CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The natural hydrologic systems are so complex that no exact laws that can explain completely and precisely the natural hydrologic phenomena have yet been formulated. As such, complicated hydrologic systems such as watersheds can only be approximated by modelling (Chow, 1972). The model should ensure judicious use of natural resources with emphasis on conservation at microlevel. Further, the model should provide location specific prescription and should have the facility for inputting remote sensing and conventional data. Socio-economic data should not be ignored as they play a crucial role in prioritization. As the GIS tool is now available for spatial data analysis, the data base should be amenable for its use.

To assess the sustainability status of a watershed with specific reference to land and water resources, a methodology is to be developed. Remotely sensed data will be effectively used for assessing the natural resources. The sub-surface system (aquifer) is to be analysed by developing suitable model. Conjunctive use of surface and ground water is aimed at for better utilization of the same. For the land use planning, a linear programming model is to be established. In order to achieve the above goal, the published research works connected with the above objectives were studied critically. A brief review of the status of the disciplines of remote sensing, GIS and analysis techniques is made in Sections 2.2 to 2.7.
2.2 TECHNOLOGY OF REMOTE SENSING

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. The electromagnetic energy sources are used to sense the objects from a distant platform fitted with sensors. The two basic processes involved in electromagnetic remote sensing of earth resources are data acquisition and data analysis. The elements of data acquisition process are (Lillisand et al., 1989) (a) energy sources (b) propagation of energy through atmosphere (c) energy interactions with earth surface features and (d) airborne or space borne sensors providing data in pictorial and/or numerical form. The data analysis process involves examining the data using various viewing and interpretation devices (Sabins, 1978) to analyse pictorial data and/or a computer to analyse numerical sensor data. From these data, thematic maps are generated and these thematics maps are digitized and integrated based upon decision rules using the tool of Geographical Information System (GIS). The basic principles involved in Remote sensing are briefly discussed below.

2.2.1 Energy Sources and Radiation for Remote Sensing

Energy is propagated by electromagnetic radiation (EMR) with a velocity of $3 \times 10^8 \text{ms}^{-1}$ from the source directly through free space or indirectly by reflection and reradiation to the remote sensor (Lillisand et al., 1989). The path of solar radiation through the atmosphere to the remote sensor is indicated in the Fig.2.1. By studying the changes in the amount and properties of the EMR important properties of the media with which it interacts can be found by proper interpretations. Fig.2.2 shows the extent of the EM spectrum and the various bands used in the analysis.
Fig 2.1 Path of solar radiation through the atmosphere to the remote sensor

Fig 2.2 The electromagnetic spectrum
2.2.2 Electromagnetic Radiation used by the Satellite

The radiance at the satellite consists of two parts (a) solar EMR scattered by the atmosphere in the direction of the sensor as denoted by the component \(^{L_A}\) in Fig.2.1 and (b) solar EMR reaching the surface of the earth and reflected in the direction of satellite sensor, as indicated by the component \(^{L_S}\) in Fig.2.1 (Robert, G. Reeves et al., 1975). The total radiance at the satellite is

\[
L = L_A + L_S \tag{2.1}
\]

In a given spectral interval the solar irradiance \(E_B\) reaching the earth surface becomes.

\[
E_B = \frac{\lambda^2}{\sin \beta} \int_{\lambda_1}^{\lambda_2} E(\lambda) \tau_B(\lambda) d\lambda \tag{2.2}
\]

where \(E(\lambda)\) = the spectral solar irradiance at the top of the atmosphere at normal incidence.

\(\tau_B\) = the monochromatic one way transmissivity of the atmosphere at elevation angle \(\beta\). \(\tau_B(\lambda)\) shows the dependence on \(\lambda\) and includes the air-mass effect corresponding to the angle \(\beta\).

For a nadir-viewing satellite sensor, the reflected spectral radiance at the sensor from the ground becomes.

\[
L_S = \frac{\sin \beta}{\pi} \frac{\lambda^2}{\lambda_1} \int_{\lambda_1}^{\lambda_2} E(\lambda) \tau_B(\lambda) \tau_T(\lambda) \rho(\lambda) R(\lambda) d\lambda \text{ (wm}^{-2}\text{Sr}^{-1}) \tag{2.3}
\]
where \( \tau_z(\lambda) \) = monochromatic transmissivity of the atmosphere in the zenith direction for solar radiation reflected by the surface to the nadir-viewing sensor.

\[ R(\lambda) = \text{the spectral response function of the channel in question.} \]

To obtain the actual radiance \( L \), the contribution \( L_A \) scattered by the atmosphere to the sensor must be added to \( L_S \), as indicated by the Equation 2.1. Reflectances for the atmosphere is computed

\[
L_A = \frac{1}{\pi} \int_{\lambda_1}^{\lambda_2} E(\lambda) \rho'_{g}(\lambda) R(\lambda) \, d\lambda \quad \text{(wm}^{-2} \text{Sr}^{-1})
\]

where \( \rho'_{g}(\lambda) \) = atmospheric reflectances (given as specific intensities) where the subscript \( g \) shows dependence on solar elevation.

Therefore the total radiance measured by a channel \( L \) is given by

\[
L = \frac{1}{\pi} \int_{\lambda_1}^{\lambda_2} E(\lambda) R(\lambda) [T_g(\lambda) T_z(\lambda) \rho(\lambda) \sin\beta + \rho'_{g}(\lambda)] \, d\lambda
\]

This is the basic mathematical model for computing the expected radiances of any band of EMR in the visible and near visible region of the EM spectrum.

2.2.3 Spectral Reflectance References or Standards

If reflectances of earth surface cover or materials, are to be useful in differentiating soil and rock types, in determining soil moisture and in identifying vegetation, reflectance measurements need to be made of the surveyed scene simultaneously with the acquisitions of the multispectral
imagery (Robert G., Reeves et al., 1975). Not only must the reflectances of the surface should be obtained, but also the reflectance of the atmosphere. To be meaningful and useful, related reflectances need to be accurately known. Relative reflectance methods can greatly reduce the work involved in measurement. As reflectances are an indication of the interaction of EMR with a surface, various test sites are used to measure the reflectances of various features under controlled conditions.

2.2.4 Data Acquisition and Interpretation

The detection of electromagnetic energy can be performed either photographically or electronically. The process of photography uses chemical reactions on the surface of a light sensitive film to detect energy variations within a scene. Photographic systems offer many advantages. They are relatively simple and inexpensive and provide a high degree of spatial detail and geometric integrity. By developing a photograph, a record of the detected signals is obtained. Thus the film acts as both the detecting and recording medium. In remote sensing the term "photography" is reserved exclusively for images that are detected and recorded on film. Electronic sensor signals are generally recorded on a magnetic tape (Lillisand et al., 1979).

2.3 Concept of GIS and Modelling

The history of using computers for mapping and spatial analysis shows that there has been parallel developments in automated data capture, data analysis and presentation in several broadly related fields. These fields are cadastral and topographic mapping, thematic cartography, Civil Engineering, geography, mathematical studies of spatial variation, soil science, surveying and photogrammetry, rural and urban planning, utility networks, remote sensing and image analysis (Burrough, 1990).
The Geographic Information System has three important components namely computer hardware, sets of application software modules and a proper organisational context. These three components need to be in balance if the system is to function satisfactorily.

2.3.1 Computer Hardware and Software

The general hardware components of a geographic information system are presented in Fig.2.3. The software package for a geographic system consists of technical modules such as (a) input and verification, (b) data storage and database management, (c) data output and presentation, (d) data transformation and (e) interaction with the user. Data input covers all aspects of transforming data captured in the form of existing maps, field observations and sensors (including aerial photography, satellites, and recording instruments) into a compatible digital form. The main software components, the data input, the components of geographical database and the data output are shown in the Figs.2.4, 2.5, 2.6 & 2.7 respectively.

2.3.2 Data Analysis and Modelling

Data analysis and modelling consist of two classes of operations viz. (i) transformation needed to remove errors from the data or to bring them up to date or to match them to other data sets, to make the data fit for analysis and (ii) analysis through suitable recording of the source data, to suit the problem in question and resorting to various modelling techniques. The spatial modelling in GIS refers to the overlay analysis of different thematic maps (Steiner, 1981). An overlay is a set of mutually exclusive contiguous regions associated with a particular area and each overlay is defined by a given attribute.
Fig 2.3 The major hardware components of the Geographical Information System

Fig 2.4 The main software components of a GIS
Fig 2.5 Data input

Fig 2.6 Data storage and database management

Fig 2.7 Data output
2.3.3 GIS Models and Integration

Two approaches or models have been widely adopted for achieving the linkage between spatial and attribute information with GIS, the cartography map model and geo-relational model (Aronson 1987; Healey 1991). In the cartographic map model, information integration proceeds by combining attributes values for cells that lie above or below one another in a stack of superposed layers. The grid cell model is relatively a simple approach to data integration both conceptually and operationally and it has been popular in the earliest days of GIS development. Fig 2.8 shows the concept of the map composition model.

In the Geo-relational model, spatial entities are usually linked with their associated attribute data by means of common spatial key. Different sets of attribute information are stored in different attribute tables and the relevant information for a given set of spatial feature is accumulated by relating (or joining) two or more tables of information. Fig 2.9 shows an illustration of geo-relational model.

2.3.4 Errors in GIS Modelling

The collection processing and analysis of data through GIS lead to improvement only if the data are sufficiently reliable. However in practice one may not get 100% error free output through GIS because of inherent errors associated at each stage of data collection, processing and analysis. Burrough (1986) discusses possible sources of errors and their implications while data are processed. The sources of errors may be divided into three main groups: (a) errors associated with the data (b) errors associated with the storage and data structures (c) errors associated with processing. Off all the errors, errors resulting from rasterizing a vector map is serious in nature which is discussed in detail below. In this study all the thematic
Fig 2.8  Concept of map composition model
Fig 2.9 Illustration of the georelational model
maps are in raster form due to scanning and subsequently they are vectorised and used in the analysis.

2.3.4.1 Errors resulting from rasterizing a vector map

When rasterizing a vector map, if the size of the grid cell is larger, it will not represent the true picture of a linear feature. There is also the problem of topological mismatch when a polygon map is approximated by a grid. Frolov and Maling (1969) considered the problem of error arising when a grid cell is bisected by a true boundary line i.e., road. The mean square of the cut off portion of each boundary cell can be estimated by

\[ V_i = a S_c^4 \]  \hspace{1cm} (2.6)

where \( V_i \) is the error variance, \( S_c \) is the linear dimension of the (square) cell and 'a' is constant. Frolov and Maling calculated the value 'a' as 0.0452 but subsequent work reported by Goodchild (1980) suggests that a better value of 'a' as 0.0619. The error variance is an estimate of area for any given polygon is given by a summation of all the errors from all the bounding cells. If 'm' cells are intersected by the boundary, the error variance will be

\[ V_i = ma S_c^4 \]  \hspace{1cm} (2.7)

Switzer (1975) presented a general solution to the problem of estimating the precision of a raster map that had been made from a polygonal thematic map.

The error of the map estimation or rasterizing process is given as

\[ L_{ij} = A_m(M_i \cap M_j) \quad i < j \]  \hspace{1cm} (2.8)
where \( L_{ij} \) = the area of the map that truly belongs to map unit \( i \) represented as map unit \( j \) on the estimated map.

\[
M_i = \text{true map unit} \\
M_j = \text{estimated map unit} \\
A_m = \text{total area of map}
\]

The total area of incorrectly mapped portion of map unit \( M_i \) is given by

\[
L_i = \Sigma L_{ij}
\]

and the total mismatch for the whole of map is

\[
L_m = \sum_{i=1}^{k} L_i
\]

The total and partial mismatch is easy to calculate if the original or 'true' maps exist in digital form.

The degree of mismatch of the estimated map is a function of two independent factors (a) the complexity of the true map (b) the geometrical properties of the sampling net. Considering the complexity of the map, a quantity \( \rho_{ij}(d) \) can be defined as the probability that a random point in true map unit \( i \) and that the cell centre point in true map unit \( j \) when the points are separated by distance 'd'.

Switzer proposed that if \( \rho_{ij}(d) \), can be thought of as infinite, differentiable function, it can be approximated by a Taylor expansion of its derivative \( P_{ij} \) and \( P_{ij}' \). The Taylor's series expansion states that any functions \( f(x) \) about a point \( x-a \), that possess a continuous derivative \( f^{(n)}(k) \), in the interval \( (a,b) \) can be approximated by the infinite series of polynomials (Sokolnikoff and Sokolnikoff (1941)).
\[ f(x) = f(a) + f'(a)(x-a) + \frac{f''(a)(x-a)^2}{2!} + \ldots + \frac{f^{(n)}(a)(x-a)^n}{n!} \quad (2.11) \]

If \( a = 0 \) the expansion reduces to
\[ f(x) = f(0) + f'(0) + \frac{f''(0)x^2}{2!} + \ldots + \frac{f^{(n)}(0)x^n}{n!} + \ldots \quad (2.12) \]

Rewriting the Equation (2.12) for the \( \rho_{ij}(d) \) results in
\[ \rho_{ij}(d) = \rho_{ij}(0) + \rho_{ij}'(0)d + \frac{(\rho_{ij}''(0)d^2}{2!} + \ldots \quad (2.13) \]

Because in general \( P_{ij}(d=0) = 0 \), the derivative \( (P_{ij}d') \) at \( d=0 \) is strictly positive, it can be shown that the mismatch area can be approximated by using the first derivative.

\[ L_{ij} = P_{ij}' \sum_{h=1}^{n} A(\text{sh})D_h \quad (2.14) \]

where
- \( n \) = number of sampling points
- \( A(\text{sh}) \) = area of cell ‘sh’
- \( D_h \) = mean distance between a random point in sampling cell ‘sh’ and datum point of the cell.

In the case of all sample cells having the same shape and the datum point at the centre of the cell equation (2.14) reduces to
\[ L_{ij} = P_{ij}' D \quad (2.15) \]

\( D \) = a value characteristic of the sample net.

The estimation of mismatch involves finding suitable estimation of \( P_{ij}' \) and \( D \).
The D can be estimated by using the following equation. For rectangular net 'D' is given by

\[
D = n^{(1/2)} \left\{ (2\sqrt{r+r^{-1}}) + r^{-3/2} \ln (r+\sqrt{1-r^{-2}}) \\
+ 2r^{3/2} \ln (r^{-1} + \sqrt{1+r^{-2}}) \right\} \div 12 \quad (2.16)
\]

where \( r = \) ratio of cell sides

\[
r = 1 = \text{(sequence net)} \quad D = 0.383 \quad n^{1/2}
\]

The local linear approximation in equation (2.15) is adequate for comparing efficiencies of sampling design, but for actual mismatch estimations it is improved by including a quadratic of order \( d^2 \). Now the estimate for mismatch becomes

\[
L_{ij} = \sum_{h=1}^{n} A_m(sh) \cdot D_h + \frac{1}{2} \sum_{h=1}^{n} A_m(sh) \cdot D^*_h \quad (2.17)
\]

where \( D^*_h = \) mean square distance between a random point in the sampling cell 'sh' and the datum point in the cell.

The above error in GIS modelling is properly taken care of in the workstation based ARC/INFO GIS software. In this study the above software has been used for GIS modelling.

### 2.4 STUDIES RELATED TO SURFACE SYSTEM

To formulate a watershed system model, the runoff is considered as an integral product of three components. (1) a conceptual watershed storage representing the storage of water on the ground surface (lakes, ponds, swamps and streams) as well as below the ground surface (soil moisture and groundwater reservoirs), (2) the total rainfall input and (3) the
total abstractions, mainly evapotranspiration. (Ven.Tee Chow, 1975). Hence the runoff is considered as a precious resource for development and the procedure of estimation is detailed below.

2.4.1 Estimation of Runoff using USDA - SCS Curve number Technique

In this study, the surface runoff is estimated using the Soil Conservation Service (SCS) curve number techniques (USDA, 1972). The above method is selected because (a) it is a reliable procedure that has been used for many years in the U.S; (b) it is computationally efficient; (c) the required inputs are generally available and (d) it relates runoff to soil type, landuse and management practice. The use of readily available daily rainfall is particularly an important attribute of the curve number technique. For many locations, the rainfall data with time increments less than 1 day are not available.

A number of researchers have published their findings with regards to the SCS curve number technique. The literature review is restricted to remote sensing based attempts and other related important works. Balanchand (1975) has attempted to use remotely sensed data to directly estimate the curve number without using ancillary soils data. He collected Landsat data for several watersheds, in Kalahoma during a full dry period. He related the measured curve numbers on this watershed to various Landsat band combinations and observed fairly good correlation. This approach has been attempted in this study.

Traditionally the SCS has used an antecedent rainfall index to estimate these antecedent soil moisture conditions (I dry, II normal and III wet). In reality, soil moisture varies continuously and thus curve number has many values instead of only three. Runoff prediction accuracy is increased by using a soil moisture accounting procedure (Williams and
Laseus (1976) to estimate curve number for each storm. Although the soil moisture accounting model is superior to the antecedent rainfall method, it does not maintain the water balance and requires calibration with measured runoff data. Considering the findings, the antecedent rainfall method is adopted in this study.

Ragan and Jackson (1976) attempted to evaluate the curve numbers for Anacostia river basin. They have used 1:4800 scale aerial photographs for detailed soil maps and field surveys to define the curve number of the watershed. Both high altitude colour infrared photographs and digital data were used to estimate the landcover of the watershed. Both the estimates were close to the conventionally determined values. They suggested that the SCS curve number estimation procedure had to be modified to make the landcover categories compatible with those that can be estimated using Landsat data. Keeping this in mind, landsat data has been used to compute the curve numbers for this study.

Hawkins (1980) examined the procedure which was established by USDA for the estimation of storm runoff volume as a function of storm volume and land condition and suggested that the constant curve number independent of storm size was not appropriate for all situations. In some instances, the runoff is a simple fraction of storm rainfall and suggested some modifications on it which can make the method realistic under certain conditions. Slack and Welch (1980) used Landsat satellite data and made similar studies as suggested by Balanchand and improved the correlation.

Velappan (1986) made a study of runoff using SCS method with remote sensing data for different landuses in Kukkalthurai Halla watershed in Nilgiris district. In that study, the author found that the runoff curve number with an initial abstraction of 0.3S_R with modification using antecedent precipitation Index (API) and ‘Correction factor’ (f) which is the ratio of observed and computed ‘runoff’ and it needs further studies for
confirming the results. This suggestion was tried but it is found that the initial abstraction of $0.20S_R$ seems to be agreeing with the observed results.

Venkatesan (1990) computed the runoff based on the precipitation and landuse pattern prepared using satellite data under the GIS environment. This approach has been used in this study.

Pramod Kumar et al., (1991) made an attempt to establish the SCS curve number from an IRS-1A LISS II digital database for the Kaliaghai river basin situated in the Midnapur district of West Bengal. Landuse/landcover map with hydrologically significant classes (cultivated, forest, fallow, waste land, impervious surface) were developed and found satisfactorily agreeing with the SCS model modified for Indian condition.

Considering the above literature, in the present study, grid wise surface runoff was computed using the landuse map prepared for pre and post monsoon rainfall conditions. The soil map used for this analysis was also prepared by using IRS-1A satellite imagery with exact spatial distribution. The exact curve numbers used depends upon the type of landuse and practice in the spatial domain in a grid to avoid spatial heterogeneity in the hydrological unit.

2.4.2 Other Hydrological Models for Surface System

The most fundamental level of classification of Hydrologic Mathematical Models would be their division with categories of conceptual-empirical (Clark 1973a,b, Kisiel 1969) genetic - statistical (Kartvelishvili, 1975), descriptive - perspective (Jackson 1975a). A concise definition was given by Clark (1973a) "Hydrological model is described as Conceptual or empirical according to whether the form of the functions (relating the variables) is or is not suggested by consideration of physical process acting upon the input variables to produce the output variables".
Considering the above definition for the hydrological model, some of the relevant studies made covering those aspects are discussed below. A distributed model for estimation of runoff volume and peak rate of flow from small watersheds (Lane I.J. 1982) is shown to produce reasonable estimates for mean runoff and flood frequency distribution. The model is simplified and constructed to require a minimum observed data for calibration. The model simulates runoff volume and peak discharge rates for individual storm events. It can also be used to estimate water yield and a surface water balance incorporating transmission losses in ephemeral stream channels. He also stated that the individual component in the model could be improved with further research and better data. Keeping this in mind, a better landuse and soil map obtained from the satellite in a spatial domain was used for computing the surface runoff in this study. Arnold et al., (1990) developed a Basin Scale Simulation Model for soil and water resources management. The water balance equation defined by his model is shown below:

\[ SW_t = SW + \sum_{i=1}^{t} (R_i \cdot Q_i \cdot ET_i \cdot P_i \cdot Q_{Ri}) \]

where
- \( SW \) = soil water content
- \( t \) = time, days
- \( R_i \) = daily precipitation, mm
- \( Q_i \) = daily runoff, mm
- \( ET_i \) = daily evapotranspiration, mm
- \( P_i \) = daily percolation, mm
- \( Q_{Ri} \) = daily return flow, mm

Since the model maintains a continuous water balance, complex basins are sub divided to reflect difference in ET for various crops, soil, etc. Thus, runoff is predicted separately for each sub area and routed to obtain the total runoff for the basin. Considering the above aspects and to overcome
the above deficiencies, the hydrological model is developed gridwise in order to get more accurate results of the various entities involved in the hydrologic system in this study.

A Geographical Information System data base was established for a small watershed (Smith, 1990) in Shelby country, Tennessee, for both surface and sub-surface water attributes. The surface water portion of the GIS was used to predict and illustrate the flood prone areas of the watershed for various levels of water level in the river. The system represents a tool for the evaluation of the impact of runoff changes due to development in watershed on the existing hydraulic conveyance structures and provides the engineer the capability of illustrating the changes. The combination of the surface and sub-surface GIS data base would permit total watershed management to include both surface water runoff as well as movement of part of the surface water into the sub-surface system.

Since this study deals with the surface and sub-surface system, in addition to the runoff, the further components in the surface hydrologic systems such as evapotranspiration, river bed recharge to the aquifer and return flow from irrigated areas are not included in the above work. The missing components in a spatial domain are taken care of in the present work.

Richard Thomson (1990) developed a model to study the effect of climate variability on hydrological models. This model helps us to study the effect of evapotranspiration on the hydrological system taking place in the Kallar Watershed model.

A simple watershed model has been developed using Landsat and NOAA data to simulate basin runoff on a daily basis (Kite 1911). A study was made to show that how a lumped hydrological model can be improved by computing the rainfall-runoff and snow melt process separately for
different landcover classes where a class consists of an area of hydrologically significant landcover that may or may not be contiguous (Kite 1992).

A decision support system for watershed management (Jacob 1995) was developed using GIS data management. He used the GIS analysis for watershed restoration programme and water quality. The full potential of GIS has not been explored in the watershed restoration programme. Hence in this study an integrated watershed development analysis was made using both the remote sensing data and workstation based ARC/INFO GIS software. Singh (1997) stressed that as land and water are inseparable capital assets to the agricultural production system, so should be the case with respect to research, extension and development for the management of these two assets. He computed the deficit or surplus water in a watershed and wanted the researchers to take up further work for suitable planning in a watershed to get maximum production from the watershed. This prompted us to take up the intensive study on watershed using remote sensing and GIS.

2.5 STUDIES ON GROUNDWATER MODELLING

In any groundwater project, the study of sub-surface system (aquifer) is a prerequisite. The following are some of the relevant previous works carried out for the study of the sub-surface system.

Fayers and Sheldon (1962) analysed three dimensional flow in a regional aquifer using curvilinear grid in his model. The dynamic behaviour of a regional groundwater basin was studied using non-uniform polygon as grids by Tyson and Weber (1964). Fiering (1964) predicted drawdowns in aquifer under variable well pumping rates and recharge. Remson et al., (1965) analysed the recharge effect of a proposed reservoir on groundwater. The extensive derivation of theoretical analysis of regional groundwater flow was carried out by Freeze and Wither Spoon (1966). Bittinger et al., (1967)
described general digital computer model for aquifer evaluation. Pinder and Bredehoeft (1968) described an application method, in conjunction with the theory and electric analogy solutions and extensive derivations of differential equations with a case history. Pricket and Lonnquist (1968a) compared digital and electric analog techniques and presented instructions on a basic methodology. Pricket and Lonnquist (1968b) also presented a method of comparison on the theory and case histories on groundwater development. The drawdown around pumped well in an aquifer was studied by Taylor and Luthin (1969).


Sathish Chandra and Pande (1975) developed a mathematical model for conducting recharge studies in Varuna basin based on water balance. A simple one dimensional model was developed to study the flow pattern to reduce the computer time and cost by Khan (1979). Sivaprakasam (1982) formulated a digital model for Madras aquifer. Smith (1983) developed a model to demonstrate several of the relationships between rainfall flux, soil, hydraulic properties, hill slope geometry and runoff characteristics. A double porosity model was developed to study the fissured groundwater pressure with fracture skin (Mochch 1984). Muthukumar (1984) carried out studies to evaluate the water balance of Madras aquifer. Five mathematical models developed to predict sub-surface flow were
compared to discharge measurements made by Hewlett and Hibbert on a uniform slopping soil at Coweele Hydraulic Laboratory (Sloan et al., 1984).

Serigio et al., (1987) studied the predictions of groundwater flow in a phreatic aquifer by development and solution of the mathematical equations. One is for stochastic Boussineq equation with dupit assumptions and other one with two dimensional laplace equation. Salikumustafa (1987) studied two recharging canals under vertical infiltrations giving water table change with respect to time. Soil water model is better than specific yield concept model for estimating ground water recharge in Sandy area (Perolaf Johnson, 1987). Subramanian (1987) conducted studies for a prescriptive groundwater model.

Remotely sensed data and a Geographical Information System (GIS) proved to be valuable tools for delineation and quantification of hydrological system (both surface and sub-surface) components (Allewijn 1988). Nielson et al., (1989) developed a groundwater model using all relevant available soil, landuse, hydrological and meteorological data for assessing the groundwater recharge. Ramalingam (1989) developed a lumped and distributed parameter model (Mathematical model) for the study of a Tank-aquifer system.

A coupled groundwater and surface water model was developed combining MODFLOW and BRANCH which is a one dimensional numerical model commonly used to simulate flow in open channel networks (Iwain Eric et al., 1991). Kilborn et al., (1991) described an interface between a groundwater model designed for well head protections and geographical system database of groundwater resources in Houston, Texas. A three dimensional Geoscientific Information System coupled with three dimensional groundwater modelling of regional aquifer systems in areas with complex geologic and climatic conditions was developed by Keith et al., (1991), Leake (1991) developed a new computer programme to simulate vertical compaction in models of regional groundwater flow. Brainard,
Edward et al., (1991) highlighted importance of three dimensional model compared to two dimensional model especially the study of vertical flow in groundwater transport.

Groundwater flow in a compressible unconfined aquifer with uniform circular recharge was carried out using Dagan's formula for large times and small times (Vitalyzlotnik, 1992). Yeh William (1992) studied the optimization of groundwater models using linear programming mixed-integer and quadratic programming, differential dynamic programming, nonlinear programming and simulation.

Roaza et al. (1993) integrated GIS in groundwater applications using numerical modelling techniques for optimal management of groundwater resources. Remote sensing data and GIS techniques were used to assess the suitable site for drilling locations for tapping groundwater (Per Sander et al., 1996). Another attempt has been made to demarcate potential zones of groundwater using remote sensing and GIS (Krishnamoorthy et al., 1996). Saraf et al., (1997) made an integrated approach of remote sensing and GIS to have an insight into the groundwater considering a hard rock terrain comprising of Deccan basalts in Vidisha district of Madhya Pradesh, India.

The above said literatures have been critically reviewed and the groundwater model has been developed by taking some of the points from the literature.

2.6 PREVIOUS STUDIES ON CONJUNCTIVE USE

In order to practice conjunctive use of the water resources, both surface and sub-surface water should be availed of in adequate quantities for utilisation. A proper assessment of the availability of surface and groundwater resource is a prerequisite for determining the scope of conjunctive use. The availability of surface water is dependent upon the
rainfall received during that season or year and the contribution from the watershed as surface and sub-surface runoff which can be measured relatively more precisely. The availability of groundwater is on the other hand not so much dependent upon the immediately preceding rainfall as the storage and movement may vary depending upon other factors like sub-surface hydrogeologic conditions and is not precisely determinable.

Number of works have been reported by various researchers. The economic advantages that could be obtained from the conjunctive use of surface and groundwater were ascertained by Banks (1953). Castle and Linderborg (1961) formulated a linear programming model to allocate groundwater and surface water to two agricultural fields. Buras and Burt (1963) illustrates the application of dynamic programming to specific conjunctive management problems. The application of digital computer simulation techniques for finding optimal solutions to water resources systems problem was attempted under the Harvard water programme by Mass et al. (1962). Chun et al. (1963) and Thomas and Burden (1965) reported applications to conjunctive groundwater and surface water management problems. Dracup (1966) created a mathematical model of a conjunctive groundwater and surface water system in southern California by using parametric linear programming. Meconnen and Menon (1967) examined the alternative organisational system for accomplishing exchanges between groundwater and surface water in the Galletin valley, Montana, based on linear programming. Boyd (1968) extended and refined their analysis. Milligon (1969) also used linear programming formulation to model optimal allocations for one hypothetical hydrologic system and two real Utah river basins. Longenbaugh (1970) adopted linear programming approach for finding optimal operating policies for the Arkansas river valley in Collarado. A digital simulation model was developed by Young and Bredehoeff (1972) for determining optimal management policies using groundwater and surface systems in the Western United States. Durabert (1978) stressed the
importance of regulation for groundwater pumping so as to use the optimal utilisation of sub-surface water.

The conjunctive use approach has been employed by a number of researchers including Labadie et al. (1983), Koltermann (1983), Illangasekare and Morel-Seytoux (1982) and Illangasekare et al. (1984). To simplify the analysis, the linear flow theory has been applied to the stream groundwater system. Illangasekare and Morel-Seytoux (1982) and Labadie et al. (1983) applied this concept by dividing the system into smaller subsystems or subareas which include a number of surface water diversions and reservoirs and groups of pumping wells. Illangasekare et al. (1984) estimated the Kernal co-efficients based an Green’s function solution to a linear form of the Boussineq equation.

John D.Bredehoeft et al. (1983) examined (south platle system in collarado) to what extent groundwater is being developed as insurance against periods of low stream flow using a simulation model for maximising the income.

Ozbilgin and Dickerman (1984) modified the USGS finite difference model of Trescot to simulate the interaction between surface water and groundwater. This approach differs from the Kernal approach by defining the total response of system components directly rather than by using the Kernel co-efficients. The application of optimization technique to conjunctive use problems includes the work of Morel-Seytoux (1975a,b) and Labide et al. (1983). The approach in general is to minimise or maximise certain functions (e.g. stream depletion, total pumping, need for water storage) that are subject to a number of constraints.

The conjunctive use of surface and groundwater to avoid water logging in the Jamuna canal, Haryana, India was adopted by erecting 256 augmentation tube wells along the canal as reported by Pundarikantan
Dharam Paul et al. (1987) conducted a study towards the conjunctive use of saline groundwater and careful mixing of fresh canal water in Punjab. Sahani (1987) discussed the use of vertical drainage as preventive and remedial measures for water logging and salinity problems in irrigated black cotton soils of Maharashtra and the reuse of such drained water conjunctively with surface water supply for irrigation. Narayanan (1987) explained that the amount of total utilisable water in Tamil Nadu during 2000 AD is likely to be 6 Mhm comprising 3.5 Mhm of surface water and 2.5 Mhm of groundwater. Shanmugam (1987) explained how surface and groundwater can be used conjunctively for irrigated agriculture.

The detailed study was made by groundwater wing of Public Works Department (Muthukumaraswamy et al., 1987) in the command area of Krishnagiri Reservoir Project (KRP) during 1982-1987 which spread over 3600 hectares. The project was designed for the systematic assessment of ground and surface water potential separately and actual practice of conjunctive use of surface and groundwater. The studies indicated that by adopting conjunctive use of ground and surface water, additional areas can be irrigated and cropping intensity can be increased. Somasundaram et al. (1987) studied the presence of nitrate in groundwater and careful mixing of good surface water conjunctively.

El-kadi (1989) reviewed available watershed models simulating infiltration and groundwater flux. Although watershed models have been used successfully in managing surface water resources, the extension to the conjunctive use for both surface water and groundwater resources is not yet feasible. Here a need exists to expand the groundwater flux formulations in new or existing watershed model. Conjunctive use models allow coordinated management and use of surface water and groundwater resources. When such models are combined with optimization techniques, an efficient policy can be decided in order to maximize the net benefit.
Nagarajan (1991) developed linear programming model for optimal allocation of surface and groundwater for the different crops. Anandaraja (1995) developed a linear programming model and studied the benefit obtained from Sathanur reservoir by conjunctively using the surface and groundwater using remote sensing data.

After critically reviewing the above said literature, a linear programming model has been developed in this study for optimum utilisation of available surface and groundwater to get maximum benefit from the watershed using Remote Sensing Data and GIS techniques.

2.7 INTEGRATION OF DATA USING REMOTE SENSING AND GIS

The natural resource maps such as landuse, soil, geomorphology, geology are prepared using the satellite data and these maps are digitized/scanned and integrated using GIS software after developing suitable decision rules for suggesting better landuse pattern. Before reviewing the various literature on this aspect an overview of GIS is given below which is used as an important tool for integration of natural resources.

2.7.1 Overview of GIS

Geographic information system brings together computer software based data base management and digital cartography (Star and Estates, 1990). A number of definitions are found in literature. (Star and Estates 1990; Tamlin, 1990; Aröff, 1983; Parker 1988). Everyone recognises that GIS is capable of performing a number of tasks including the acquisition, storage, management, analysis and display of locational data.
In essence, GIS can be viewed as an enhanced information system that aids decision making by referencing data to spatial or geographical coordinates. Lanfer (1989) noted that, because most water resources data can be referenced geographically, GIS is ideally suitable as a research and management tool.

Evans and Myers (1990) used a Geographic Information System to implement the DRASTIC (Depth to water table, net Recharge, Soil media, Topography, Impact on Vadose zone, and hydraulic conductivity) model (Atkinson et al., 1989; U.S.E.P.A. 1987; Aller et al., 1985) for evaluating the groundwater pollution in a given hydrogeologic setting. Evan and Myers demonstrated that GIS used in conjunction with DRASTIC model resulted in an effective and efficient tool for preparing an emergency response plan in the event of a spill or accident that could potentially impact groundwater resources. In another GIS application Holiday and Wolfe (1991) successfully used GRASS (Geographic Resource Analysis Support System) to create a nitrogen fertilizer pollution potential index by combining spatial data on the availability of nitrogen fertilizer as a potential pollutant with aquifer susceptibility to pollution.

Crowell (1989) outlined the development of GIS to assist the Southwest Florida Water Management District with the inventorying of regulatory permits for groundwater and surface water pumping. The GIS was used to integrate the geographic locations of the permit sites with other types of information such as surface water and stormwater management district boundaries and local use types.

Stuebe and Johnsten (1990) used GIS techniques to assist in modelling stormwater runoff. Specifically they used the GRASS software package to help estimate runoff volumes. Their results indicate that GIS derived runoff estimates were comparable to manual estimates using the Soil Conservation Service runoff curve number model and that the GIS
techniques provide a modelling alternative to the manual estimates method. Sasowsky and Gardenear (1991) incorporated a GIS approach to help simplify model parameterisation in evaluating the accuracy of surface runoff model simulations. Andrew School Master and Paul (1991) developed a spatial decision support system to assist decision makers in the evaluation of alternative solutions to water supply problems.

2.7.2 Evaluation of Land Resources using GIS

Land resources evaluation is the most necessary for the rational utilization of the limited cultivated area. Crude land evaluation methods were prevalent 200 years ago. Now the evaluation behaviour is analysed with the progress in resource surveys and the planning of the landuse (Fu Buojie 1990). Land resources evaluation now involves integration, quantification and scientification (Zheng Zhixiang 1986). Land Resources Information System (LRIS) is one type of GIS designed for the purpose of land evaluation, planning and management. Tian Lianghu, Zhao Yuanhong (1992) developed a fuzzy expert model and a Huariyan Land Resources Information system called HL RIS for land resources evaluation.

He evaluated the land resources by considering the various land factors such as soil, topography, meteorology, landuse etc. In the process of evaluation land area was divided into tiny units to avoid errors in analysis. The characteristics of these homogenous units are given below.

If 'i' stands for i\textsuperscript{th} unit, f\textsubscript{i} stands for ith factor, then the characteristics of i\textsuperscript{th} unit can be described as

\[ L^i = Q(f_1^i, f_2^i, ... f_m^i) \]
\( f_1[i] \) is the \( i \)'th factor on the \( i \)'th unit. If time is considered, the above equation reduces to

\[
LQ_{[i,t]} = Q(f_1[i,t], f_2[i,t], \ldots, f_m[i,t])
\]

\( LQ_{[i,t]} \) is the characteristic of \( i \)'th unit on time \( t \). This equation demonstrates that the characteristic of land is determined by pertinent factors of time and location.

Land evaluation modelling is the process of assessing the land productivity and landuse suitability. It is related closely to the land natural attributes and socio-economic factors. There are two theories normally considered for the land evaluation.

**Theory I**

Land must be cultivated according to the most suitable use. Under this theory, land evaluation is conducted for the purpose of land quality and suitability to crops.

**Theory II**

Land must be used at its greatest productivity as long as the ecological balance is not destroyed. Under this theory it is deemed that if possible and profitable, the barren land may be made suitable for raising some crops considering socio-economic factors.

In the present study, an integrated analysis of various parameters using GIS is attempted for integration and effective utilisation of land without adopting any optimization procedure.

### 2.7.3 Integration of Data

A number of researchers have attempted to integrate the remote sensing data using GIS. Some of the works carried out by the earlier researchers are briefly discussed below.
Steffenson (1987) made an intensive vegetation resource inventory using GIS and developed a vegetative model for future forest planning needs. A detailed analysis was conducted (Malee Hutacharoen 1987) in a small watershed within the Chiang main province to determine soil degradation and soil erosion, caused by deforestation and forest related farming practices. The surface vegetation is mapped using a multi temporal, Landsat MSS data set and others to create a data base containing vegetation cover, elevation, slope length, soil erodability factors, rainfall and runoff factors. The conservation practice factors were used in the Universal Soil Loss Equations (USLE) to calculate the soil loss for the Maeklang watershed. He also discussed the effect of the associated forest burning practice on soil degradation and erosion in the watershed.

Smith et al., (1987) discussed that the micro computer based GIS and image analysis techniques could be used as a new tool to facilitate and improve agricultural field management of a watershed. He also developed a model for managing the watershed by suitable application of fertilizers to get best crop production.

Macarthy et al., (1987) discussed that integrating the spatial model of GIS with forest simulation and optimisation models adds the necessary criteria for solving adjacency constraints during optimization. Mu-Lin-Wu (1992) explained how a 3D GIS has been used for soil and water conservation engineering as a part of design of water harvesting structures such as dams etc. in a watershed.

Star et al., (1992) stressed the need for an integrated system for analysis of remote sensing data and other attribute data needed for analysis should reside in the same system and Integrated Geographical Information System (IGIS) has to be developed for analysing the resources available in the watershed. Nickolas Faust (1992) explained that the recent changes in
computing technology are causing dramatic effects in the manner in which image processing and GIS functions can be applied to real world problems.

Maling P. Julius (1992) conducted a study in Philippines for assessing various landcovers such as soil erosion prone areas, upland cultivation and property values. He used three types of GIS software (viz) ARCINFO, TYDAC SPANS and CRIES for overlay analysis of attribute maps produced to a large extent using remote sensing techniques. The resulting decision maps are basic consideration for the effective management of sloping lands and more importantly for revenue collection in prime agricultural lands.

The potential of the remote sensing techniques has been recognized as a means to prepare dynamic landuse maps spatially and accurately, at various levels of confidence. But the applications of multi-spectral classification techniques in extracting landcover classes has been a subject of discussion for many years (Strahler 1980, Buckland 1994, Corves and Place 1994, Johnson 1994). This inconsistency occurs because of similarities in spectral response among various cover classes (Bocco and Valenzuela, 1991, Adinarayana et al., 1994).

There has been successful discrimination of different vegetation categories of similar spectral characteristics by the integration of remote sensing and GIS through the introduction of knowledge based rules (Chibula and Nyquist 1987, Duane et al., 1990, Bocco and Valenzuela 1991, Kimes et al., 1991, Jezhing et al., 1991, Adinarayana et al., 1994, Parachini and Folving 1994), but there have been no attempts to identify the actual classes under the cloud/shadow region and to map the agricultural landuse pattern of Kharif and Rabi seasons in the mountainous terrains of heterogeneous nature.
Rondal D. Jose et al., (1994) conducted a study for development of watershed management strategies using satellite derived landcover map in combination with other land factors (soil, slope, geomorphology) in determining appropriate landuses for the watershed. The analysis was done through a series of map overlays using ARC/INFO GIS package. In this analysis the groundwater and other water potentials are not considered and also the analysis was made on qualitative basis without quantifying the various natural resources.


Smith et al., (1995) conducted a study to determine the potential of multi temporal, multisensory data to identify management practices that are consistent with sustaining agricultural resources. The ground and satellite data were integrated in a GIS and hierarchical classification system was developed to separate ground cover types for identifying soil conservation classes using satellite imagery. Stevan et al., (1995) compared four satellite data classification techniques including GIS rule based model and concluded that a combination of hybrid and GIS rule based classification methods are the most promising for forest wetland delineation.

Adinayarana et al., (1996) described methodology for GIS-assisted mapping of landuse and natural resources in a rain-infested heterogeneous hilly watershed. He generated the digital database of Kharif and Rabi landuse pattern and the relevant watershed resources, the development of multi-disciplinary knowledge based rules after georeferencing the information data layers to link the databases for an
improved agricultural landuse pattern of the watershed in GIS format, without quantifying the water resources.

Schistad Solberg et al., (1996) developed a Markov Random field model for classification of satellite imagery by fusing Landsat TM images, multi temporal ERS 1 SAR images and GIS ground cover maps for landuse classification and it is found to be useful for classification of multi source satellite imagery.

Dhane Nellis et al., (1996) discussed the sustainability of watershed considering the various factors viz. landuse/landcover obtained from Remote sensing data, soil properties, erosion index and aquifer thickness qualitatively in GIS without quantifying the various resources available in the watershed. Moreover he did not consider the availability of water potential which is more vital for analysis.

2.8 CONCLUSIONS

After the comprehensive literature survey, the main conclusions arrived at are as follows. It is decided to develop a model for the surface system and sub-surface system of a watershed considering the various hydrological processes involved. The various inflows going into the system such as rainfall recharge, river bed recharge, return flow from irrigation and sub-surface inflow would be assessed. Similarly the various outflows from the system such as extraction for human and animal population, extraction for irrigation, evapotranspiration of natural vegetation and sub-surface outflow from the system and net changes in the storage would be computed. A distributed model for the aquifer system to be developed to study the hydrological responses for the changes in the landuse. The evaluation of land resources would be attempted as suggested in the model developed by Zhang Zhixiang. An improved agriculture pattern by integrating Remote Sensing data and GIS technology by developing a
knowledge based rules as suggested by Adinarayana et al., would be adopted to model in this study. The methodology suggested by Dhane Nelli et al., for studying the sustainability status of the watershed should be improved. The present study also aims at modelling the watershed for assessing the sustainability status by considering the available surface and sub-surface water and required water on a quantitative basis for improved landuse pattern as suggested by the knowledge based rules developed for better management by adopting conjunctive use of both surface and ground water. The present study also contemplates to assess the sustainable (optimal) landuse pattern by developing linear programming model considering the various constraints in the watershed development.