irrigation in the area

R_{wc} = Recharge from water conservation structures

R_t = Recharge from tanks and ponds

The estimation of recharge from groundwater irrigation (R_{gw}), recharge from water conservation structures (R_{wc}) and recharge from tanks and ponds (R_t) may be made based on the norms presented in Section of GEC report. For the computation of recharge area the impervious area like road, building structure are removed for calculation. The derived values are shown in Table 5.1.

Table 5.1 Recharge Area of the tank catchments

Tank No	**Tank Name**	**Recharge Area (Km^2)**
1	Duraiswamypuram	1.82
2	Ammapatti	1.32
3	Oorampatti	2.62
4	Villampatti	1.82
5	Sittarajapuram	1.9
6	Anaikuttam	1.51
7	Minampatti	1.83
8	Thayilpatti	0.8
9	Anupankulam	1.35
10	Melaottampatti	3.35
11	Muthalanayakkanpatti	3.5
12	Anayiur	0.8
13	Sengulam	0.9
14	Kattalaipatti	0.6
15	Venkatachalapuram	0.55

5.2.2.1 Recharge from Irrigation

The area irrigated by surface water and groundwater is derived from the Resourcesat data. As per GEC norms, irrigated area is less than 100 ha can be taken as Non-Command area. The cultivable crop is paddy for monsoon season and non-paddy for non-monsoon. Based on the crop types minimum water requirements are assumed as 1.2 m per day and 0.7 m per day for paddy and non-paddy crops respectively. The computation values for recharge from irrigation are given the Table 5.2.

Table 5.2 Area irrigated by Surface water and Groundwater

Tank No	Tank Name	Surface Water		Groundwater	
		Area (Km^2)	Area (Ha)	Area (Km^2)	Area (Ha)
1	Duraiswamypuram	0.2	20.43	0.04	3.66
2	Ammapatti	0.32	32.21	0.29	29.22
3	Oorampatti	0.42	42.26	0.66	66.37
4	Villampatti	0.08	8.24	1.54	153.75
5	Sittarajapuram	0.55	54.68	2.21	221.29
6	Anaikuttam	0.09	9.25	0.08	8.32
7	Minampatti	0.04	4.25	0.58	57.67
8	Thayilpatti	0.29	29.1	0.03	3.28
9	Anupankulam	0.33	32.76	0.14	14.03
10	Melaottampatti	2.21	221.28	0.96	96.18
11	Muthalanayakkanpatti	0.17	16.89	0.34	33.81
12	Anayiur	0.16	15.82	0.46	45.68
13	Sengulam	0.38	37.93	0.53	53.32
14	Kattalaipatti	0.73	72.57	0.02	2.45
15	Venkatachalapuram	0.37	36.74	0.26	26.2
	Total	6.34	634.42	8.53	853.1

5.2.2.2 Recharge from Tank

The number of days water available in the tank ranges from 60-90 days. Therefore, 90 days is taken as N. The seepage factor is taken as 1.4 mm per day as per GEC norms. The computation values for recharge from tanks are given the Table 5.3. Which provides the final computation values of distributed rainfall recharge for the monsoon of 2009-10.

Table 5.3 Distributed Rainfall Recharge from rainfall, surface water irrigation, groundwater irrigation and tank during monsoon

Tank No	**Tank Name**	**R (Mm^3)**	**R_{sw} (Mm^3)**	**R_{gw} (Mm^3)**	**R_t (Mm^3)**	**R_{rf} (Mm^3)**
1	Duraiswamypuram	3.74	0.12	0.0089	0.64	2.89
2	Ammapatti	2.9	0.19	0.072	0.99	1.68
3	Oorampatti	5.44	0.26	0.162	3.17	1.87
4	Villampatti	5.29	0.05	0.38	0.83	4.03
5	Sittarajapuram	9.63	0.32	0.54	0.64	8.13
6	Anaikuttam	7.82	0.005	0.02	0.44	7.35
7	Minampatti	15.89	0.02	0.14	0.23	15.5
8	Thayilpatti	5.05	0.17	0.008	0.99	3.88
9	Anupankulam	8.95	0.19	0.03	2.56	6.17
10	Melaottampatti	13.94	1.32	0.24	0.24	12.14
11	Muthalanayakkanpatti	16.8	0.10	0.08	5.51	11.21
12	Anayiur	7.15	0.09	0.11	0.72	6.23
13	Sengulam	4.35	0.22	0.13	2.2	1.8
14	Kattalaipatti	4.41	0.44	0.006	0.96	3
15	Venkatachalapuram	3.68	0.22	0.006		3.46

The water level fluctuation method considers the various recharge components into account such as surface water, groundwater and also recharge from tanks input. The gross draft for all uses is also taken into account which is output components. The water conversation structures like check dam and so on is absent. The above table reveals that the recharge is more in tanks catchments namely Melaottampatti, Muthalanayakkanpatti at the same time discharge also more here. The return flow components from irrigation are also more here because of larger command area.

5.2.3 Recharge in the Non-Monsoon Season

The recharge during the non-monsoon season where all the recharge components including rainfall recharge and recharge from other sources during the non-monsoon season are computed. The only difference is that rainfall recharge during non-monsoon is computed using RIF method only. If the rainfall during the non-monsoon period is less than 10% of the annual rainfall, the recharge due to rainfall is taken as zero. The total recharge during non-monsoon is the sum of recharge from rainfall and recharge from other sources and is given in Table 5.4. In the study area, non-monsoon rainfall is 180 mm which is above the limit of 10% the recharge for non-monsoon is estimated by RIF.

(i) Rainfall Recharge from Irrigation

The recharge due to return flow from irrigation may be estimated, based on the source of irrigation (ground water or surface water), the type of crop (paddy, non-paddy). The method is given below .

$$R_{irr} = A \times M \times R \quad \ldots (5.5)$$

$$R_{irr} = R_{sw} + R_{gw} \quad \ldots (5.6)$$

Where; A = Area of Cultivable land in Ha.

M = Minimum Crop water requirements.

R = Return Flow Factor.

(ii) Rainfall Recharge from Tanks

The recharge from tanks is based on the water available in the tank; normally Seepage factor can be taken as 1.4mm per day is taken. The 60% of the maximum water spread area may be used instead of the average area of the water spread. The method is given below in Eqn 5.7.

$$R_t = A \times W_p \times N \times 0.6 \qquad \dots (5.7)$$

Where; A = Area of water spread in Tank (Ha)

W_p = Seepage factor and

N = Number of days water availability in tank

Table 5.4 Rainfall Recharge during Non-Monsoon

Tank No	**Tank Name**	**R_{rf} (Mm^3)**
1	Duraiswamypuram	0.06
2	Ammapatti	0.04
3	Oorampatti	0.18
4	Villampatti	0.08
5	Sittarajapuram	0.318
6	Anaikuttam	0.32
7	Minampatti	0.37
8	Thayilpatti	0.03
9	Anupankulam	0.09
10	Melaottampatti	0.16
11	Muthalanayakkanpatti	0.36
12	Anayiur	0.03
13	Sengulam	0.08
14	Kattalaipatti	0.09
15	Venkatachalapuram	0.23

5.2.4 Percent Difference

The rainfall recharge computed by Water Level Fluctuation method during monsoon season is to be compared with recharge computed by Rainfall Infiltration Factor method. Percent Difference is computed to quantify the difference in between these two estimated figures. The percent difference is calculated by applying the following Eqn 5.8.

$$PD = \frac{R_{Rf}\langle wtfm \rangle - R_{Rf}\langle rifm \rangle}{R_{Rf}\langle rifm \rangle} \times 100 \tag{5.8}$$

Where;

R_{Rf}(wtfm) = Rainfall Recharge for normal monsoon season rainfall estimated using Water Table Fluctuation Method

R_{Rf}(rifm) = Rainfall Recharge for normal monsoon season rainfall estimated using Rainfall Infiltration Factor Method

In case the difference between the two sets of data is within –20% and +20%, It can be concluded that the estimates by both the methods are in agreement and hence the estimate by water level fluctuation method will be used in the further computations. If the difference is less than –20% then 0.80 times of the estimate calculated using Rainfall Infiltration factor Method will be utilized and if the percent difference is more than+20%, 1.20 times of the estimate calculated using Rainfall Infiltration factor Method will be utilized as the recharge due to rainfall during Monsoon season. This is one of the Validation procedures inbuilt in the methodology to assess the accuracy of the computation and if found erroneous, an attempt is made to reduce the error.

5.3 ALLOCATION OF GROUNDWATER RESOURCE FOR UTILISATION

The net annual ground water availability is to be apportioned between domestic, industrial and irrigation uses. Among these, as per the National Water Policy, the requirement for domestic water supply is to be accorded priority.The estimate of allocation for domestic and industrial water requirement may vary for the units in different states. In situations where adequate data is not available to make this estimate, the following empirical relation is recommended in Eqn 5.9.

$$\left.\begin{array}{l}\text{Allocation for domestic and}\\ \text{industrial water requirement}\end{array}\right\} = 22 \text{ X } N \text{ X } L_g \text{ mm per year} \qquad \ldots(5.9)$$

Where; N = Population density in the unit in thousands per sq. km.

L_g = Fractional load on ground water for domestic and industrial Water supply (≤ 1.0).

Groundwater draft is the extraction of water from the groundwater for all uses. As per GEC norms, the computation is based on population data. So, the population data for 2001 is collected from collectorate office of Virdhunagar District and census department. GEC 1997 has recommended for delineation of sub-area within a block. The tank catchments are taken as hydrological units. The slope and soil texture are important hydrological units. To delineate from taluk to village in each tank cascade system for calculation of groundwater draft, the origin of the watershed from the remotest point is considered and village level groundwater draft is given in Table 5.5. The calculated groundwater draft for each tank is given in Table 5.6.

Table 5.5 Administrative Block and Village level groundwater Draft

S No	Block	Village Name	Population	D_{dom} (Mm^3)
1	Sattur	Athipatti	210	0.01
		Ammapatti	2516	0.18
		Metamalai	4367	0.33
		Chinnakananpatti	2949	0.22
		Kattlampatti	1695	0.13
		Sattur	1877	0.15
		Omttampatti	435	0.03
		muthamlingapuram	1340	0.1
		Chokkalingapuram	1793	0.09
		Nallamuthanapatti	378	0.03
		Perryampatti	1363	0.18
2	Vembakottai	Reddiapatti	1883	0.14
		Duraiswamypuram	7946	0.59
		Peranayakkanpatti	2406	0.34
		Vetriloorani	4536	0.34
		Alankulam	4969	0.37
		Thayilpatti	8785	0.65
3	Sivakasi	A.Thulukapatti	1912	0.14
		Alamarathupatti	1057	0.07
		Anaikuttam	2878	0.21
		Anaiyur	19878	1.48
		Anupankulam	10990	0.82
		Bhoovanathapuram	543	0.04
		Chithamanaickenpatti	1269	0.09
		Chokkalingapuram	1793	0.14

Table 5.5 (Continued)

S No	Block	Village Name	Population	D $_{dom}$ (Mm^3)
		Chokkampatti	553	0.04
		Erichanatham	2479	0.18
		Injar	929	0.06
		Kalayarkurichi	2098	0.16
		Kariseri	3526	0.26
		Kattachinnampatti	534	0.03
		Kitchanaickenpatti	1971	0.14
		Kothaneri	736	0.05
		Koundampatti	1227	0.09
		Krishnaperi	826	0.06
		Krishnapuram	492	0.03
		Kumilankulam	1097	0.08
	Sivakasi	Lakshminarayanapuram	896	0.06
		M.Pudupatti	1810	0.14
		Mangalam	2648	0.19
		Maraneri	1613	0.12
		Melamathur	2970	0.22
		Nadayaneri	1882	0.14
		Naduvapatti	1776	0.13
		Namaskarithanpatti	976	0.07
		Naranapuram	9331	0.69
		Nedungulam	1095	0.08
		Niraimathi	601	0.04
		Pallapatti	24326	1.8
		Periapottalpatti	965	0.07
		Poolavoorani	1648	0.12
		Pudukkottai	2191	0.16
		Rangapalayam	692	0.06
		Saminatham	3023	0.23
		Sengamalanachiarpatti	9629	0.72
		Sengamalapatti	2703	0.2
		Sevalur	1983	0.15
		Sithurajapuram	13273	0.99

Table 5.6 Distributed Groundwater Draft of each Tank System

Tank No	**Tank**	**Village**	**Population**	**D_{dom} (Mm^3)**
1	Duraiswamypuram	Duraiswamypuram	7,946	0.59
		Kitchanaickenpatti	1,971	0.14
2	Ammapatti	Ammapatti	2,516	0.19
3	Urampatti	Maraneri	1,613	0.12
		Pallapatti	24,326	1.82
4	Villampatti	Periapottalpatti	965	0.07
		Villampatti	2,468	0.19
5	Sittarajapuram	Reddiyapatti	3,005	0.22
		Sengamalapatti	2,703	0.2
		Sithurajapuram	13,273	0.99
		Subramanipuram	955	0.07
		Oorampatti	1,809	0.14
6	Anaikuttam	Anaikuttam	2,878	0.22
		Paranayakkanpatti	2,406	0.18
7	Minampatti	Viswanatham	22,154	1.66
		Sivakasi	72,168	5.41
8	Thayilpatti	Tayilupatti	8,785	0.66
		Vettrilaioorani	4,536	0.34
9	Anupankulam	Anupankulam	10,990	0.82
10	Melaottampatti	Chinnakkamanpatti	2,949	0.21
		Melaottampatti	1,110	0.08
11	Muthalanayakkanpatti			
12	Anayiur	Anayiur	19,898	1.5
13	Sengulam			
14	Kattalaipatti			
15	Venkatachalapuram	Venkatachalapuram	8,409	0.64

5.4 ANNUAL REPLENISHABLE GROUNDWATER RESOURCE

The Annual Replenishable Ground Water Resource of the area is the sum of recharge during monsoon and non-monsoon seasons. An allowance is kept for natural discharge during non-monsoon season by deducting 5% of Annual replenishable Ground Water Resource, wherever WLF method is employed to compute rainfall recharge during monsoon season and 10% if RIF method is used.

5.5 NET ANNUAL GROUNDWATER AVAILABILITY

The Net annual ground water availability is the available resource after deducting the natural discharges from the Annual replenishable Groundwater Resource and is expressed as in Eqn 5.10

$$\text{Net Annual Groundwater Availability} = \left\{ \begin{array}{l} \text{Annual replenishable Groundwater Resource} \\ - \text{Natural Discharge during non-monsoon season} \end{array} \right\} \quad \text{-- (5.10)}$$

5.6 STAGE OF GROUNDWATER DEVELOPMENT

The stage of Groundwater Development is to be computed as given below in Eqn 5.11

$$\text{Stage of Ground Water Development} = \left\{ \frac{\text{Existing Gross Ground Water Draft for all uses}}{\text{Net Annual Ground Water Availability)}} \times 100 \right\} \quad \dots (5.11)$$

Table 5.7 Details of Groundwater Resource Estimation

Tank No	Tank Name	R_{rf} (Mm^3)	R (Mm^3)	R_{sw} (Mm^3)	R_{gw} (Mm^3)	R_t (Mm^3)	Net Water Available (Mm^3)	Gross Draft (Mm^3)	Percentage (%)	Stage of Development
1	Duraiswamypuram	0.26	3.74	0.12	0.0089	0.64	0.34	0.84	25	Safe
2	Ammapatti	0.16	2.9	0.19	0.072	0.99	0.15	0.44	29	Safe
3	Oorampatti	0.82	5.44	0.26	0.162	3.17	0.78	2.44	32	Safe
4	Villampatti	35	5.29	0.05	0.38	0.83	0.35	1.8	19	Safe
5	Sittarajapuram	1.44	9.63	0.32	0.54	0.64	1.41	0.75	188	Over-exploited
6	Anaikuttam	1.52	7.82	0.005	0.02	0.44	1.59	2.25	71	Semi-critical
7	Minampatti	1.77	15.89	0.02	0.14	0.23	1.75	8.57	204	Over-exploited
8	Thayilpatti	1.12	5.05	0.17	0.008	0.99	0.1	1.75	57	safe
9	Anupankulam	0.45	8.95	0.19	0.03	2.56	0.45	1.82	247	Over-exploited
10	Melaottampatti	1.63	13.94	1.32	0.24	0.24	1.6	1.54	108	Over-exploited
11	Muthalanayakkanpatti	1.68	16.8	0.10	0.08	5.51	1.5	1.25	120	Over-exploited
12	Anayiur	0.13	7.15	0.09	0.11	0.72	0.14	2.35	59	Safe
13	Sengulam	0.45	4.35	0.22	0.13	2.2	0.41	1.85	22	Safe
14	Kattalaipatti	0.15	4.41	0.44	0.006	0.96	0.17	1.25	14	Safe
15	Venkatachalapuram	0.12	3.68	0.22	0.006		0.13	1.09	12	safe

5.7 CATEGORIZATION OF ASSESSMENT UNITS

The assessment units are to be categorized for ground water development based on two criteria namely stage of ground water development and long-term trend of pre and post monsoon water levels. There are four categories, namely – 'Safe', 'Semi-critical', 'Critical' and Over-exploited' areas. Table 5.7 shows that status of groundwater of the tank catchments. The tank catchments like Muthalanakkanapatti, Anupankulam, Melaottampatti, Minampatti tank catchments shows the Over – Exploited status of groundwater development. But the important fact that these tanks also show the higher recharge, which is relatively high The Anaikuttam tank catchment is in the semi-critical where the other catchments show safe stage in groundwater development.

CHAPTER 6

SURFACE AND GROUND WATER DYNAMICS OF AN IRRIGATION TANK CLUSTERED CATCHMENT USING PHYSICALLY BASED MODEL – MIKE SHE

6.1 GENERAL

A comprehensive water resources assessment for any region should include tanks and depressions particularly in tank irrigated areas in order to quantify and manage it in a sustainable manner, which can be achieved through integrated surface and groundwater modelling. The methodology of integrated modelling is explained in five stages as an estimation of Surface water components i.e. Tanks and Overland flow, Reference Evapotranspiration, Unsaturated zone component, Groundwater component and tank aquifer interaction. The process of flow routing through tank cascades comprises of overland flow, storage in tanks and depressions, flow through the tank cascades and coupling of MIKE 11 and MIKE SHE is discussed under surface water components. Reference Evapotranspiration and Unsaturated zone flow modelling were discussed individually. Modelling of groundwater zone has been explained subsequently. A detailed flow chart of the methodology is enclosed as Figure 6.1. Stored rainfall in tanks and depressions starts to flow through streams towards the next tank.

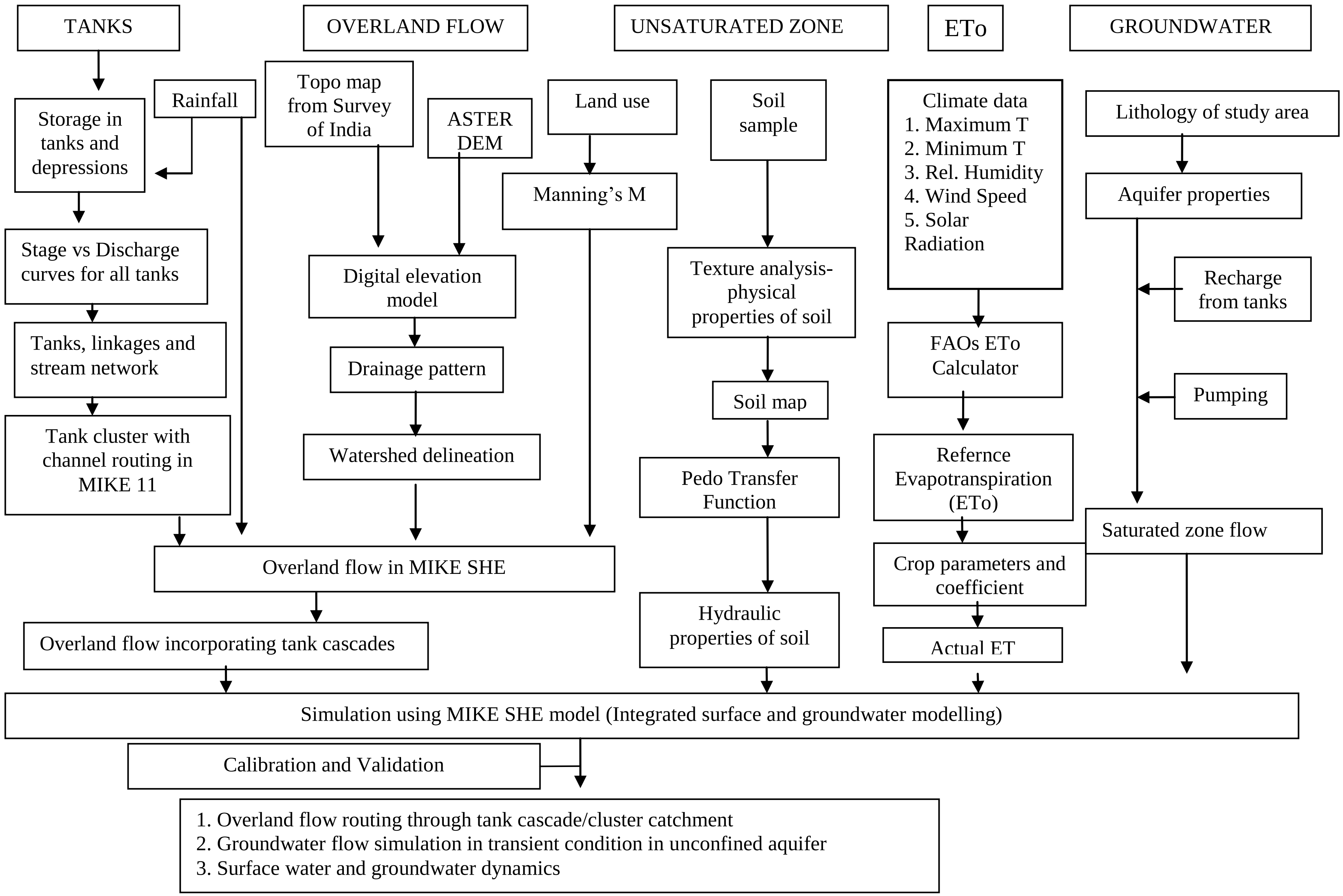

Figure 6.1 Methodology flowchart of Integrated surface and groundwater Modelling of the tank clustered sub-basin

Simulation of this mechanism requires DEM, Manning’s M and Land use data. Upon feeding the above data as input, flow over land and flow through the tanks is simulated separately in MIKE 11 and MIKE SHE respectively. These two flows have to be coupled so as to obtain the cumulative flow in the surface component and detailed coupling mechanism is discussed in forthcoming sections of this chapter. A portion of rainfall and the stored water in tanks enters underground aquifer over a prolonged period through soil strata of the unsaturated zone whose dynamics is simulated by unsaturated zone module of MIKE SHE.

The saturated zone module of MIKE SHE simulates the groundwater flow and head elevations spatially. Both unsaturated and saturated zone modules need soil map, water retention capacity and hydraulic conductivity of unsaturated zone, the spatial extent of the aquifer, aquifer depth, boundary conditions, initial conditions and soil hydraulic properties such as horizontal and vertical hydraulic conductivities, specific storage / specific yield data. Once the model is calibrated and validated, it is capable of simulating the overland flow through tank cascades and groundwater level in the unconfined aquifer. The mechanism of exchange of water from tanks with that of the aquifer is discussed at the end of this chapter.

6.2 SIMULATION OF TANK CASCADED CATCHMENT USING MIKE SHE

Simulation of surface and groundwater interaction is a dynamic process which could be possibly carried out using a fully integrated comprehensive model like MIKE SHE. The hydrological processes are described by physical laws in MIKE SHE. Processes of simulation engines, representation of the study area as model domain and feeding the input parameters in order to characterize the study area are described in the following Subsections.

6.2.1 MIKE SHE – General Description

MIKE SHE a physically based deterministic and distributed model has the capability of modelling the entire process of the hydrologic system. MIKE SHE contains simulation engines for several modules such as Overland flow (OL), Rivers and Lakes (OC), Unsaturated flow (UZ), Evapotranspiration (ET) and Saturated flow (SZ). Conceptualization of the hydrological processes through the modules in MIKE SHE has been explained in Figure 6.2. These modules take care of the processes such as canopy interception, overland flow, evaporation from ponded water, evapotranspiration from soil and green cover, infiltration, flow-through channels and tank cascades and flow in the unsaturated zone and saturated zone.

Modules and processes of the simulation engine of MIKE SHE are given in Figure 6.3. For this study 1-D and 2-D diffusive wave Saint Venant equations are used for channel and overland flow, 1-D Richards‘s equation for unsaturated zone flow and a 3-D Finite difference Darcy flow equation for saturated zone flow. These partial differential equations are solved by finite difference methods (DHI 2004). The FRAME component enables MIKE SHE modules having different time steps to run in parallel and to exchange information (Abbott et al. 1986).

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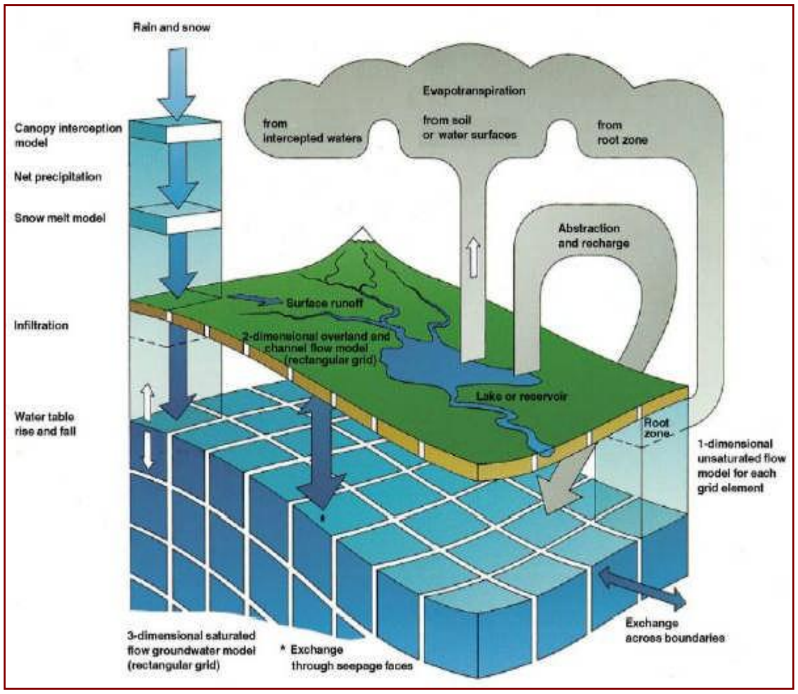
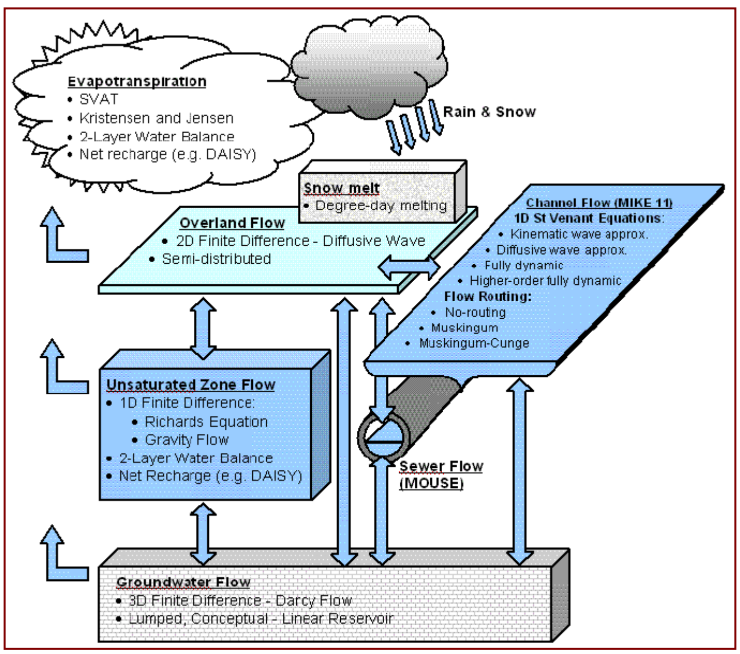


Source: (Refsgaard & Storm 1995)

Figure 6.2 Conceptualization of hydrological processes in MIKE SHE



Source: (Graham & Butts 2005)

Figure 6.3 Modules and processes of simulation engine in MIKE SHE

6.2.1.1 Overland flow process

Overland or surface flow is the effective precipitation after accounting for losses such as evaporation and infiltration and results in surface runoff. Overland flow is governed by diffusive wave approximation of Saint Venant's equation. For two-dimensional surface water flow, it is common to simplify the governing equations by neglecting momentum losses due to lateral inflows, local and convective accelerations. This is known as the diffusive wave approximation, which is implemented in MIKE SHE using two-dimensional finite-difference approaches.

The principle of Finite Difference Method is that the derivatives in the partial differential equation are approximated by linear combinations of function values at the grid points. The finite difference method can be characterized by taking uniformly spaced grids at each node, such that each derivative is approximated by an algebraic expression which references the adjacent nodes. A system of algebraic equations can be obtained by evaluating the previous step for each node and the system is then solved for the dependent variable. Diffusive wave approximation of Saint Venant's equation has been described below.

Using rectangular cartesian (x, y) coordinate in the horizontal plane, let the ground surface level be (x, y), the flow depth be h (x, y) (above the ground surface) and the flow velocities in the x-and y-direction be u (x, y) and v (x, y) respectively. Let i (x, y) be the net input into overland flow (net rainfall after infiltration). Then the conservation of mass is given as

$$\frac{\partial h}{\partial \mathrm{t}} + \frac{\partial}{\partial x}(uh) + \frac{\partial}{\partial y}(vh) = i \qquad (6.1)$$

where h is the flow depth above ground surface (m);

u is the velocity (m/s) in the x-direction;

v is the velocity (m/s) in the y-direction; and

i is the net input over overland flow (m /s).

And the momentum equation is given as

$$S_{fx} = S_{Ox} - \frac{\partial h}{\partial x} - \frac{u \partial u}{g \partial x} - \frac{I \partial u}{g \partial t} - \frac{qu}{gh} \quad (6.2)$$

$$S_{fy} = S_{0y} - \frac{\partial h}{\partial y} - \frac{v \partial v}{g \partial y} - \frac{I \partial v}{g \partial t} - \frac{qv}{gh} \quad (6.3)$$

where S_f the friction slopes in the x-and y-direction and S_O is the slope of the ground surface. Equation (6.1), (6.2) and (6.3) are known as the Saint Venant's equations and when solved gives a fully dynamic description of shallow (two-dimensional) free surface flow. Therefore, in order to reduce the complexity of the problem the last three terms of the momentum equation are dropped thereby ignoring momentum losses due to local and convective acceleration and lateral inflows perpendicular to the flow direction. This is known as the diffusive wave approximation, which is used in MIKE SHE. Considering only flow in the x-direction the diffusive wave approximation is expressed as

$$S_{fx} = S_{0x} - \frac{\partial h}{\partial x} = - \frac{\partial zg}{\partial x} - \frac{\partial h}{\partial x} \quad (6.4)$$

Further simplifying the above Equation (4.4) using the relationship z = zg + h, it reduces to

$$S_{fx} = -\frac{\partial}{\partial x} - (zg + h) = - \frac{\partial z}{\partial x} \text{ in the x-direction} \quad (6.5)$$

$$S_{fy} = -\frac{\partial}{\partial y} - (zg + h) = - \frac{\partial z}{\partial y} \text{ in the y-direction} \quad (6.6)$$

Use of diffusive wave approximation allows the depth of flow to vary significantly between neighboring cells and backwater conditions can be simulated. For, any numerical solution of nonlinear differential equations numerical problems can occur when the slope of the water surface profile is very shallow and the velocities are very low. If a Stickler or Manning-type law for each friction slope is used then with Stickler coefficients K_x and K_y in the two directions is given as

$$S_{fx} = \frac{u^2}{\mathrm{h}^{4/3}\ \mathrm{K}_\mathrm{x}^2} \tag{6.7}$$

$$S_{fy} = \frac{v^2}{\mathrm{h}^{4/3}\ \mathrm{K}_\mathrm{y}^2} \tag{6.8}$$

Substituting Equations (4.5) and (4.6) into Equations (4.7) and (4.8) results in

$$\frac{u^2}{\mathrm{h}^{4/3}\ \mathrm{K}_\mathrm{x}^2} = \frac{\partial z}{\partial \mathrm{x}} \tag{6.9}$$

$$\frac{v^2}{\mathrm{h}^{4/3}\ \mathrm{K}_\mathrm{y}^2} = \frac{\partial z}{\partial y} \tag{6.10}$$

After simplifying Equations (6.9) & (6.10) and multiplying both sides of the equations by *h*, the relationship between the velocities and the depths may be written as

$$uh = K_x \left(-\frac{\partial z}{\partial x}\right)^{1/2}\ h^{5/3} \tag{6.11}$$

$$vh = K_y \left(-\frac{\partial z}{\partial y}\right)^{1/2}\ h^{5/3} \tag{6.12}$$

The quantities *uh* and *vh* represent discharge per unit length along the cell boundary, in the x- and y- directions respectively.

6.2.1.2 Unsaturated flow process

MIKE SHE model provides three options to calculate flow in the unsaturated zone and they are Richard‘s equation, a simplified gravity flow, a simple two-layer water balance method for shallow water tables and a net recharge method. The flow in the unsaturated zone is assumed to be vertical. In this study, Richard‘s equation is used. The pressure head-based Richards equation, based on Darcy‘s law and continuity equation, assumes the soil matrix to be incompressible and soil water to be at constant density and is given as

$$C\frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{\partial \psi}{\partial z}\right) + \frac{\partial K}{\partial z} - S \qquad (6.13)$$

where C is the soil water capacity (mm^{-1});

ψ is the pressure head (mm);

K is the saturated hydraulic conductivity (mm/s);

Z is the gravitational head (mm); and

S is the root extraction sink term (s^{-1}).

Richard‘s equation is solved numerically using the finite difference implicit approximation method, associated with the Gauss-Seidal iteration formula, thus removing the stability and convergence problems due to heterogeneous soil properties.

6.2.1.3 Saturated flow process

Coupled flow from the surface water enters the saturated zone through the vadose zone and it is represented by three-dimensional Darcy’s equation. MIKE SHE allows for three-dimensional flows in a heterogeneous aquifer with unconfined conditions. Three-dimensional Darcy's equation is solved numerically by Preconditioned Conjugate Gradient (PCG) solver in a transient state and is expressed as

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t} \qquad (6.14)$$

where K_{xx}, K_{yy} and K_{zz} are the hydraulic conductivity along *x, y* and *z* axes (mm/s)

h is the hydraulic head (mm),

Q is the source/sink term (s^{-1}), and

S is the specific storage coefficient (m^{-1}).

The equation is non-linear for unconfined flow and the storage coefficient is not constant and changes from a specific storage coefficient for confined conditions to a specific yield for unconfined conditions.

6.2.2 Coupled MIKE SHE / MIKE 11 Model for Overland Flow

MIKE SHE model uses the diffusive wave approximation of Saint Venant's equation for overland flow computation. MIKE SHE itself is not able to characterize the tank cascaded system fully as it is not able to represent drainage network and surplus weirs which are an integral part of the tank structures. Moreover routing through the tank cascade system involves complex channel networks and requires fully dynamic Saint Venant's equation, solved using discretization technique of finite difference approximation and is used in the model MIKE 11. Flow routing through tank cascade system can be modeled by combining the models of MIKE SHE and MIKE 11.

A coupled MIKE SHE/MIKE 11 model has been developed for the study area incorporating tank cascaded system for a period of three years (2009 to 2011) for which the tank water level data were available for model calibration and validation. The first step in modelling is the representation of study area as model domain and feeding the input parameters in the network of square grids. For this modelling study covering an area of 142 km^2 was done in uniform cell size of 90 x 90 m computational square grids.

6.2.2.1 Data processing for overland flow component

The process of flow routing through tank cascades involves processes such as storage in tanks and depressions, flow through the tank cascades and overland flow. Stored rainfall in tanks and depressions starts to flow through streams and over land surface towards the next tank. Simulation of this mechanism requires DEM, precipitation data, climatic data, Manning's M and land use data. The first phase involved in modelling is data preparation of inputs parameters in terms of required format by the model. The DEM map created using elevation details of the study area from various sources such as contours and spot levels from SOI toposheets, ASTER and differential GPS data were given as input. Differential GPS was used for obtaining the elevation details of the tank bed and stream network. This will form the basic data source for the creation of DEM of the study area as well as the basin delineation. DEM model thus prepared given as input to the model, plays a major role in hydrological modelling for flow direction and accumulation analysis.

The natural topographic divide of the sub-basin i.e ridge line acts as the boundary of the model. Thiessen polygons were created in ArcGIS software, which provides the influencing areas of the three rain gauge stations and is given in Figure 6.4. Rainfall time series from three rain gauge stations namely Sattur, Sivakasi and Vembakottai were fed as input to the model. The measured rate of precipitation has been prepared as time series file in MIKE SHE's time series editor and given as input. Two climate stations namely Alangulam and Pudur are available just nearby the study area and their influencing areas are demarcated using Thiessen polygon technique and the climatological data from these stations such as Maximum temperature, Minimum temperature, Relative humidity, Wind speed and Solar radiation were used for time series ET_0 calculation using FAO's ET_0 calculator.

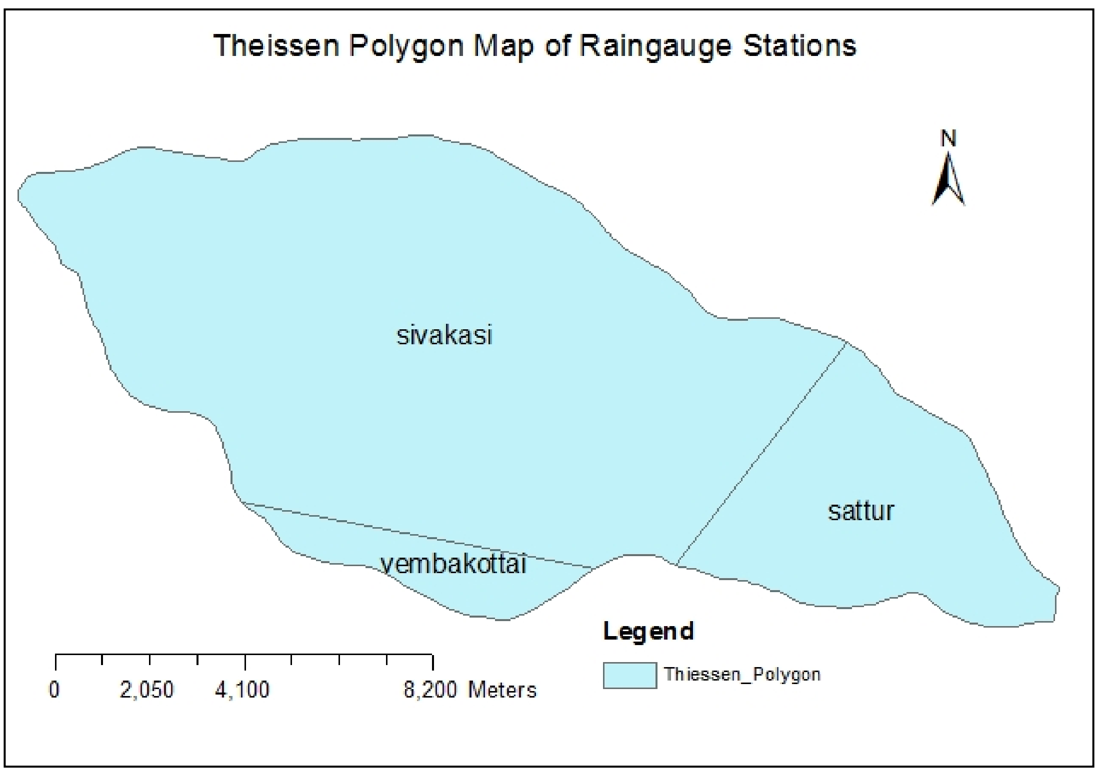


Figure 6.4 Theissen polygon map of rain gauge stations

6.2.2.2 Characterization of tank cascaded system in MIKE 11

Flow through tank cascades and streams were simulated in the simulation engine of MIKE 11 and then coupled with MIKE SHE. The more accurate way of incorporating tank cascades can be done through MIKE 11 only which requires more time for setting up and simulation. It requires due care and more data pertaining to tanks such as tank bund demarcation, water spread area, cross sections of tanks and channels, Manning's M for channel etc, are required.

Stream flow and flow through tanks are simulated using MIKE 11 simulation engine. All the stream network and tanks are overlaid on study area image and markings are made to identify the cross sections of streams while delineating them in MIKE 11. The drainage network was delineated in MIKE 11 which consists of several streams in which tanks are incorporated as streams with wider cross sections.

The procedure involved in setting up of study area model domain in MIKE 11 is similar to that of MIKE SHE. The numbers of reaches had been drawn and the branches are joined and defined with upstream and downstream ends and are classified as losing stream and gaining stream. Defined chainages for each stream and the cross section file had been prepared separately which contains numerous cross sections in a single file which was being named and identified through the chainages. Once this file is imported, the defined cross sections would sit precisely on the respective chainages. Boundary conditions of the stream ends were defined and the hydrodynamic conditions of the streams were also specified.

MIKE 11 simulation engine requires Network, Cross section, Boundary, Hydrodynamic and Time series files for simulation. Position and alignment of streams and tanks are defined in Network file. Totally there are six streams and sixteen tanks in the study area. Chainages are assigned at desired points i.e. start or end points of streams or at intermediate points. At least three points are required for tanks i.e. start, middle and end. Delineated tank cascade and stream network in MIKE 11 has been shown in Figure 6.5.

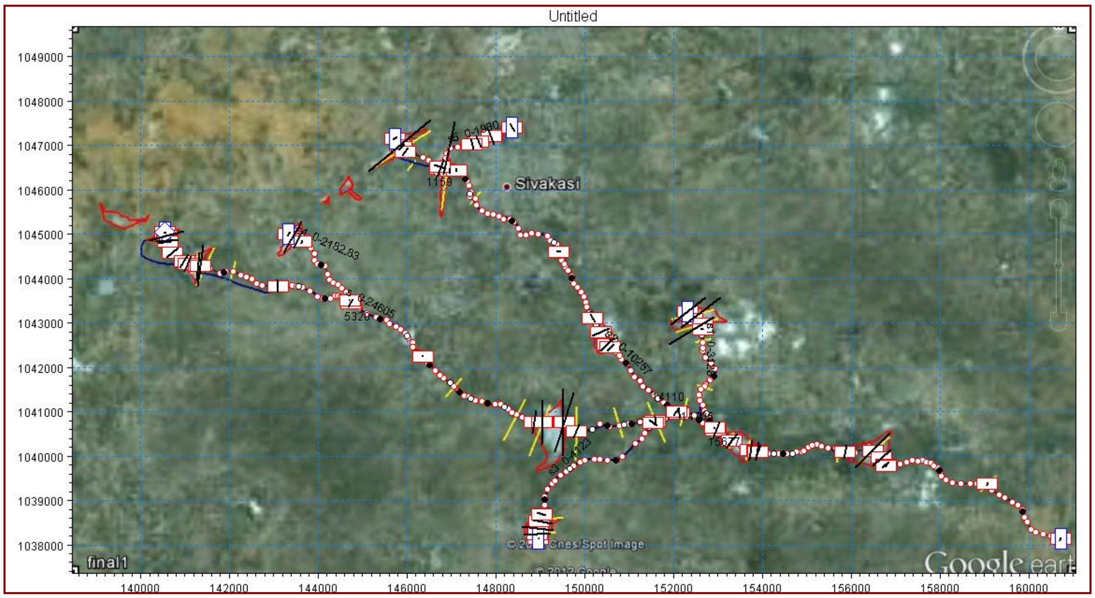


Figure 6.5 Delineation of tank cascade and stream network in MIKE 11

Kinematic routing method was selected and the discharges in streams were computed by Muskingum – Cunge method. Coupling reaches are defined using groundwater link tab. All the six streams were considered as coupling reaches, hence accurate quantification of flow had been done and is shown in Figure 6.6. Flood areas have to be defined manually so as to reduce the complexity of simulation. Overbank spilling was considered as it allows the water to spill out during flooding with specified minimum flow area for spilling.

Capturing of tank cascades and possible flooding area in MIKE 11 has been shown in Figure 6.7.

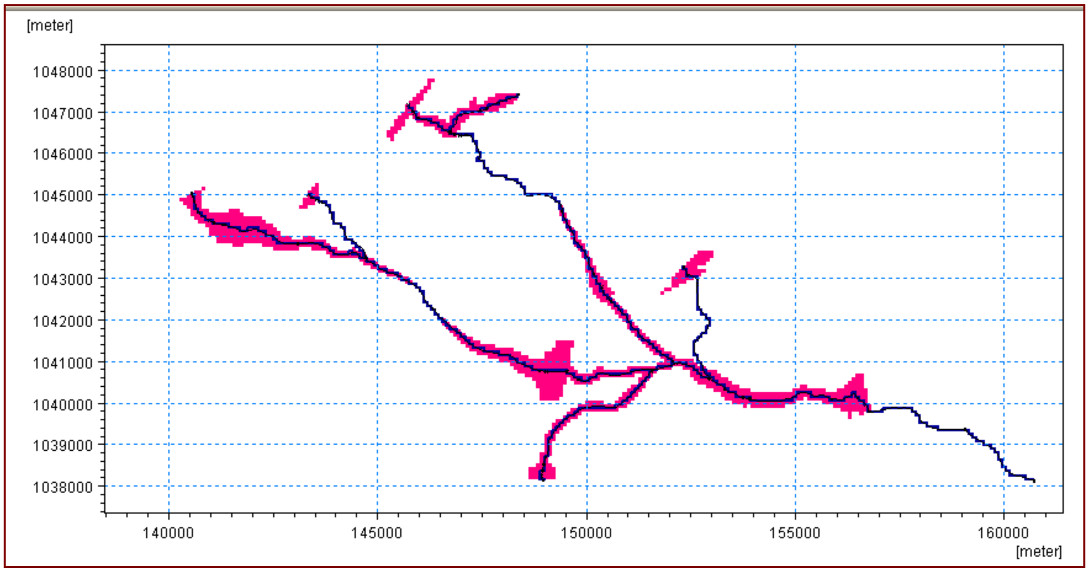


Figure 6.6 MIKE 11 and MIKE SHE coupling reaches

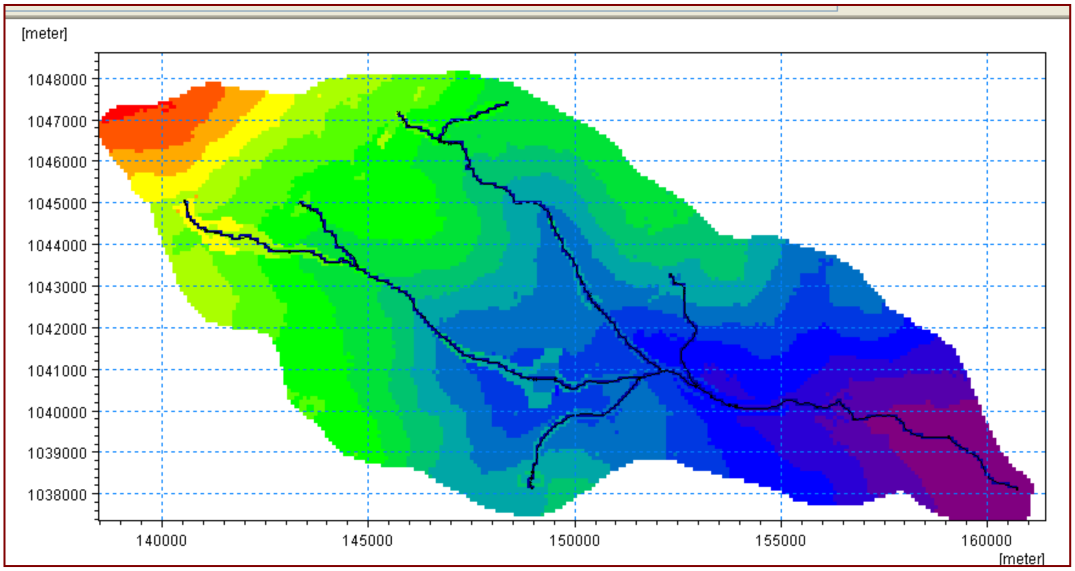


Figure 6.7 Capturing of tanks and flood areas in MIKE 11

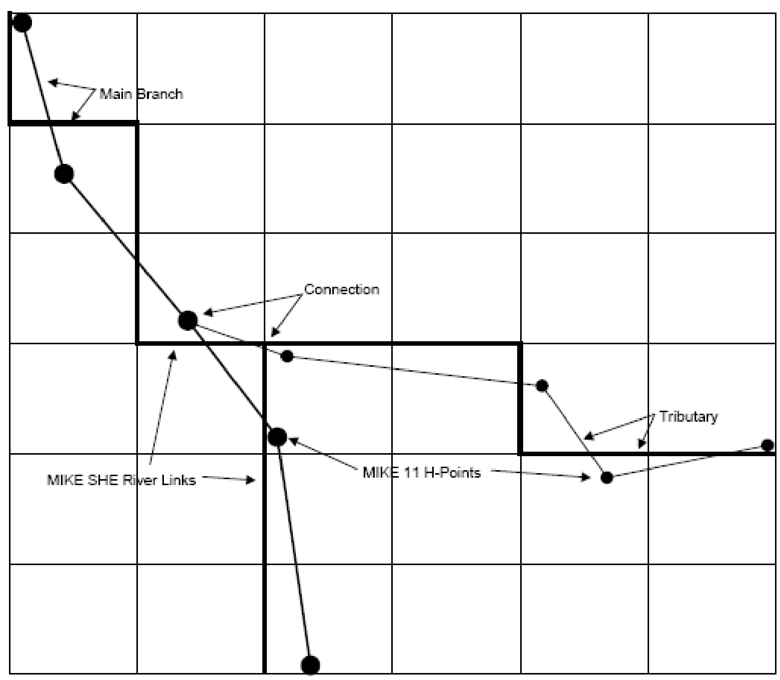
Cross sections of the streams and tanks were defined in the cross section file. The cross sections of the tanks have been obtained using handheld GPS. Streams were not having defined path in the research area, so they have been considered as a waterway defined by DEM. A uniform M value of 20 was assigned for the channel's transversal resistance distribution. Inflow to the stream was assigned as both upstream and downstream boundary condition for the streams. Inflow to the tanks was given as internal boundary condition by specifying the inflow at defined intermediate points.

6.2.2.3 Coupling MIKE SHE / MIKE 11

After feeding the input data in MIKE 11, flow through the tanks and flow over land surface were simulated separately in MIKE 11 and MIKE SHE respectively. When MIKE 11 was coupled with MIKE SHE it acts as a module. The tanks were represented by polygons in MIKE SHE with individual detention storage depth for each tank whereas in MIKE 11 the stream network was delineated and tanks were encoded or incorporated as stream portions having wider cross sections which enable water to be stored to tank’s full capacity up to the level of surplus weir and the rest has been allowed to flow down to the next linked tank. Routed flow from tank cascades was then coupled with MIKE SHE's overland flow module and both together accounts for the surface flow.

The coupling between MIKE 11 and MIKE SHE has been made via river links, which are located on the edges that separate adjacent grid cells. The location of each of MIKE SHE river link can be determined from the coordinates of the MIKE 11 river points, where both digitized points and H-points (points where MIKE 11 calculates the water levels) of the specified coupling reaches are included on the river points as in Figure 6.8. Since the MIKE SHE river links are located on the edges between grid cells, the details of the MIKE 11 river geometry can only be partly included in MIKE SHE, depending on the MIKE SHE grid size (DHI 2011).

The representation of more refined the MIKE SHE grid, more accurately the river network can be reproduced and this also leads to the restriction that each MIKE SHE grid cell can only couple to one coupling reach per river link. The tank cascade system like river link network was created by MIKE SHE's set-up program, based on a specified subset of the MIKE 11 river model, called the coupling reaches.



(Source: MIKE SHE User manual, DHI 2014)

Figure 6.8 MIKE 11 branches and H-points in a MIKE SHE grid with river links

6.2.3 Unsaturated and Saturated Flow Modelling

A portion of the rainfall gets absorbed by the soil surface and reaches the unsaturated and saturated zone. And also a portion of stored water in tanks also enters underground aquifer over a prolonged period through soil strata of the unsaturated zone. This water movement and dynamics can be simulated by integrated modelling approach which consists of simulating overland flow module, unsaturated zone module and saturated zone module altogether in MIKE SHE.

Saturated zone module of MIKE SHE simulates the groundwater flow and head elevations with spatial variations. Both unsaturated and saturated zone modules need datasets like soil map, water retention capacity, hydraulic conductivity of unsaturated zone, the spatial extent of the aquifer, aquifer depth, boundary conditions, initial conditions and soil hydraulic properties. Soil hydraulic properties include horizontal and vertical hydraulic conductivities and specific storage / specific yield.

6.2.3.1 Data processing and model set up for unsaturated zone

Characterization of unsaturated zone is the most important step in the construction of an integrated model. Unsaturated zone is the central portion of an integrated model as it governs the most important processes such as evapotranspiration and infiltration. Likewise, the parameters such as the water-holding capacity of the soil layer and root zone depth are used to determine the quantum of water reaching the atmosphere through ET. The reference ET value purely depends on the climate and can be calculated from weather data of the two climatic stations using FAO's ET_0 calculator. The FAO Penman-Montieth method was used for determining ET_0 value. Time series data of calculated evapotranspiration has been shown in Figure 6.9 with a maximum value of 4.7 mm/day and minimum of 2.1 mm /day.

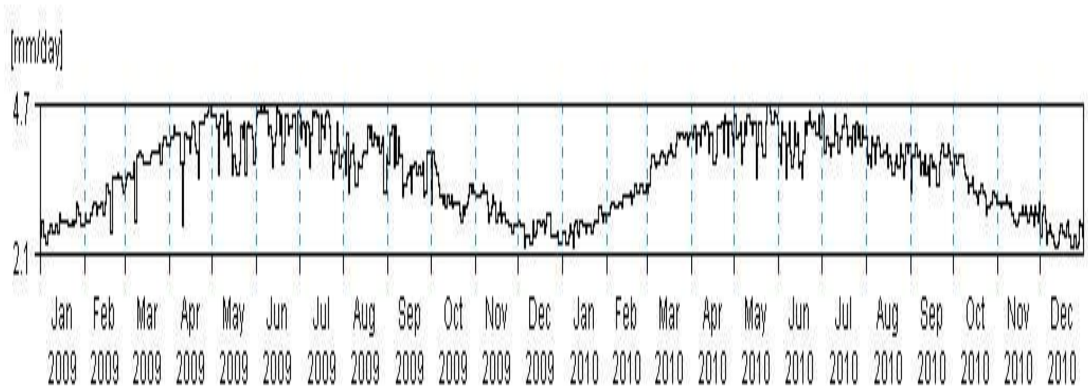


Figure 6.9 Reference evapotranspiration time series data

The actual ET was calculated by MIKE SHE based on empirical equations, derived by Kristensen and Jensen in 1975 during the simulation as a function of the land use type by taking into account of leaf area index (LAI), root zone depth (RD) and crop coefficients. LAI is defined as the area of leaves per unit ground surface area and the value varies between 0 and 7 based on the crop type. Root zone depth is defined as the depth of roots establishment and it various with vegetation type. The vegetation details have been characterized under the land use section. Polygon shapefile of land use map prepared using LISS IV Remote sensing data was used which consists of cropland, barren land and degraded land, settlement and industries, shrubland etc. was given as input.

In the study sub-basin, crop production has been practiced only for two seasons. Samba season in which almost all the cultivable areas are under Paddy crop and during the second season farmers cultivate millets and other vegetable crops. The LAI, RD and crop coefficients for various land use types were specified in MIKE SHE. Crop coefficients, LAI and rooting depth for paddy, millet crops and shrubs are obtained from reviewing various literature (Mahajan et al. 2011& Wijesekara 2013) and specified for each land use type and are given in Table 6.1.

Table 6.1 LAI, RD and Kc values for different land use

Land Use Type	**LAI (m^2 m^{-2})**	**Root depth (mm)**	**Crop coefficient (K_c)**
Shrub land	5	2400	0.8
Paddy crop	3.5	450	0.8
Millet and vegetable crops	3	700	0.65
Water bodies	0	0	1
Degraded or Barren ground	0	0	1
Buildups and settlement	0.5	100	-

Hydraulic conductivity of top soil ascertains the amount of infiltration. The distributed soil map depicts the distribution of soil texture types such as sandy loam, clay loam, clay, loamy sand, sandy clay loam and silty loam etc., Distributed soil map was prepared as polygon shape file and each soil polygon possesses different vertical layers. The number of vertical layers varies from two to six. Each layer will have its own hydraulic properties. Hydraulic properties of the unsaturated zone such as saturated hydraulic conductivity and water retention capacity are calculated using ROSETTA calculator which is being used in HYDRUS 1D model. ROSETTA calculation requires the percentage of sand, silt and clay for obtaining hydraulic properties. Both layer-wise and polygon wise hydraulic properties were calculated and the complex unsaturated zone structure had been characterized.

MIKE SHE also enables vertical discretization of the unsaturated columns. Polygons having similar soil type can be considered as separate columns. Each layer of the column has been discretized into several numbers of cells that decide the layer thickness. Cell size represents the layer thickness at the top of the unsaturated zone and is small with 0.1 mm and its size has been gradually increased along the depth as 0.2 mm, 0.5 mm and 0.6 mm. Total depth of top soil is 1.5 m and unsaturated layer extends up to the weathered gneiss layer. The level of dynamic water table decides the depth of unsaturated zone.

6.2.3.2 Dataset up and characterization of saturated zone

Types of geological layers and their hydraulic properties were given as input in saturated zone module. Datasets pertaining to the saturated zone are Horizontal and vertical hydraulic conductivities and Specific yield. A single layer has been considered for saturated zone demarcation as hard rock protrude at just a few meters below ground level in the study area. The lower level of the aquifer i.e. aquifer bottom was defined as distributed raster map in ArcGIS software. Values of horizontal and vertical hydraulic conductivities and specific yield obtained from the pumping test data were given as input.

6.2.3.3 Interaction mechanism between tank and aquifer

The mechanism of exchange of water from tanks with that of the aquifer has been described here. In this study, the tank-aquifer exchange can be calculated in both ways i.e. inflow to the tank from the aquifer and flow from tank to the aquifer which depends on the head gradient available to the adjacent groundwater cells. The assumption is said to be valid in the domain if the width of the stream (tank) is small when compared to the model cells. The exchange flow Q, between a saturated zone grid cell and the tank, is calculated as a conductance C, multiplied by the head difference between the river and the grid cell and is given by

$$Q = C \times \Delta h \qquad (6.15)$$

The Equation (4.15) is calculated twice - once for each cell on either side of the stream (tank) link. This allows for different flow to either side of the stream when there is a groundwater head gradient across the stream. The head difference between a grid cell and the stream is calculated as

$$\Delta h = h_{grid} - h_{str} \qquad (6.16)$$

where h_{grid} is the head in the grid cell and h_{str} is the head in the stream (tank) link. If the groundwater level drops below the stream bed elevation, the head difference is calculated as

$$\Delta h = z_{bot} - h_{str} \qquad (6.17)$$

where, z_{bot} is the bottom of the simplified stream (tank) link cross section, which is equal to the lowest point in the MIKE 11 cross-section. In Equation (6.15) the conductance C, between the cell and the river link will depend on the conductivity of the aquifer material only.

6.2.3.4 Initial and boundary conditions and simulation time steps

Important parameter required by the distributed model is the surface roughness coefficient or Manning‘s 'm' which is the inverse of the commonly used Manning’s 'n' (Stickler roughness coefficient). Manning's m for the different land uses was assigned in distributed manner which was taken from Manning's n table (Venti Chow 1959). Each tank was assigned its own detention depth which varies from 1648 mm to 4139 mm.

Areas excluding tanks were assigned a detention depth of 1 mm. Initial water depth is the depth of water present above the ground surface during the initiation time of simulation. Tank water depth has been defined as initial water depth in this study. Periodically monitored tank water levels and the stage details were assigned as time series file. Stages rise to full tank level during monsoon season i.e. from October to December and are emptied during the dry period. As the simulation period starts by January, obviously the tanks were empty and hence the value of zero was assigned. Detention storage depth has also been defined in the same manner. The depth of water assigned is the boundary condition for overland flow. Threshold water depth for the overland flow was kept as 0.001 m and the threshold gradient for applying low gradient flow reduction was kept as 0.0001 m.

For the saturated zone, initial potential head, outer and internal boundaries were defined in a distributed manner. The initial potential head was defined using the groundwater levels at the start of the simulation period. Zero flux was assigned for outer boundary condition. For internal boundary condition, the water levels in tanks are assigned. The internal boundary in MIKE SHE has to be defined only if internal boundaries of tanks or streams were not defined in MIKE 11 simulation engine. As this study involves different scenarios, internal boundary conditions were defined in both MIKE SHE and MIKE 11 and the appropriate module was selected according to the scenarios. For the pumping wells as the study area comprises of dug wells as rock outcrop encountered at lower depth from ground level, limited pumping is only possible and exact distributed pumping data were not available.

The groundwater draft was given based on the GEC (Groundwater Estimation Committee) recommendations estimated in chapter 5. This ascertains the total groundwater draft and the draft for domestic and agriculture use tank wise. The total draft was distributed in tank command wise and was assumed to be pumped at dry seasons i.e. April and September by a single well in that block. Dug wells were modeled as bore wells by increasing the filter depth i.e. entire depth of the well was assumed to be the filter depth so that it matches with the pumping of dug wells.

Three years of measured water level data of tanks and observation wells are available for model calibration and validation. Two years period from 01st January 2009 to 31st December 2010 was chosen for calibration and the period 01st January 2011 to 31st December 2011 was chosen for validation. These three years were considered as dry, wet and normal year based on the rainfall of 387 mm in 2009, 1158 mm in 2010 and 701 mm in 2011. The model was calibrated over a period of a wet and dry year from January 2019 to December 2010 and validated for the normal year from January 2009 and December 2009 respectively. The initial time step was set as 24 hrs. The maximum overland time step was kept as 30 minutes.

MIKE SHE has the flexibility of using variable time steps for simulation while modelling the flow characteristics and various hydrological processes (Demetriou and Punthakey 1999). Thus the tank cascaded study area characteristics of surface, subsurface and saturated zones were set up and represented very well using the coupled MIKE SHE /MIKE 11 model. The simulation of flow processes were carried out and the model results were evaluated through calibration and validation process.

CHAPTER 7

RESULTS AND DISCUSSION OF SUB-BASIN STUDY

7.1 GENERAL

The coupled and integrated model MIKE SHE / MIKE 11 was set up with the study area characteristics of surface, subsurface and saturated zone. The coupled model has been able to simulate the hydrological components of the tank cascaded catchment. The model simulation has to be evaluated through calibration and validation of simulated values with that of observed values. Two parameters have been chosen for this purpose, which are runoff discharges to the tank systems and groundwater levels. Simulated discharges i.e. flow that reach the tank system after being routed through overland and other tanks have been compared against the observed runoff yield to the tank system.

Computation of runoff yield reaching the tank system can be determined using the Stage Vs Discharge curve of the tanks as direct flow data are not available. The change in the Stage value of the tank provides the runoff reaching the tank system. Similarly, simulated groundwater levels are compared against the observed levels at the field in selected number of observation wells. Three years (2009, 2010 and 2011) of measured water level data of tanks and observation wells were used for calibration and validation. These three years were considered as dry, wet and normal year based on the rainfall of 387 mm in

2009, 1158mm in 2010 and 701mm in 2011. The model was calibrated over a period of wet and dry year and validated for the normal year of rainfall.

7.2 MODEL CALIBRATION

The process of model calibration involves adjusting the model parameters in such a way so that the simulated and observed values match to a better extent. In this process, some of the model parameters are varied by a trial and error procedure until it gets good convergence between simulated and observed values and by keeping all other parameters as constant. Manual calibration of an integrated model is difficult and time-consuming as well. Hence Auto calibration was done by defining upper & lower bounds and an initial value for each parameter.

Several hundreds of run were made to calibrate the model until it fetches convergence. Sensitivity analysis was not done as it required a high computational time of 6.5 hours for a single run. Auto calibration was done for the wet and dry year of rainfall period from 01/01/2009 to 31/12/2010 with the objective function of observation values given for discharges at three tank outlets and head elevation in eleven observation wells. The three tanks taken were namely Oorampatti situated at the head reach, Sitturajapuram at the middle reach and Muthalanaikanpatti at the tail reach of the tank cascade system.

7.2.1 Calibration parameters

The catchment characteristics of the physical and hydrologic components are represented by model parameters. An iterative process during calibration, sets the model parameters from within an appropriate range so that the simulated and observed values match to a better extent. As distributed data was available for the overland flow module and are able to characterize fully, hydraulic parameters of unsaturated and saturated zones such as horizontal hydraulic conductivity, vertical hydraulic conductivity and specific yield of saturated zone parameters were taken for calibration.

Refsgaard & Storm (1995) mentioned that the number of parameters taken for adjustment during the calibration process of a distributed hydrological model like MIKE SHE should be as small as possible. Population Simplex Evolution method has been used for calibration with a maximum 150 number of model runs and population size of 25 with a number of loops as 5. The initial parameter values and the ranges taken for model calibration are given in Table 7.1.

Table 7.1 Initial values and ranges for parameters of model calibration

S.No	**Parameters**	**Unit**	**Initial Value**	**Lower Bound**	**Upper Bound**
1	Horizontal Hydraulic Conductivity	m / s	7.932E-05	5.794E-06	8.612E-04
2	Vertical Hydraulic Conductivity	m / s	1.913E-06	5.793E-07	8.795E-05
3	Specific Yield	-	0.0838	0.011	0.312

After a long period of simulation, Autocal tool produced reasonable hydraulic parameter values of horizontal hydraulic conductivity, vertical hydraulic conductivity and specific yield values and are given in Table 7.2.

Table 7. 2 Auto calibrated values of the model parameters

S.No	Parameters	Unit	Auto-calibrated values
1	Horizontal Hydraulic Conductivity	m /s	7.742E-04
2	Vertical Hydraulic Conductivity	m /s	8.613E-05
3	Specific Yield	-	0.0164

7.2.2 Model performance assessment

The quality of calibration process can be analyzed from the degree of deviation of values between observed and simulated data. The model simulation results can be evaluated using statistical measures. Statistical parameters such as Mean Error (ME), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Mean deviation and Correlation coefficients were used to analyze the results in order to evaluate the model performance during calibration and validation process.

Mean error is the measure of on average the predicted water levels and runoff, higher or lower than those of observed values. MAE is the measure of average deviation between observed and simulated water levels or runoff. RMSE is similar to standard deviation which is the measure of the difference between predicted and observed values and is more sensitive to the extreme values. It is sensitive to the extreme values and deals with both systematic and random errors. The Nash and Sutcliffe coefficient measures the goodness-of-fit between observed and simulated daily stream flow and ground water levels. The qualitative assessment of model performance can be obtained through graphical displays of hydrographs and head elevations of the observation wells. The correlation coefficient and error matrix value of observed and simulated values of calibration process is given in Table 7.3.

Table 7.3 Correlation Coefficient and Error Matrix of observed and simulated discharges and head elevations in saturated zone after calibration

Name	Data type	ME	MAE	RMSE	STDres	R (Correlation)
HEAD@WELL2	head elevation in saturated zone	3.74	5.38	6.47	5.28	0.55
HEAD@WELL10	head elevation in saturated zone	2.93	3.11	4.04	2.78	0.70
HEAD@WELL11	head elevation in saturated zone	0.11	1.40	1.63	1.63	0.87
HEAD@WELL20	head elevation in saturated zone	0.56	1.32	1.54	1.43	0.85
HEAD@WELL23	head elevation in saturated zone	-2.29	2.40	2.82	1.65	0.92
HEAD@WELL24	head elevation in saturated zone	0.06	1.84	2.27	2.27	0.83
HEAD@WELL25	head elevation in saturated zone	-4.83	5.12	5.51	2.65	0.75
HEAD@WELL36	head elevation in saturated zone	-4.25	4.31	5.12	2.85	0.78
HEAD@WELL48	head elevation in saturated zone	-6.58	6.72	7.72	4.05	0.30
HEAD@WELL61	head elevation in saturated zone	-0.83	3.04	3.41	3.31	0.25
HEAD@WELL65	head elevation in saturated zone	0.78	3.75	4.55	4.49	0.70
Sim:Q@oorampatti	overland flow @ tank outlet	0.267	0.267	1.258	1.117	0.90
Q@sitturajapuram	overland flow @ tank outlet	-0.242	0.242	1.290	1.186	0.95
Q@mutalanaikkanpatti	overland flow @ tank outlet	-0.021	0.055	0.913	0.908	0.95

The correlation coefficient values are above 0.7 expect for the wells No. 2, 48 and 61. The error matrix value shows minimum errors except for the well No. 2, 10 and 48. All other observation wells and tank discharge values the error of ME, MAE, RMSE is less than ± 5 which is generally accepted. This indicates that model predictions are quite accurate.

7.3 MODEL VALIDATION

The model was validated using the parameters that are fine-tuned in the calibration process using the observed data. Entire model setup was kept constant except the rainfall was changed to validate the model for the period from 1/1/2011 to 31/12/2011 (normal year). Upon successful validation of the model, simulated runoff yield to the tank system and groundwater levels were analyzed using the observed data through statistical parameters. Correlation coefficient and Error matrix of observed and simulated discharges at the three tanks and head elevations at eleven observation wells of validation process have been given in Table 7.4. The error matrix of validation process shows much minimum error, most of them within ± 5.

Statistical parameters were used to analyze the results of the validation process. The coefficient of determination is a measure of accuracy to which the measured values match with that of predicted values. The average deviation provides the information of whether the model over or under-predicted the values. The Nash-Sutcliffe coefficient is the measures of goodness-of-fit between observed and simulated values of water levels and runoff.

Table 7.4 Correlation coefficient and Error matrix of observed and simulated values after validation

Name	Data type	ME	MAE	RMSE	STDres	R (Correlation)
HEAD@WELL2	head elevation in saturated zone	7.50	9.19	10.17	6.86	0.58
HEAD@WELL10	head elevation in saturated zone	5.09	5.78	6.45	3.96	0.72
HEAD@WELL11	head elevation in saturated zone	1.80	2.77	3.05	2.46	0.88
HEAD@WELL20	head elevation in saturated zone	0.56	1.35	1.57	1.47	0.84
HEAD@WELL23	head elevation in saturated zone	-2.30	2.41	2.83	1.65	0.92
HEAD@WELL24	head elevation in saturated zone	0.04	1.85	2.27	2.27	0.83
HEAD@WELL25	head elevation in saturated zone	-4.86	5.14	5.54	2.66	0.75
HEAD@WELL36	head elevation in saturated zone	-4.25	4.31	5.11	2.84	0.78
HEAD@WELL48	head elevation in saturated zone	-6.69	6.83	7.87	4.14	0.38
HEAD@WELL61	head elevation in saturated zone	-0.93	3.13	3.52	3.40	0.30
HEAD@WELL65	head elevation in saturated zone	0.74	3.77	4.57	4.51	0.70
Sim:Q@oorampatti	overland flow @ tank outlet	0.281	0.281	1.302	1.271	0.91
Q@sitturajapuram	overland flow @ tank outlet	-0.288	0.288	1.308	1.276	0.96
Q@mutalanaik kanpatti	overland flow @ tank outlet	-0.027	0.056	0.940	0.939	0.96

The statistical analysis shows that the correlation coefficients were above 0.7 for all wells except for well No. 2, 48 and 61 and for discharge at tanks all are above

0.9 which shows a good correlation between the simulated and observed values. The modelling error matrix values were found to be very low further indicating good simulation of the coupled model. The deviation in three wells of well No. 2, 10 and 48 seems to be slightly high may be because of change due to pumping wells nearby and can be minimized if pumping data of wells in the surrounding area are taken accurately

The qualitative assessment of model performance was obtained through graphical displays of hydrographs at the tanks and head elevations of the observation wells and is given in Figure 7.1 and Figure 7.2. The calculated Nash-Sutcliffe coefficients were given in Figure 7.1 for the tank discharges at three tanks namely Oorampatti tank at the upstream, Sitturrajapuram tank in the middle and Muthalanaikkanpatti tank at the downstream. The Nash-Sutcliffe coefficients for these three tanks were found to be 0.91, 0.94 and 0.92 respectively and that confirms the good prediction capability of the model.

7.4 WATER BALANCE ANALYSIS

Water balance analysis has been done for the years 2009, 2010 and 2011. The annual water balance summaries for the three years (dry, wet and normal years) are presented in Table 7.5. For the year 2011, which resulted in normal rainfall, the overland storage was found to be 5.75 MCM and groundwater storage as 19.8 MCM. The year 2009 was found to have low overland and groundwater storage due to the dry year resulted in a rainfall of 387 mm. The overland storage and groundwater table in the year 2010 was found to be higher when compared to the previous year 2009 that is because of the occurrence of excess rainfall in that year measuring 1158 mm. It is evident from this table that Integrated model is capable of quantifying the water availability at micro scale in an efficient manner.

Table 7.5 Water budget analysis for Sindapalli Uppodai sub-basin

Sub-basin area: 144 (sq.km)	**2009 (Dry year)**		**2010 (Wet Year)**		**2011 (Normal year)**	
	mm	**MCM**	**mm**	**MCM**	**mm**	**MCM**
Overland storage	22.87	3.24	69	9.78	40.62	5.75
Groundwater storage	80.12	11.37	238.01	34.72	140	19.88

The total storage capacity of all the tanks in the sub-basin has been estimated as 9.056 MCM. The overland storage estimated for the wet year 2010 is 9.78 MCM indicating that in that year almost all the tanks were filled due to excess rainfall and the difference in value is the amount of runoff stored in depressions and drainage channels. The model thus able to characterize and simulate the tank cascaded catchment very well. Groundwater head elevations in the saturated zone was also simulated successfully using three-dimensional Darcy’s equation by groundwater solver of MIKE SHE. MIKE SHE has taken care of the effects of tanks by considering the tank recharge component in an effective manner. The evaluation of calibration and validation process with the statistical parameters and the water balance analysis indicates the good performance of the model in generating the surface and groundwater flow through the tank cascade system.

7.5 SCENARIO SIMULATIONS

The fully calibrated model was further analyzed in order to identify the effects of incorporation of tank cascades through scenario simulation. For this purpose, three scenarios were formulated. Scenario one involves simulation of surface and groundwater with integrated MIKE SHE model without incorporating the tank cascade (surface storage) system. Scenario two involves integrated coupled MIKE SHE/MIKE 11 simulation with the incorporation of tank cascades system. Scenario three involves integrated coupled MIKE SHE/MIKE 11 simulation with the tank cascades (MIKE 11) and natural depressions

Scenario 1: Integrated MIKE SHE model without tank cascade

Scenario 2: Integrated MIKE SHE with tank cascades (MIKE 11coupled)

Scenario 3: Integrated MIKE SHE with tank cascades (MIKE 11) and natural depressions

7.5.1 Scenario 1: Integrated MIKESHE modelling without tank cascade

To facilitate this analysis, only MIKE SHE simulation engine was consideration i.e. without tanks. In this case, the detention storage was assigned a uniform value of 1 mm for the entire basin. Maximum flow observed in the sub-basin was 96 m^3/s. The difference in head elevations given by the model and observed data is more as tank recharge is discarded when tank cascade is not taken into consideration. Figure 7.1 shows the head elevations in observation well without considering tank cascade.

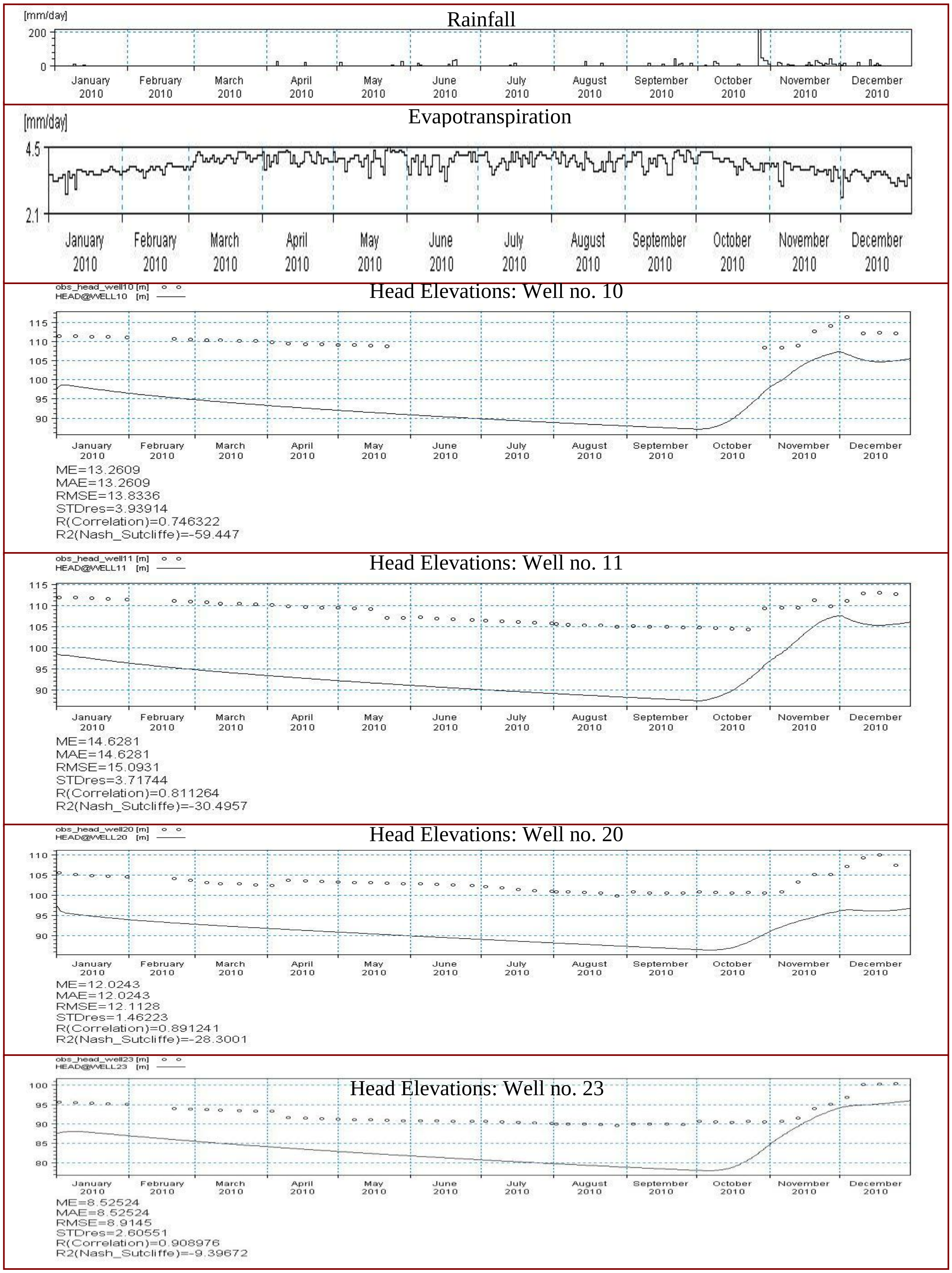


Figure 7.1 Head elevations in observation well without considering tank cascade

7.5.2 Scenario 2: MIKE SHE with tank cascades (MIKE 11)

For this analysis, tank cascades modelled in MIKE 11 was coupled with the integrated model MIKE SHE. In this case, the detention storage was assigned as zero for the entire basin as tank hydraulic particulars and boundary conditions (inflow for each tank) were defined in MIKE 11 itself. Figure 7.2 shows the hydrograph at tank outlet in the year 2009-2010. The presence of tank cascades arrested the flow of water then and there and hence the flow was found reduced in the streams. Obviously, the flow during the month of November 2010 was reduced slightly due to interventions of tanks. Groundwater levels were found to be increased from November to December as a portion of water allowed to enter the aquifer is more than the case where tanks were not included. i.e. Flow during the end of October was stored in tanks and were allowed to enter aquifer during November to December. Hence an increasing 'S' pattern is observed. Whereas when tanks were not considered, water level started to increase during October itself and started decreasing or remains same during November to December. Hence Scenario 1 proves that the model is capable of analyzing change in flow and phreatic depth at a regional scale.

Saturated hydraulic conductivity of the vadose zone and tank bed conductance played a major role in this scenario as the rate of infiltration and quantum of water entering the aquifer were decided by these parameters. Tank bed conductance was in the range of 0.03 m^2/s and considered as uniform over the study area. It was calculated based on the following formula

$$C = (K_v \text{ x } W \text{ x } B) / D$$

Where C – Tank Bed Conductance (m^2/s)

K_v – Hydraulic Conductivity (m/s)

W – Width of cell (m); B – Breadth of cell (m)

D – Depth of aquifer (m)

Ground water head elevations for the period 2009-2010 for four observation wells were shown in Figure 7.3.

7.5.3 Scenario 3: MIKE SHE with tank cascades (MIKE 11) and natural depressions

In this analysis, tank cascades modelled in MIKE 11 was coupled with the integrated model MIKE SHE and natural depressions were also considered. The inclusion of natural depressions was done in MIKE SHE simulation engine by delineating polygons representing area and storage depth of the natural depressions. Storage depth of natural depressions varies from 0.3 m to 1.5 m which were surveyed with hand GPS. Also, no variation in depth to the phreatic surface was observed. Incorporation of tank cascades in an integrated model itself is a new approach. This approach was improved to the next degree by incorporation of natural depressions so as to find the applicability of integrated model in micro level. In this scenario, no change in the quantum of flow at tank outlets and depth to the phreatic surface was noticed. This is due to less available data regarding natural depressions.

If the natural depressions would have been modelled in MIKE 11 in a detailed manner as done for tank cascades, it might have produced better results which require extensive data such as cross section area of natural depressions, improved drainage pattern and exact alignment & cross sections of streams carrying away flow from natural depressions. Topographic survey on a larger scale such as 1:1000 or 1:2000 is required for preparation of the above-said data sets.

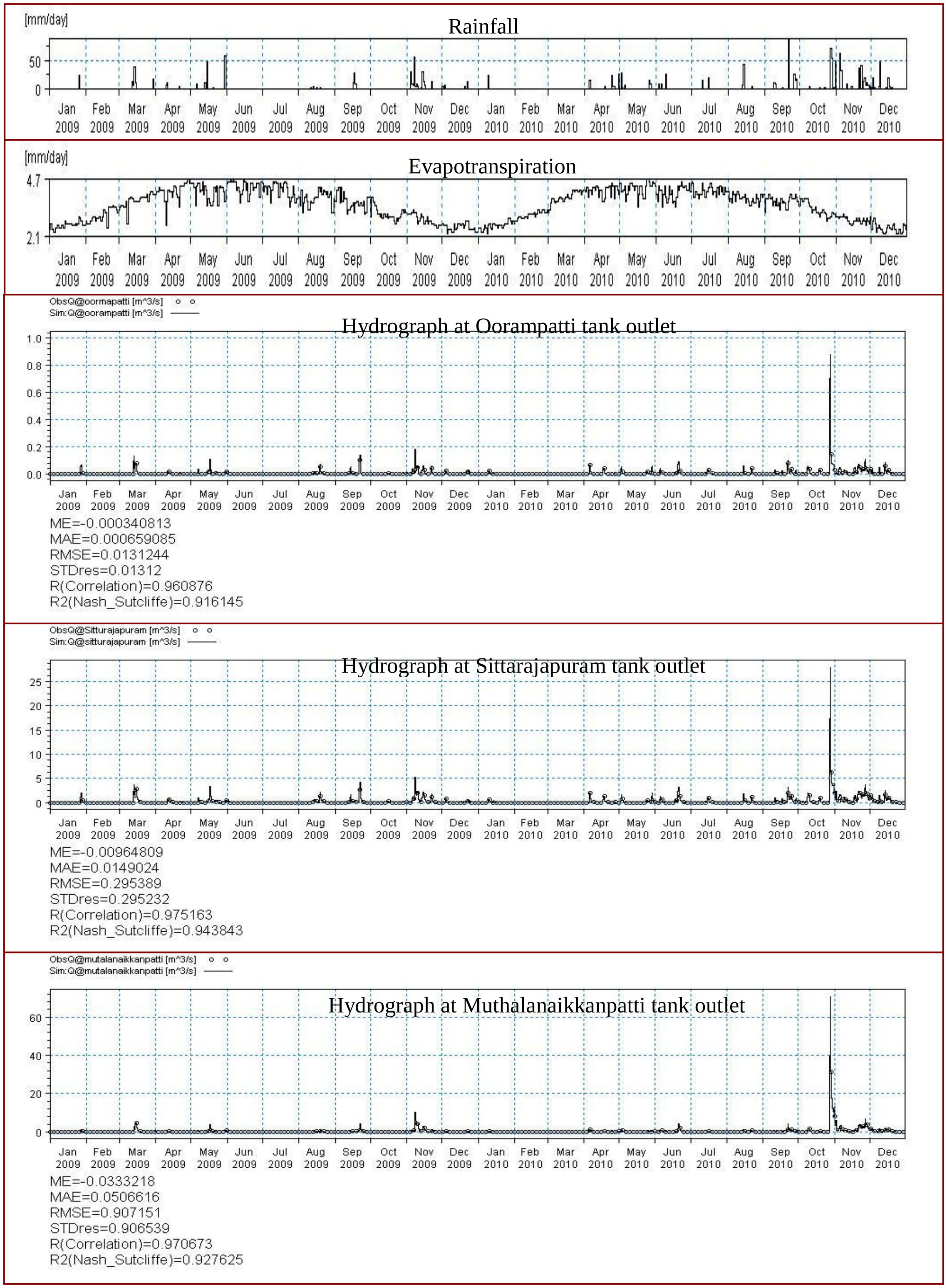


Figure 7.2 Results of observed and simulated Hydrographs at tanks outlet

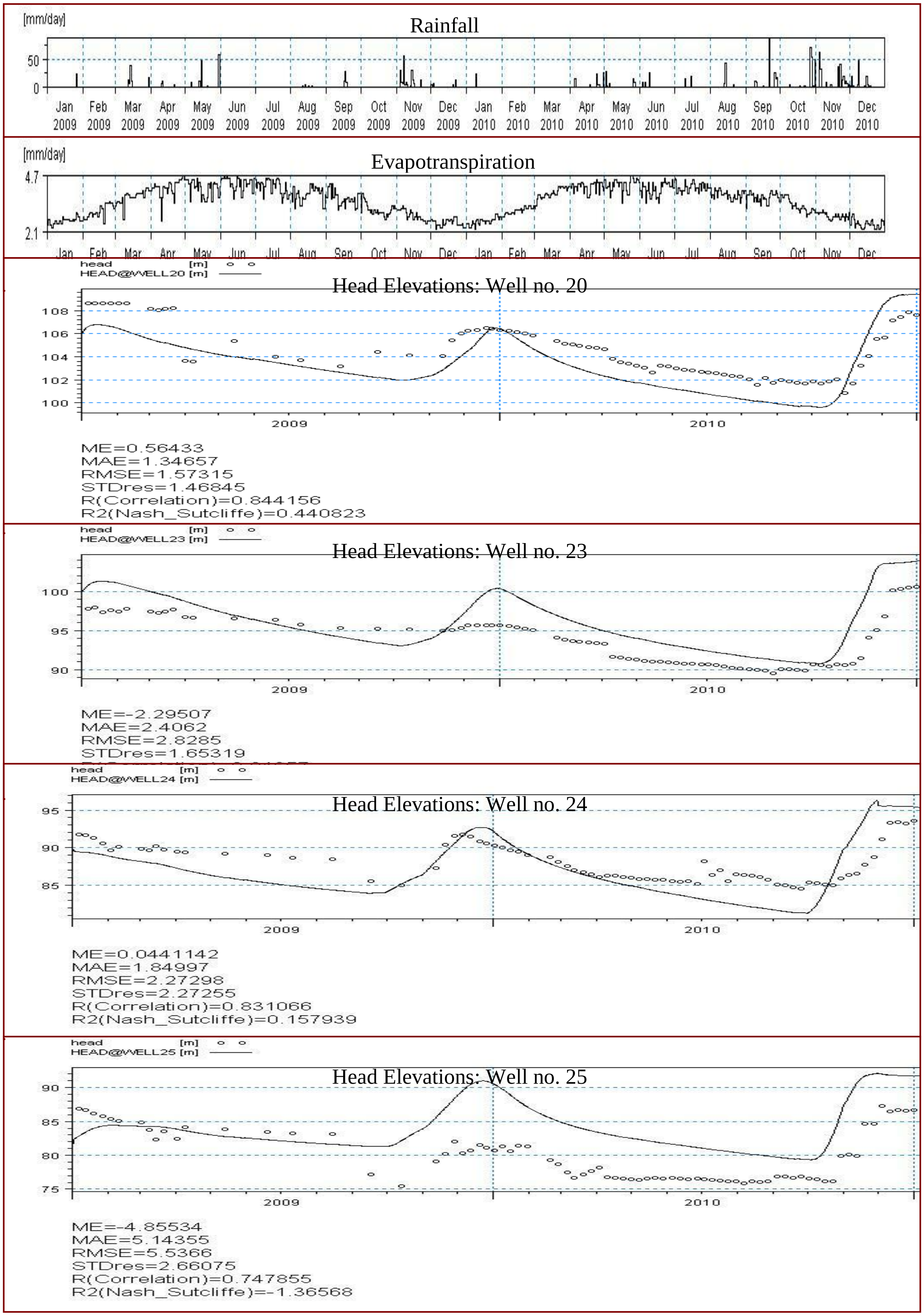


Figure 7.3 Head elevations in observation wells considering tank cascade system

7.6 DISCUSSIONS OF THE RESULTS

(I) Integrated Modelling in MIKE SHE with the incorporation of tank cascaded system shows that there was a change in Overland flow when tank cascades were incorporated with the integrated MIKE SHE model. After incorporation of tank cascades; overland flow has been found to be reduced.

(ii) Water balance analysis has been done for the years 2009, 2010 and 2011. The annual water balance summaries for the three years (dry, wet and normal years) are presented in Table below. For the year 2011, which resulted in normal rainfall, the overland storage was found to be 5.75 MCM and groundwater storage as 19.8 MCM. The year 2009 was found to have low overland and groundwater storage due to the dry year resulted in a rainfall of 387 mm. The overland storage and groundwater table in the year 2010 was found to be higher when compared to the previous year 2009 that is because of the occurrence of excess rainfall in that year measuring 1158 mm. It is evident from the table below that the Integrated model is capable of quantifying the water availability at micro scale in an efficient manner.

(iii) The total storage capacity of all the tanks in the sub-basin has been estimated as 9.056 MCM. The overland storage estimated for the wet year 2010 is 9.78 MCM indicating that in that year almost all the tanks were filled due to excess rainfall and the difference in value is the amount of runoff stored in depressions and drainage channels. The model thus able to characterize and simulate the tank cascaded catchment very well. Groundwater head elevations in the saturated zone was also simulated successfully using three-dimensional Darcy's equation by groundwater solver of MIKE SHE. MIKE SHE has taken care of the effects of tanks by considering the tank recharge component in an effective manner. The evaluation of calibration and validation process with the statistical parameters and the water balance analysis indicates the good performance of the model in generating the surface and groundwater flow through the tank cascade system.

(iv) Upon inclusion of tank cascades, a change in recharging pattern in saturated zone has been observed. When tanks were not included, the flat and drop trend was observed in groundwater levels during the month of November and December 2009. Also the water level started rising in the month of October itself. Maximum rainfall (around 200mm) occurred in the study area during the end of October 2009, as tanks were not included, there was no delay in recharging time and hence water level raised by October 2009 itself which was not the original case in the study area.

(v) Upon inclusion of tank cascades, the ground water levels were same up to start of November and increasing gradually to form an increasing “S” pattern during November and December. The delay in rising of water levels is due to the presence of tank cascades. Rainfall occurred during end of October 2010 was stored in tanks and gradually allowed to enter the aquifer. This phenomenon made a change in the recharge pattern during November and October 2010. The inclusion of tanks have been captured well by the integrated model. This proves the importance of surface bodies in the integrated analysis.

CHAPTER 8

SUMMARY AND CONCLUSIONS OF THE MICRO LEVEL STUDY

8.1 SUMMARY

The primary and secondary data are used to set up the complex integrated model by coupling MIKE SHE and MIKE 11 model and the dynamics of water movement has been simulated successfully. The model simulation has been evaluated through calibration and validation of simulated tank yield and head elevation values of well with that of observed values. Three years (2009, 2010 and 2011) of measured water level data of tanks and observation wells were used for calibration and validation.

The statistical parameters obtained from the calibration and validation such as error matrix, correlation coefficient and Nash-Sutcliffe coefficient values indicate good simulation and prediction capability of the integrated model developed for the tank cascaded catchment. The semi-arid sub-basin features and processes comprising of surface tank cascades and stream networks, unsaturated and saturated zones were able to be characterized well and simulated successfully by the coupled MIKE SHE/MIKE 11 model in an integrated manner. GIS has been found to be very useful in creating the database for setting up the model.

8.2 INFERENCES OF THE STUDY

(i) Overland flow through tank cascades and stream network was routed in a distributed manner using diffusive wave approximation of Saint Venant's equation. The presence of tank cascades arrested the flow of water and hence the flow was found to be reduced in the streams. Hydrograph at tank outlets was found to match with the observed values and peak flow has been observed to increase almost in all the tanks by the end of October, because of the Northeast monsoon.

(ii) Groundwater head elevations in the saturated zone have been simulated successfully using three-dimensional Darcy's equation using groundwater solver of MIKE SHE. The maximum flow in saturated zone was observed to be more for scenario 2 analysis, carried with by incorporation of tank cascades than for scenario 1 analysis, considered without tank cascades. This increase in flow in Scenario 2 is due to storage of water in tank cascades and hence the water recharge from the surface storage structures, tanks to the aquifer has been ensured.

(iii) Integrated water balance analysis done using water balance tool of MIKE SHE results in determining total overland storage for the year 2010 which received excess rainfall than the normal as 9.78 MCM and was found to match with the full tank capacity levels of all the tanks as 9.056 MCM. Also, the subsurface storage was calculated as 34.72 MCM. This kind of water budgeting analysis helps in promoting the regional water budgeting computation at a micro level, which is essential for a semi arid region.

(iv) Scenario analysis indicates the change in overland flow and recharging pattern in the saturated zone when tank cascades were incorporated in the model. In scenario 1 without tank cascade, the flat and drop trend observed in groundwater levels during the month of November and December and rise in water level starts in the month of October itself. In scenario 2, upon the inclusion of tank cascades, the water levels were same up to the end of October and increasing gradually to form an increasing “S” pattern during November and December. The delay in rising of water levels is due to the presence of tank cascades. Rainfall occurred during the end of October was stored in the tanks and gradually allowed to enter the aquifer.

Analysis of results shows that the model is capable of simulating physical processes in a tank cascaded semiarid sub-basin effectively through modular approach. Hence it is understood from the study that any hydrological analysis should taken into account of the surface water bodies without fail. As all the hydrologic processes are interlinked, a change in one component seriously affects the other. In order to have a sustainable development, integrated hydrological analysis is must. MIKE SHE integrated model serves the purpose well and found to be the best integrated model. Quantification of surface water and ground water availability could be done in an integrated manner accurately. The capability of MIKE SHE to analyse tank catchment wise water budget would help water users and planners to utilise the available water in a sustainable manner.

8.3. Conclusions/Recommendations

(i) Analysis of results shows that MIKE SHE along with MIKE 11 is capable of simulating physical processes in a tank cascaded semiarid sub-basin effectively through modular approach.

(ii) The study reveals the importance of incorporating the surface water bodies in modelling as it has great influence on water balance analysis of integrated modelling and for appropriate water resource estimation.

(iii) The Scenario analysis with and without inclusion of tank cascaded system indicates the change in overland flow and recharging pattern in the saturated zone when tank cascades were incorporated in the model. Thus the inclusion of tank cascaded system in the model helps in assessing water resource potential accurately and may lead to optimal and sustained utilization of resources.

8.4. How do the conclusions/ recommendations compare with current thinking:

The study reveals that the components and physical process of the tank cascaded catchment have been captured by the model very well. The study also proves that the importance of incorporation of surface water bodies in hydrological simulation has great influence on water balance. Thus this study helps in determining the accurate estimation of surface and groundwater potential for the catchments with invening surface storage structures like tanks, lakes and reservoirs. Potential estimation and water balance analysis using mathematical models are important for the optimal allocation for various purposes like agriculture, domestic and industrial use in a tank cascaded catchments.

8.5. Field tests conducted

i. Tank Capacity survey was done and Stage Vs Capacity curves were developed for all the tanks of the study area.

ii. The tank water level during the monsoon were monitored.

iii. Infiltration test has been carried out at various locations.

iv. Soil samples were collected and textural analysis of soil was done.

v. Groundwater well network was established and the ground water level was monitored in the sub basin.

vi. Pumping test was carried out at one location for determining the specific yield.

vii. Resistivity survey was done at nine locations of the study area.

8.6. Software generated, if any:

MIKE SHE developed by DHI, a physically based model is used in the study.

8.7. Possibilities of any patents/copyrights. If so, then action taken in this regard:

This project attempted the pioneer study of incorporation of the tank cascaded system by coupling MIKE SHE and MIKE 11 for simulating the surface and ground water potential. A copyright of this work has to be obtained.

8.8. Suggestions for further work

(i) Use of high-resolution digital elevation model with a reduction of cell size from 90m to 60m or 30m may help in to incorporate small natural depressions and also may result in good convergence of model results.

(ii) The small natural depressions and establishing their link to nearby streams or tanks can be considered while modelling in MIKE 11.

Hydrological modelling of water resources is vital for any water resources project planning. Tanks are the predominant water storage structure in South India. Understanding the hydrological processes of tank cascades basin is a complex and challenging task. The present study attempted the incorporation of tank cascade in the integrated model MIKE SHE. Hence the yield calculation of such catchments with intervening storage structures can be carried out using the developed methodology of the present study.

Signature	Signature
(Head of the Department)	(Principle Investigator)
Name:	Name:
Date	Date

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APPENDIX I

Ph.D Thesis

1. R. Sudharsanan, "Rainfall-Runoff Modelling of Tank Clustered Catchment Using GIS", Ph.D Thesis, Anna University, 2014.

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APPENDIX II

PUBLICATIONS MADE OUT OF THE RESEARCH SCHEME

International Journal

1) R.Sudharsanan, Dr.M.Krishnaveni (2013),"Un-Gauged Tank Catchment Yield Estimation based on Synthetic Unit Hydrograph Method", International Journal of Earth Sciences and Engineering, Volume 06, No.02, Pg 347 – 353.

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National Journal

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