CHAPTER I
INTRODUCTION

1.1 Introduction

Water is one of the most important natural resource occurring both as surface water and groundwater. It is vital for all life on the earth. Developments of our society are dependent on the availability and use of adequate water. This precious resource is sometimes scarce, sometimes abundant, but unevenly distributed, both in space and time. Groundwater represents the second most abundant available freshwater resources and constitutes about 30% of fresh water resources of the globe (Subramanya 2008; Krishnamurthy and Srinivas 1995; Saraf and Chaudhary 1998; Pietroniro and Prowse 2002; Jaiswal et al. 2005; Hoffmann and Sander 2007; Hoffmann 2005; Prakash and Mishra 1993; Ballukranya 2001; Rai et al. 2005; Lancaster and Lancaster 1997; Abu-El Shar and Rihani 2007; Pliakas et al. 2005; Sharma and Murthy 1994; Constantz et al. 2001; Ghayoumian et al. 2007). More than 1.5 billion people in the world are known to depend on the groundwater for their drinking water requirements. The groundwater is derived from precipitation and recharge from surface water. It is the water that has infiltrated into the earth directly from precipitation, recharge from streams and other natural water bodies and artificial recharge due to the action of man. Groundwater has been a popular resource of water in many tropical countries. Groundwater is easy to extract, and it remains well
protected from the hazards of pollution that the surface water has to put up with. However, situations wherein we have encountered overexploitation of groundwater resources are not uncommon. Insufficient knowledge regarding the basics of groundwater is the primary reason why we have not been able to use groundwater resources to their full extent. Thus, there is a growing emphasis on groundwater management in the hard rock area (Idornigle et al. 2006; Shrivastva and Bhattacharya 2006; Bobachev 2003; Smith and Pain 2009; Jha et al. 2010; Singh and Singh 2009; Mukherjee 2008; Lokesh and Narayana 1996 and Rao 2002; Jarvis et al. 2006; Portoghese et al. 2005; Jha et al. 2007; Ibrahim et al. 2001; Al Qudah 2003; Abu Jaber et al. 1998; Bajjali and Abu Jaber 2001; Abu Jaber 2001; Sener et al. 2005; Solomon and Quiel 2006; Zohdy et al. 1974; Fitterman and Stewart 1986; Taylor et al. 1992; Majumdar and Pal 2005; Ayolab 2005; Al Azaizeh 2003; Kimberley and Abu Jaber 2005; Abu Jaber et al. 2003; Al Qudah 2003).

1.2 Overview of Groundwater in India

India is the largest country within the Indian Sub Continent, both in terms of land area and population. Major parts of the country receive precipitation between 750 and 1500 mm/year, with extremely low precipitation in the western parts (<150 mm/year) and some of the world’s highest rainfall in the northeastern parts (>2500 mm/year). Most of the total precipitation occurs during the southwest monsoon season from June to September (CGWB 2014b). The major aquifers are related to the major river
basins that drain the country. The total land of the country can be divided into 20 major river basins (CGWB 2014c), which may be further separated into four groups according to their origin and flow pattern. The Himalayan rivers are Ganges, Brahmaputra, Indus that originate from the melted high altitude glaciers and snow, and are perennial throughout the hydrological year, the rivers of Indian craton are Mahanadi, Godavari, Krishna, Pennar, Cauvery, Narmada and Tapti are mostly rain-fed and strive on baseflow, the coastal rivers, mostly non-perennial, and rivers of the western desert originate within small fluvio-aeolian basins, and are rain-fed ephemeral and disconnected from the groundwater systems. The Ganges basin system is the largest river system in the country, with a catchment area of 86.1 million hectare (CGWB 2014c).

The Indus Ganges, Brahmaputra (IGB) systems that together drain the northern Indian plains form a regional alluvial aquifer system that is regarded as one of the most productive aquifers of the world. In contrast, groundwater is available in a limited extent within the weathered zone and underlying fractured aquifers within the remaining two-thirds of the country. The northern porous and permeable aquifers are both of unconsolidated and semi unconsolidated alluvial sedimentary type whereas fractured aquifers are mostly composed of Pre Cenozoic crystalline rocks, consolidated sedimentary formations and multilayered basalt flows of the Indian craton (CGWB 2014b). Intense irrigational activities are prevalent in
the highly fertile IGB basin, which is also the most populous part of the country. Renewable groundwater resources have been estimated to be $433 \text{ BCM}$, with annual groundwater draft of $245 \text{ bcm}$ in 2011. Of these, $223 \text{ BCM}$ of groundwater was used for irrigation, and the rest $23 \text{ BCM}$ was used for domestic and industrial purposes (CGWB 2014b). Increasing agricultural demand for a rising population has resulted in a fourfold increase in production of crops (50–204 million tons) between 1950s to 2000 (Kumar et al. 2005) severely stressing groundwater resources. Rapid depletion in groundwater storage has been observed in the intense agricultural regions in the Indian Sub Continent (Rodell et al. 2009; Tiwari et al. 2009; Bhanja et al. 2014; CGWB 2014b). More than a 4 m decline in groundwater levels with respect to the decadal mean groundwater level has been observed in several parts of the country (CGWB 2014b). Additionally, similar to its eastern neighbor Bangladesh, groundwater in large parts of the north Indian shallow alluvial aquifers are anoxic, and are enriched with elevated As concentrations (Mukherjee et al. 2008; Saha et al. 2010; Bhattacharya et al. 2011, 2014).

Elevated groundwater, as concentrations have been identified in groundwaters of 86 districts in 10 Indian states (CGWB 2015). The pollution is believed to have further aggravated due to extensive groundwater abstraction (Mukherjee et al. 2011). High concentrations of groundwater fluoride have also been observed, mostly in the crystalline aquifers in parts
of 19 states (Maheshwari 2006; CGWB 2015). Elevated levels of groundwater iron (Fe) and nitrate (NO\textsubscript{3}-) have also been reported from several aquifers of the country (CGWB 2015). Seawater intrusion resulting in aquifer salinization has been observed in many of the coastal aquifers adjoining the Bay of Bengal and Arabian Sea, however, highly brackish groundwater are also prevalent in the inland aquifers of several states (CGWB 2015; Verma and Phansalkar 2007; Rodell et al. 2009; Tiwari et al. 2009; Shamsudduha et al. 2012; Bhanja et al. 2014; CGWB 2014a; Bates et al. 2008). Such inland salination may be linked with mineral dissolution and agricultural pollution. Frequent, wide spread floods, caused by intense precipitation and rejected recharge are common in parts of eastern India.

1.3 Groundwater in Tamilnadu

In the Tamil nadu state, There are four major geological formations. They are an Archaean group of rocks, upper gondwana group of rocks, Cretaceous formations, Tertiary formation.

\textit{Archaean group of rocks:} The Archaean formation consists of igneous and metamorphic rocks. It covers the entire Eastern Ghats and Western Ghats. It lies in the northwest, south and southwest portions and covers most of the regions of Tamilnadu and formed as a relict mountain. Generally, the unconfined aquifer is quite common in these formations. The average depth of weathered and jointed zones is extending upto 16 m, the
water table lies for about 13m below ground level. The water potential of these formations is moderate.

**Upper Gondwana group rocks:** In Tamilnadu the upper Gondwana formations are found in two different places, one west to Ariyalur and the other near Sriperumputhur area. The upper Gondwana clay formations act as a impermeable layer. Hence, the storage of water in these formations is very low.

**Cretaceous Formations:** the cretaceous formations are mainly found in and around Ariyalur area. Small patches of outcrops also occurs in northwest of Virudhachalam and Tanjore. The cretaceous formations are made up of compact calc sandstone. The area yield moderate potential of groundwater. Due to presence of fossil, gypsum and carbonate materials the quality of water is salty in nature. The cultivation in this region is very poor due to saltwater.

**Tertiary formation:** the tertiary formations are considered to be an important region to store huge quality of groundwater. The tertiary region lies all along the eastern coast of Tamilnadu. Most of the areas of this formation show the presence of an artesian aquifer. In Neyveli area the artesian aquifer lies at a depth of 75 m below groundwater. Below this first artesian aquifer there is also another confined aquifer, which lies at a depth of 92 m below ground level. In the first confined aquifer lignite seam act as an impermeable layer to create artesian condition. The confined aquifer also
found in the Aranthagi Taluk of Pudukkottai district. Aquifer in these regions also occurs at a depth of more than 300m. The flowing wells are found in Avudaiyar Kovil. Ambalavanan and Nagudi areas. The artesian aquifer also found in very deep levels in areas of Mannargudi and also in Thiruthuraipoondi area. In Thiruthuraipoondi the flowing wells are found in the town itself (Kulkarni et al, 2009; World Bank 2009; Shah 2009; Kulkarni et al. 2011; Vijay Shankar et al, 2011; Mac Donald Davies et al. 2005; Foster and Chilton 2003; Badarayani et al, 2009).

1.4 Need for Groundwater Management

The role of groundwater in the socio economic development of a country like India with an agriculture based economy cannot be over emphasized. Groundwater has occupied an important place in stabilizing Indian agriculture and as a means for drought management. The irrigation potential created from groundwater in the country increased phenomenally from 6.5 Million hectare (m ha) during 1951 to about 45 m ha during 2001 owing to its ubiquitous availability, low cost technology for its abstraction, government loans/subsidies and also deemed ownership as easement to land (Romani, 2006). This rapid growth of groundwater development without regulation, incentives for management has resulted in problems related to declining groundwater levels and deterioration of its quality in several parts of the country. There is concern among planners about the sustainability of groundwater resources, and in turn, the economy of the
country. Groundwater, being a hidden resource, needs to be developed with proper understanding of its occurrence and availability in time and space. Its scientific and judicious management is the key to sustainability of this vital resource.

1.5 Study Area

The Nagavathi watershed, lies in the Dharmapuri district of Tamil Nadu, falling between latitudes from 11°45'N to 12°15' N and longitudes from 77°30' E to 78°30 E. It covers within the Survey of India Toposheets nos. 57H/16, 57L/4, 58E/13, and 58I/1 and covers an area of about 482 km². The watershed area primarily shows dendritic to sub dendritic drainage patterns, consisting of about 650 streams which are ephemeral in nature and flowing from NE to SW direction.

The watershed is of 32 km length and is enclosed by Masakkallu reserve the forest in west, Thamboran malai in the east, Elagiri reserve forest in the centre and Mettur Stanley reservoir in south west. Groundwater is withdrawn from a several number of irrigation dug wells and bore wells as well as tanks and canals which have been developed across streams and watershed. The Nagavathi is a tributary of the Cauvery river appears only rainy season other season normally dry. The base map of the study area is shown in Fig.1.1.
Fig. 1.1 Satellite Image IRS P6 LISS IV of the Nagavathi Watershed
1.6 Administrative Setup

The Dharmapuri District in Tamil Nadu state in southern part of India. It is the first district detached from Salem district in Tamil Nadu after the independence of India. The geographical area of the district is 4498 sq.km and the district comprises two revenue divisions, namely Dharmapuri and Harur. There are seven taluks, namely Dharmapuri, Harur, Karimangalam, Nallampalli, Palacode, Pappireddipatti, Pennagaram. This district has one Municipality in Dharmapuri. There are eight panchayat unions including Dharmapuri, Nallampalli, Palacode, Pennagaram, Karimanagalam, Morappur, Harur, and Pappireddipatti. Dharmapuri District has Panchayats with 470 Revenue villages including 10 Town panchayats and 8 Panchayat Unions.

1.7 Transport and Communication

The Dharmapuri district is having a network of surfaced and unsurfaced roads. National Highways such as NH-7 connecting Kanyakumari and Kashmir, NH-46 linking Chennai to Bangalore and NH-66 from Pondicherry to Bangalore pass through the District and Salem and Bangalore. There are two broad gauge Railway lines linking Chennai through Morappur to Coimbatore and Chennai through Bangalore to Delhi passing through the District. Hogenakkal and Theerthamalai are two important tourist places of Dharmapuri District.

1.8 Agriculture

The District economy mainly depends on agriculture. Nearly 70% of the workforce is dependent on agriculture and allied activities. The district is
one among the most backward and drought prone area in the state. It is the major producer of Paddy, Maize, Saamai, Cumbu, Ragi, Red gram, Green gram, Black gram, Horse gram, Turmeric, Sugarcane, Mango, Banana, Tapiaco, Groundnut and Gingelly. Exotic crops like dates are also being cultivated by some farmers in and around Ariyakulam.

1.9 Horticulture

Dharmapuri district forms the most important horticultural belt in the state. As the area is drought prone it has become essential to switch over to cultivation of drought tolerant perennial fruit crops in this district. Dharmapuri district accounts for more than 60 to 70% total mango production in Tamil Nadu. Mango is the main horticulture crop of this district. It has the highest area under the fruit crops. Nearly one third area of the district consists of mango trees and the district accounts for nearly one half of the mango yield of the state. Palacode is the main area where tomato is cultivated. Chilli is cultivated mainly at Pennagaram.

1.10 Geology

The Nagavathi watershed geologically consists of a wide range of crystalline rocks including Champion Gneiss, Charnockite, Syenite, Pink Pegmatite and Pyroxene Granulite. Highly migmatized rocks and weathered surfaces were observed at many places of the study area. Groundwater occurrence is essentially restricted to weathered and fractured zones. Dharmapuri district is endowed with sizeable reserves of granite. High quality black granite is available in Pennagaram, Harur and Palacode blocks. Quartz is available at Kendiganapalli Village of Pennagaram Taluk,
A. Velampatti of Harur taluk and Pethathampatti of Pappireddipatti Taluk. Another high value mineral available here is molybdenum, which is identified as a good conductor. It is available in Harur.

1.11 Aim and Objectives

The present work aims to generate the database and has adopted proper scientific methods for integrated sustainable groundwater management in the Nagavathi Watershed through geospatial techniques. To achieve the above aim, the following objectives has been formulated.

- To carry out detailed investigation of the geology and geomorphology of the study area which have a direct bearing on the groundwater regime.
- Conceptualization of the aquifer management with the help of Integrated approach of geological, hydrogeological and hydrogeophysical studies.
- Detailed study of the quality of groundwater in the aquifers and its variations with space and time.
- To determine the major ionic constituents dissolved in groundwater, to evaluate its suitability for domestic, irrigation and industrial purposes in the study area using geospatial techniques.
- To identify suitable remedial measures for sustainable groundwater management plan through GIS based AHP approach.

1.12 Research Methodology

The systematic methodology adopted in this study has been given in the flow chart Fig. 1.2.
Conclusion

Rainfall data in season wise

$\rho_a$, value and Thickness (IPI2 WIN)

Electrical Method (Schlumberger array)

Geophysical Survey

Groundwater Samples

Hydrogeological studies

pH & EC

Hydrometerological Data

Rainfall data in season wise

Results and Discussion

Groundwater Management

Classification

Hydrogeochemistry

WHO

Fig1.2 Simplified Methodology flow diagram
1.13 ORGANISATION OF THE THESIS

The Studies and findings have been arranged in seven chapters in the Doctoral thesis.

CHAPTER-I. INTRODUCTION: Introduces the need and objectives of this study. The importance of the groundwater and status in Tamil Nadu, details of the study with reference to geomorphology, rainfall, water level, drainage, geology, communication and transport network of the study area.

CHAPTER-II. HYDROGEOLOGY: Nagavathi watershed generally encounters warm climate and experiences about 37° C as the highest temperature especially in March and May in a year. The study area becomes cool in December to February, with 17°C as minimum temperature recorded in January. The seasons in the study area has been classified as pre monsoon (March-May), SW monsoon (June-September), NE monsoon (October –December) and Post monsoon (January February). The Seasonal Variation of Rainfall pattern recorded for the period of ten years (2007-2016) have been analyzed from 5 rain gauge station located in the watershed.

The study area receives rainfall from the southwest monsoon of 30.56 % (711.22 mm), Northeast monsoon of 40.71 % (854.21 mm), Pre monsoon of 23.75% (474.98 mm) and the post monsoon of 4.98 % (14.75 mm) of the total mean annual rainfall. The Dharmapuri district receives average annual precipitation ranging from 760 to 910 mm.
Groundwater level fluctuations of 5 wells monitored during 10 years from 2007 to 2016. Groundwater level data have been calculated as depth of water level and it is used for interpolation study in Geographic Information Systems (GIS) environment for the winter, summer, southwest, northeast and average annual monsoon season water level thematic maps have been generated.

CHAPTER-III. WATERSHED MORPHOMETRY: The quantitative drainage morphometric parameter has been carried out for the Nagavathi watershed independently by estimating their linear aspects like stream number, stream order, stream length, mean stream length, stream length ratio, bifurcation ratio, aerial aspects like drainage density, stream frequency, texture ratio, elongation ratio, form factor, circularity index, length of overflow, constant of channel maintenance, drainage texture, compactness coefficient and relief aspects like basin relief, relief ratio, ruggedness number, gradient ratio, melton ruggedness ratio, slope, relative relief, shape factor and leminscate.

The Nagavathi river has been identified as a fifth order stream, further the watershed have been classified into eight micro watershed. Mostly the streams are predominantly controlled by structural and lithological controls.

CHAPTER-IV. HYDROGEOCHEMISTRY: For evaluating the hydrogeochemical parameter representative groundwater samples were collected from 46 dug and bore wells during the pre and post monsoon periods
and The groundwater samples were analyzed for major cations Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\), K\(^+\), and anions Cl\(^-\), HCO\(_3\)^-, CO\(_3^{2-}\), SO\(_4^{2-}\), NO\(_3^-\) and F.

The important constituents that influence the water quality for irrigation are Total Dissolved Solids (TDS), Electrical Conductivity (Ec), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Permeability Index (PI). Piper’s Trilinear diagram (1944) was used for assessing the water type. Using United States Salinity Laboratory (USSL) diagram (1954), Wilcox’s diagram (1955) and Doneens diagram (1964) interpretation, irrigation water quality suitability was ascertained. The Gibb’s diagram (1970) was constructed to understand the mechanism behind the quality of groundwater. World Health Organization (WHO) (1984 and 1993) recommended standards for drinking water have been taken as the guidelines for demarcating the groundwater quality.

**CHAPTER-V. GEOPHYSICAL STUDIES:** One Dimensional (1D) electrical resistivity survey has been carried out in selected locations across Nagavathi watershed. Nagavathi watershed is positioned in an undulated terrain and is dominantly underlain by Charnockite and gneissic rocks.

Forty Six Vertical Electrical Soundings (VES) using Schlumberger electrode configuration were conducted over the entire Nagavathi watershed, using an equal grid method. The field data have been processed in the IPI2 win software and different types of curves were identified.
In the study area consisting of hard rocks, groundwater prospection is difficult task without proper understanding of subsurface lithology. From the VES results, geoelectric layers such as topsoil, weathered, fractured and infinitely a hard rock layer has been identified and eight thematic maps involving spatial distribution of resistivities and thickness were delineated.

**CHAPTER VI. SUSTAINABLE GROUNDWATER MANAGEMENT:**

Groundwater management studies usually the weighted overlay analysis involves different thematic layers that have to be assigned with arbitrary weights for the assessment of study area. In this research, Analytic Hierarchy Process (AHP) is involved to find out the normalized weight of thematic layers by pair wise comparison matrix analysis and the eight thematic layers are overlain based on the normalized weight using GIS to demarcate potential groundwater recharge and discharge zones. The thematic layers subjected to weighted overlay analysis. The comparisons are made using a scale of absolute judgements that represents, how much more, one factor dominates over another with respect to a given attribute. The judgements may be inconsistent, and how to measure inconsistency and improve the judgments, when possible to obtain better consistency is a concern of the AHP. Finally, potential groundwater management map has been prepared based on the priority given to GIS based AHP approach.

**CHAPTER VII. SUMMARY AND CONCLUSION:** An attempt has been made in this study to analyse Geological, Hydrogeological, Hydrogeophysical and
Hydrogeochemical data analysis, the quantitative and qualitative characteristics of groundwater and GIS based AHP approach for sustainable groundwater management have been assessed.

In this study mainly focusing occurrence, availability and distribution of groundwater by adopting an integrated approach which is useful for the sustainable groundwater management in the Nagavathi watershed of Cauvery basin.