CHAPTER 2
REVIEW OF LITERATURE

2.1 GENERAL

Review of available literature on a particular problem or study helps to identify the research gaps and focus on various aspects of problems several researchers and academicians who have studied on various issues tend to provide meaningful solutions that help to formulate general policy. The present study in this chapter on the basis of research and in agreement with the objectives of the present study, the work made on different aspects of Integrated Water Resources Management for sustainable irrigation is reviewed.

The virtual role of irrigation in the economic development of the countries has attracted not only individual research scholar and government but also the international organizations like Asian Development Bank, World Bank (IBRD) etc. Such studies focus their impact on the Socio-economic conditions of the people and other related variables of the agricultural transformation in India and abroad some of these studies deal with regional level impacts and some other have been conducted at macro level. The database of these studies has been both primary and secondary since there are numerous studies in this field. Here trying to give a brief review of literature pertaining to the contributions of sustainable irrigation.

A large number of studies available on IWRM for Sustainable Irrigation, the brief overview and historical reviews done under the following headings.

- Overview of Sustainable Irrigation
- Overview of Water Resources in India & Karnataka
- Review of Literature of Morphometric analysis
- Review of Literature of Intensity Duration Curves
- Review of Literature of Runoff Estimation
- Review of Literature of Groundwater Prospect Zones
- Review of Literature of Soil Erosion Estimation
• Review of Literature of Evapotranspiration
• Review of Literature of Land Suitability for irrigation

2.2 SUSTAINABLE IRRIGATION: ISSUES & CHALLENGES

Irrigation is not sustainable if water supplies are not reliable. Especially in areas of water scarcity the major need for development of irrigation is to minimize water use. Effort is needed to find economic crops using minimal water, to use application methods that minimize loss of water by evaporation from the soil or percolation of water beyond the depth of root zone and to minimize losses of water from storage or delivery systems.

Nowadays, during a period of dramatic changes and water resources uncertainty there is a need to provide some support and encouragement to farmers to move from their traditional high-water demand cropping and irrigation practices to modern, reduced demand systems and technologies. It is well known that crop yield increases with water availability in the root zone, until saturation level, above which there is little effect [9]. The yield response curve of specific crops depends on various factors, such as weather conditions and soil type as well as the reduction of the agricultural inputs like fertilizers and pesticides (FIGURE 2-1). Therefore it is difficult for a farmer to tell at any given moment whether there is a water deficit or not.

Since overabundant water usually does not cause harm, farmers tend to “play safe” and increase irrigation amount, especially when associated costs are low. Over-irrigation can cause among others temporal water shortage to other farmers, water-logging conditions for the crop, favorable environment for disease development, loss of nutrients due to leaching or deep percolation, contamination of the aquifers from agrochemicals, reduction of crop yield and deterioration of the quality and increase of production cost.
FIGURE 2-1: PLANT YIELD RESPONSE TO WATER

Sustainable water management in agriculture aims to match water availability and water needs in quantity and quality, in space and time, at reasonable cost and with acceptable environmental impact. Many parameters like crop growth stage and its sensitivity to water stress, climatic conditions and water availability in the soil determine when to irrigate or the so-called irrigation frequency. However, this frequency depends upon the irrigation method and therefore, both irrigation scheduling and the irrigation method are inter-related.

2.2.1 WATER LOGGING AND SALINITY ISSUE

In agricultural point of view, Water logging of land is a situation of adverse air water proportion in the sub soil root zone. Primary reasons for water logging are over irrigation, lack of conjunctive irrigation, seepage from canals and irrigation channels. Farmers with their lands in head reaches of a command area are more susceptible to the problem of water logging and as a result, salinity. Farmers have become poorer owing to these growing problems.

2.2.2 LOCALIZED IRRIGATION ISSUE

Localized irrigation is widely recognized as one of the most efficient methods of watering crops [10]. Localized irrigation systems (trickle or drip irrigation, micro-sprayers) apply the water to individual plants by means of plastic pipes, usually laid on
the ground surface. With drip irrigation water is slowly applied through small emitter openings from plastic pipes with discharge rate \( \leq 12 \, \text{l/h} \). With micro-sprayer (micro-sprinkler) irrigation water is sprayed over the part of the soil surface occupied by the plant with a discharge rate of 12 to 200 l/h. The aims of localized irrigation are mainly the application of water directly into the root system under conditions of high availability, the avoidance of water losses during or after water application and the reduction of the water application cost (less labor).

Studies in diverse countries as India, Israel, Spain and United States have consistently shown that drip irrigation reduces water use by 30 to 70\% and raises crop yields by 20 to 90\% [11].

### 2.2.3 Irrigation Scheduling Issue

Irrigation scheduling is the decision making process for determining when to irrigate the crops and how much water to apply. It forms the sole means for optimizing agricultural production and for conserving water and it is the key to improving performance and sustainability of the irrigation systems. It requires good knowledge of the crops’ water requirements and of the soil water characteristics that determine when to irrigate, while the adequacy of the irrigation method determines the accuracy of how much water to apply.

Irrigation scheduling techniques and tools varies greatly and has different characteristics relative to their applicability and effectiveness. Timing and depth criteria for irrigation scheduling [12] can be established by using several approaches based on soil water measurements, soil water balance estimates and plant stress indicators, in combination with simple rules or very sophisticated models.

### 2.2.4 Soil Water Estimates and Measurements

Soil water affects plant growth directly through its controlling effect on plant water status. There are two ways to assess the availability of soil water for plant growth: by measuring the soil water content and by measuring how strongly that water is retained.
in the soil (soil water potential). The accuracy of the information relates to the sampling methods adopted and to the selection of locations where point observations are performed due to the soil water variability both in space and depth [13]. Soil water estimates and measurements used for irrigation scheduling include: soil appearance and feel, soil water content measurement (TDR), soil water potential measurement (tensiometers, soil spectrometers and pressure transducers), remotely sensed soil moisture.

2.2.5 CROP STRESS PARAMETERS

Instead of measuring or estimating the soil water parameters, it is possible to get a signal from the plant itself indicating the time of irrigation but not defining the irrigation depths. This message can either come from individual plant tissues, where a correct sampling is required, or from the canopy as a whole.

Therefore, crop stress parameters are useful when irrigation depths are predefined and kept constant during the irrigation season. Crop water stress parameters include leaf water content and leaf water potential, changes in stem or fruit diameter, sap flow measurement, canopy temperature, remote sensing of crop stress (Deumier et al., [14]; Idso et al., [15]; Jackson et al., [16]; Itier et al., [17]).

2.2.6 SOIL – WATER BALANCE

The aim of soil water balance approach is to predict the water content in the rooted soil by means of a water conservation equation:

\[ \Delta (AWC \times \text{Root depth}) = \text{Balance of entering} + \text{outgoing water fluxes}, \]

Where AWC is the available water content. Soil water holding characteristics, crop and climate data are used by sophisticated models to produce typical irrigation calendars. This approach can be applied from individual farms to large regional irrigation schemes. However, it needs expertise, support by strong extension services or links...
with information systems. Its effectiveness is very high, but depends on farm technological development and/or support services.

**2.3 OVERVIEW OF SUSTAINABLE IRRIGATION**

The goal of sustainable irrigation is to meet society’s food and textile needs in the present without compromising the ability of future generations to meet their own needs. Practitioners of sustainable agriculture seek to integrate three main objectives into their work:

- A healthy environment,
- Economic profitability, and
- Social and economic equity.

Every person involved in the food system—growers, food processors, distributors, retailers, consumers, and waste managers—can play a role in ensuring a sustainable agricultural system.

There are many practices commonly used by people working in sustainable agriculture and sustainable food systems. Growers may use methods to promote

- Soil health,
- Minimize water use, and
- Lower pollution levels on the farm.

Considering the burning issues of hunger, poverty, escalating food prices, population growth rate, resource degradation and the need of sustainable agriculture, it is imperative to go in for watershed irrigation and management involved therein. Nearly 58% of the cultivated area in the country is under rain fed agriculture, which contributes to 40% of the total food production. For this to be understood, carrying capacity (CC) estimates are quite necessary. Ecologists define CC of an ecosystem as the population of humans and animals that can be sustained, based on the primary productivity of plants, with the available resources and services without damaging the resource base-soil, water and environment. In other words, CC is the maximum rate of resource consumption and waste discharge that can be sustained indefinitely in a region without progressively impairing productivity and ecological integrity. CC can be enhanced with technological, financial and managerial inputs. Later, irrigation, fertilizers, genetic enhancement, pesticides and mechanization enhanced the quantity of food produced and the CC. When the available resources, land, water and energy
are limited, consumption and the technologies that improve the resource base become the key determinants of CC.

India, with 1,349,707,628 (1.34 billion) people is the second most populous country in the world, while China is on the top with over 1,415,489,506 (1.41 billion) people (FIGURE 2-2). The total population in India was estimated at 1299.0 million people in 2016, according to the latest census figures. Looking back, in the year of 1950, India had a population of 359.0 million people.

**FIGURE 2-2: INDIAN POPULATION**

Production of fruits and vegetables plays a vital role in nutritionally balanced diet for the population. Fertilizers have played a major role in the increased productivity of cereals. The Indian soils are depleted of organic matter and there is an urgent need for higher use of balanced fertilizers. Rainfed agriculture with nearly 58% of the cultivated area contributes 40% of the country’s food production. Even after full irrigation potential of the country is realized, half of the cultivated area will continue to be under rain fed farming. Much of the acreage under coarse cereals (85%), pulses (83%) and Oil seeds (70%), substantial area under rice (42%) and nearly 65% of cotton area is rain fed.

Hence, it is necessary to increase the productivity of major rainfed crops to meet the ever increasing demand of food and fiber. Moreover, rainfed regions are home to about
40% of the human and 60% of the livestock population, and the performance of rainfed agriculture is critical to achieve and sustain higher growth in agriculture.

2.3.1 BASIC FACTS OF AGRICULTURE

a. Agriculture a State subject – so primary thrust in the realm of States
b. Population - >125 cr; 58% workforce in agriculture. 58% workforce employed in agriculture with around 40% rural poverty - classical shift of labour with structural change of economy not seen in India
c. Food grains production – 265.6 m MT in 2013-14,
d. 121 m farm holdings, 127 m cultivators and 107 m agricultural labourers
e. Average size of operational holdings – 1.3 hectare, small & marginal holdings – 82%, 61% < 1 ha.
f. Rain fed agriculture covers around 200 m ha or 56% of cropped area. Accounts for 48% of area under food crops and 68% under non-food crops. Holds the key - 40% of future foodgrains increase expected to come from rainfed areas.
g. Decline in Agriculture contribution in GDP from 36.4% in 1982-83 to 18% in 2014-15 (as per new CSO series)
h. General decline in per calorie consumption in rural India & per capita availability of foodgrains while India has been a net exporter
i. Right to Food Act – need for adequate production to address demand-side issues. Key lies in achieving a significantly higher growth than population growth rate
j. MSP for principal crops doubled in last 10 years
k. Progress on irrigation tardy – only 42% cropped area irrigated; created potential not utilized.
l. Over-reliance on ground water – serious crisis in many states due to over-extraction.
m. Growth of most Asian economies has been supported, if not entirely based, on fast agricultural growth – rural surpluses traditional economic growth drivers
n. At policy level, agriculture should be integrated with rural development – in practice divorced – worse, agriculture less romantic!
2.3.2 Policy Challenges

➢ To maximize food grains production for food security
➢ To provide higher incomes to farmers for rural prosperity
➢ To offset by challenge to keep inflationary pressures at bay – producers vs. consumers interests
➢ To use agricultural growth to mitigate rural poverty
➢ To ensure agricultural sustainability - water & soil-nutrient balance and increasing yields
➢ To balance international volatility vs. consistency in trading policy
➢ To mitigate effects of climate change

2.3.3 EFFECT OF IRRIGATION IN AGRICULTURE

Arun S. Patel [18] observed in his article on ‘Irrigation: Its Employment Impact in the Command Areas of Medium Irrigation Projects in Gujarat’ that the expansion of irrigation and the spread of new technology help to improve the standard of living and generation of additional employment opportunities at the required level of productivity. Irrigation brings changes in the crop pattern. They are:

(i) A shift from inferior cereals and pulses to superior cereals,
(ii) A shift from food grains to non-food grains both short and long duration crops, and
(iii) A shift from crops if Indigenous (desi) varieties to HYVs both in respect of food grain and also non-food grain crops and
(iv) Augmentation of area under double and multiple cropping which in turn provides more opportunities of work to the agriculturists at the farm level.

Sundar et. al., [19] studied on ‘Farmers’ Organization for Efficient Water Use in Irrigated Agriculture - An Overview’, that the efficient utilization of irrigation potential. In order to improve the utilization of irrigation potential and crop yields, they suggested proper maintenance of the main canal and distribution system above the pipe-outlet, development of field channels, adoption of a rotational system, on-farm development, extension education, coordination among the development departments and training personnel at various levels.
Ramakrishnan et. al., [20] explains on ‘Water Use Pattern in Tambaraparani Irrigation System’ viewed that water is a crucial input in agricultural development and it also influences the use and productivity of other resources in crop production. The study made at the head and tail reach situated farmers of the Tambaraparani irrigation system revealed that the cropping intensities were 300% and 260% in the head and tail reaches respectively, indicating significant difference between the farms in the two reaches in input use.

Jayant Patil [21] studied on sustainable irrigation management in India in this article author explains efficient operation of the system is one of the key factors which enable actual flow of envisaged benefits to the users. It has been observed that about 25 percent of the conveyance lessees are through main canal and distributaries and about 20 percent in the water courses such huge losses are attributed to the serious short comings in terms at technical and management inputs in the system maintenance of the system had been deteriorating day by day especially the secondary and tertiary systems keeping in mind equity, reliability and timeliness in irrigation water distribution.

Lekhi et al., [22] explain about irrigation the most important input required for agricultural development in India is irrigation as it facilitates multiple cropping and increases crop productivity. Seema Purushottam [23] conducted study on trends in land use and crop acreages in Karnataka and their repercussions specialization at district level during liberalization period. Increasing acreage of pulses in Bidar and Gulbarga, increasing acre aging acreage of land under coconut in Tumkur, decreasing acreage of cotton together with increasing acreage of oilseeds in Bijapur may reflect growing specialization of crops in these districts.

Suresh Pal [24] author summaries in the study water has been identified one of the main thrust areas of XII Plan since agriculture uses more than 80 percent of water its management for irrigation becomes important. The evidence from different case studies indicated that participatory approaches help in controlling over exploitation of ground water. This is done through formation of user groups, developing mutually agreed regulations and creating awareness among the user formers.
Krishnamurty [25] revealed that India has an irrigation potential of 139.89 million hectares at this only 108.2 million hectares (77.35 percent) have been utilized. At present about 30 percent of the net cultivated area has the benefit of irrigation massive investment was made on irrigation during the planning period up to seventh five year plan a sum of Rs.16,590/- crore have been spent on irrigation development

Sebak Kumar et al., [26] in their study the results of the preliminary study on tank irrigation in the dry zones of the state bear important policy implication. The following are considered important while making the tank improvement programmes in the state water availability will improve the tank productivity. It is seen that the average period of water availability for irrigation is about 6 months. Hence, by improving the catchments and field channels it is possible to increase the water inflows in to the tanks.

2.3.4 IMPACT OF CROPPING PATTERN

Bagi [27] viewed in the article on ‘Economics of Irrigation in Crop Production in Haryana’ that irrigation primarily reduces the uncertainty of crop production and consequently increases agricultural productivity in a number of ways.

1. It can increase crop yields even without any increased use of inputs.
2. Lower risk and uncertainty of crop production.
3. It makes possible to grow crops all year around and hence can increase the cropping intensity. Fourth, cultivation of better quality and high value crops may become feasible.

Rajkishor [28] author evaluated the use of water and its impact on cropping pattern at different locations of a canal irrigation system in Bomnal minor canal in Orissa. The study revealed that due to the availability of adequate water at the head reach and the mid reach, the formers had devoted a considerable proportion of area to labour and capital-intensive crops like high yielding rice and potato.

Verma et. al., [29] focused on “Impact of Rescheduling of Irrigation Water on Farm Incomes and Cropping Pattern - A Case study of Jaisamand Dam in Alwar District of
Rajasthan”. In this study Linear programming technique was used to develop optimal cropping pattern for the command area. The optimal cropping pattern in turn resulted in optimal distribution of irrigation water of the reservoir.

Nathan [30] study revealed that different climatic conditions and well considered irrigation extent a major influence on the growth and quality of citrus fruits lime, mandarin, grapes and lemons while citrus flourish in mild winter and can susceptible height frost conditions, warm summers reflect well on their quality profile variations in the day and night temperature helps in better color development in citrus.

Hangaragi [31] concluded that cropping pattern of the district has not changed significantly in spite of population growth. In the present scenario needs to strengthen the irrigation facilities, soil and moisture conservation, adoption of biotechnology, forestation, changing in the cropping pattern, agronomic practices, livestock development, rural communications, development of medium, small and marginal farmers and agricultural laborers and setting up agro-based industries.

Ahmad Fahim Rahimi et al., [32] summaries in their study the pattern of cropping is a major feature of the agricultural land use in an area. Systematic understanding of cropping pattern changes over the years is very important, for the farmers to get better returns, for the entrepreneurs to decide the government and lawmakers to check over or under production of farm products, thus ensuring the required overall balance.

2.4 OVERVIEW OF WATER RESOURCES

Human water consumption is straining water resources worldwide (Vogel et al., [33]; Wada et al., [34]; Lall et al., [35]), with developing nations particularly vulnerable to water scarcity. The causes of water scarcity are complex (Srinivasan et al., [36]) and in south India have been associated with urbanization, groundwater depletion (Reddy, [37]), degradation of rainwater harvesting structures, and interstate water disputes (Anand, [38]). Effective management of water scarcity in this region is impeded by lack of adequate data to quantify and understand how human activities affect hydrology.
2.4.1 RENEWABLE WATER RESOURCES OF INDIA

Water is a relatively scarce resource in India since we have 16.0 per cent of the world’s population and only 4.0 per cent of the usable fresh water. Irrigation is the sector that uses water the most. Nearly 80% of the world’s water resources are used in irrigation. In India also irrigation uses more than 80% of the available water. The water resources in India are estimated at 4000 cubic kilometer given the geographical area of 3.3 million square kilometer and an average annual rainfall of 1170 mm (Table 2-1).

<table>
<thead>
<tr>
<th>Table 2-1 : Water resources of India</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Annual Precipitation</td>
</tr>
<tr>
<td>Average runoff in all the rivers</td>
</tr>
<tr>
<td>Utilizable surface water</td>
</tr>
<tr>
<td>(i) By conventional means</td>
</tr>
<tr>
<td>(ii) Replenishable groundwater</td>
</tr>
<tr>
<td>Present utilization</td>
</tr>
<tr>
<td>Demand by 2025 AD</td>
</tr>
<tr>
<td>Demand by 2050 AD</td>
</tr>
<tr>
<td>Possible additional water utilization through Inter Basin Water Transfer Scheme of GOI</td>
</tr>
</tbody>
</table>

Source: Ministry of Water Resources, Government of India (GOI)

India is blessed with many rivers with varying catchment area and water resources potential. The catchment areas of these rivers are divided into 20 river basins. The major river basins are listed in Table 2-2. Of the major rivers, the Ganga -Brahmaputra – Meghna system is the largest with catchment area of about 11 lakh sq km. The other major rivers with catchment area about one lakh sq km or more are: Indus, Godavari, Krishna, Mahanadi and Narmada.
Table 2-2: Major River Basins (Unit: BCM)

<table>
<thead>
<tr>
<th>River Basin</th>
<th>Catchment Area (Sq. Km.)</th>
<th>Average Water Resources Potential</th>
<th>Utilisable Surface Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ganga</td>
<td>861452</td>
<td>525.02</td>
<td>250.0</td>
</tr>
<tr>
<td>Brahmaputra</td>
<td>194413</td>
<td>537.24</td>
<td>24.0</td>
</tr>
<tr>
<td>Barak &amp; Others</td>
<td>41723</td>
<td>48.36</td>
<td></td>
</tr>
<tr>
<td>Indus (up to Border)</td>
<td>321289</td>
<td>73.31</td>
<td>46.0</td>
</tr>
<tr>
<td>Godavari</td>
<td>312812</td>
<td>110.54</td>
<td>76.3</td>
</tr>
<tr>
<td>Krishna</td>
<td>258948</td>
<td>78.12</td>
<td>58.0</td>
</tr>
<tr>
<td>Mahanadi</td>
<td>141589</td>
<td>66.88</td>
<td>50.0</td>
</tr>
<tr>
<td>Narmada</td>
<td>98796</td>
<td>45.64</td>
<td>34.5</td>
</tr>
</tbody>
</table>

Source: Ministry of Water Resources, Government of India (GOI)

The area of water bodies at all-India level has been presented in Table 2-3. Other than rivers and canals, total water bodies cover an area of about 7.4 Mha.

Table 2-3: Inland Fishery Water Resources

<table>
<thead>
<tr>
<th>RIVERS &amp; CANALS (LENGTH IN KM)</th>
<th>195210</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Water Bodies (area in Mha)</td>
<td></td>
</tr>
<tr>
<td>Reservoirs</td>
<td>2.91</td>
</tr>
<tr>
<td>Tanks, Lakes &amp; Ponds</td>
<td>2.41</td>
</tr>
<tr>
<td>Flood Plain Lakes &amp; Derelict Water</td>
<td>0.80</td>
</tr>
<tr>
<td>Brackish Water</td>
<td>1.24</td>
</tr>
<tr>
<td>Total</td>
<td>7.40</td>
</tr>
</tbody>
</table>

Source: Ministry of Water Resources, Government of India (GOI)

Nearly 50 per cent of water is lost to evaporation, percolation, sub-surface flows to oceans and only 1953 Billion Cubic Meter (BCM) of water is available. The temporal and special variation in the availability of water reduces it further to 1086 BCM [39]. With 1,896 billion cubic meters (BCM) of surface runoff—636 and 1,260 BCM of...
externally renewable water resources and internally renewable water resources (Table 2-4).

**Table 2-4. Renewable Water resources of India.**

<table>
<thead>
<tr>
<th>River Basins</th>
<th>Total Water Resources</th>
<th>Utilizable Surface Water</th>
<th>Total Ground Water</th>
<th>Potentially Utilizable Water</th>
<th>Puwr % Of Trwr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indus (Up to border)</td>
<td>73.3</td>
<td>46.0</td>
<td>27</td>
<td>72.5</td>
<td>99</td>
</tr>
<tr>
<td>Ganga</td>
<td>525.0</td>
<td>250.0</td>
<td>172</td>
<td>422</td>
<td>80</td>
</tr>
<tr>
<td>Brahmaputra and Meghna</td>
<td>585.6</td>
<td>24.0</td>
<td>36</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Subernarekha</td>
<td>12.4</td>
<td>6.8</td>
<td>2</td>
<td>9</td>
<td>70</td>
</tr>
<tr>
<td>Brahmani-Baitarani</td>
<td>28.5</td>
<td>18.3</td>
<td>4</td>
<td>21</td>
<td>74</td>
</tr>
<tr>
<td>Mahanadi</td>
<td>66.9</td>
<td>50.0</td>
<td>17</td>
<td>66</td>
<td>99</td>
</tr>
<tr>
<td>Godavari</td>
<td>110.5</td>
<td>76.3</td>
<td>41</td>
<td>117</td>
<td>106</td>
</tr>
<tr>
<td>Krishna</td>
<td>78.1</td>
<td>58.0</td>
<td>26</td>
<td>84</td>
<td>108</td>
</tr>
<tr>
<td>Pennar</td>
<td>6.3</td>
<td>6.9</td>
<td>5</td>
<td>12</td>
<td>187</td>
</tr>
<tr>
<td>Cauvery</td>
<td>21.4</td>
<td>19.0</td>
<td>12</td>
<td>31</td>
<td>147</td>
</tr>
<tr>
<td>Tapi</td>
<td>14.9</td>
<td>14.5</td>
<td>8</td>
<td>23</td>
<td>153</td>
</tr>
<tr>
<td>Narmada</td>
<td>45.6</td>
<td>34.5</td>
<td>11</td>
<td>45</td>
<td>99</td>
</tr>
<tr>
<td>Mahi</td>
<td>11.0</td>
<td>3.1</td>
<td>4</td>
<td>7</td>
<td>64</td>
</tr>
<tr>
<td>Sabarmati</td>
<td>3.8</td>
<td>1.9</td>
<td>3</td>
<td>5</td>
<td>135</td>
</tr>
<tr>
<td>WFR1</td>
<td>15.1</td>
<td>15.0</td>
<td>11</td>
<td>26</td>
<td>173</td>
</tr>
<tr>
<td>WFR2</td>
<td>200.9</td>
<td>36.2</td>
<td>18</td>
<td>54</td>
<td>27</td>
</tr>
<tr>
<td>EFR1</td>
<td>22.5</td>
<td>13.1</td>
<td>19</td>
<td>32</td>
<td>142</td>
</tr>
<tr>
<td>EFR2</td>
<td>16.5</td>
<td>16.7</td>
<td>18</td>
<td>35</td>
<td>212</td>
</tr>
</tbody>
</table>

*Source: GOI [40], CWC [41]*

**Notes:**
1. WF1 includes west flowing rivers of Kutch, Saurashtra including Luni;
2. WF2 includes west flowing rivers between Tapi and Kanayakumari;
3. EF1 includes east flowing rivers between Mahanadi and Pennar;
4. EF2 includes east flowing rivers between Pennar and Kanayakumari;
5. Minor river basins drainage into Bangladesh and Myanmar

### 2.4.2 RENEWABLE WATER RESOURCES OF KARNATAKA

Karnataka is unique in respect of its water resources as compared to the rest of the country. Rainfall varies from 400 mm to 4000 mm across different agro-climatic zones.
The average normal rainfall of Karnataka is about 1220 mm. About 70% of the rainfall is received during the south west monsoon during the months between June and September. Karnataka is second most arid state after Rajasthan with 19 out of 30 districts being drought prone. The basin wise breakup of this yield is given in the Table 2-5.

Table 2-5 : Basin Wise Breakup of Yield in Karnataka

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>River System</th>
<th>Estimated average yield in M.cum TMC Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Krishna</td>
<td>27,451 969.44 27.90</td>
</tr>
<tr>
<td>2</td>
<td>Cauvery</td>
<td>12,034 425.00 12.23</td>
</tr>
<tr>
<td>3</td>
<td>Godavari</td>
<td>1,415 49.97 1.44</td>
</tr>
<tr>
<td>4</td>
<td>West Flowing river</td>
<td>56,600 1998.83 57.51</td>
</tr>
<tr>
<td>5</td>
<td>North Pennar</td>
<td>906 32.00 0.92</td>
</tr>
<tr>
<td>6</td>
<td>South Pennar</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Palar</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>98406 3475.24 100</td>
</tr>
</tbody>
</table>

Source: GOI [40], CWC [41]

The irrigation potential by different sources is depicted in Table 2-6

Table 2-6 : Irrigated Areas in India and Karnataka

<table>
<thead>
<tr>
<th>India</th>
<th>Karnataka</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Source</td>
<td>Capacity (M Ha)</td>
</tr>
<tr>
<td>Major And Medium Irrigation (Surface Water)</td>
<td>32.69</td>
</tr>
<tr>
<td>Minor Irrigation (Surface Water)</td>
<td>10.89</td>
</tr>
<tr>
<td>Minor Irrigation (Ground Water)</td>
<td>45.73</td>
</tr>
<tr>
<td>Total</td>
<td>89.31</td>
</tr>
</tbody>
</table>

Source: GOI [40], CWC [41]
Surface water is available in Karnataka in the form of rivers, lakes, waterfalls, reservoirs, etc. Karnataka has surface water potential of around 102 km. Being the seventh largest state in India (area-wise), Karnataka possesses about six percent of the country’s total surface water resources of about 17 lakh million cubic metres (Mcum). Karnataka is blessed with seven river basins. There are 36,753 tanks in the state and they have a capacity of about 684518 hectares. The rivers, along with their tributaries, account for much of Karnataka’s surface water resources. About 60 percent of the state’s surface water is provided by the west flowing rivers while the east flowing rivers account for the remaining portion. The annual average yield in the seven river basins of the state is estimated to be around 3,475 TMC. The yield in the six basins, excluding the west flowing rivers is estimated to be 1,440 TMC.

Groundwater resources in Karnataka has estimated to be around 485 TMC. Groundwater resources have not been exploited evenly across the state. In areas where adequate surface water is available, exploitation of ground water resources is minimum. Exploitation of ground water in the dry taluks of North and South interior Karnataka is higher as compared to Coastal, Malnad and irrigation command areas of the state. In about 43 taluks there is over exploitation of ground water resources. Further, groundwater exploitation has exceeded 50% of the available ground water resources in 29 taluks of the State.

2.5 REVIEW OF LITERATURE OF MORPHOMETRIC ANALYSIS

Morphometric analysis is a significant tool for prioritization of micro-watersheds even without considering the soil map [42]. Topographic features such as slope, curvature, and degree of convergence have an important impact on runoff production and the nature and strength of the flow connectivity. For instance, as the mean slope length becomes shorter, the time required to reach an effective channel decreases, leading to a steeper rising hydrograph limb and a higher peak discharge. Primary terrain attributes include slope, aspect, plan and profile curvature, flow-path length, and upslope contributing area. Most of these topographic attributes can be calculated from the directional derivatives of a topographic surface. The primary topographic attributes
that can be computed by terrain analysis from DEM data and their significance are listed in Table 2-7.

Horton [43] in his studies reveals about the drainage basin characteristics and its need for assessing the groundwater recharge zone studies. Chow [44] stated influence of the geological parameters on construction the recharge structures. Morphometric analysis stream networks have been used to quantitatively describe stream basins with the goal of understanding their processes and evolution (Horton, [45]; Strahler, [46], [47], [48] & [49]). This quantitative Morphometric analysis of watersheds was continued by a series of methodological and theoretical papers spanning more than a quarter century (Langbein et. al., [50], Schumm [51]) showed that tectonic zones in the Indus Valley of Ladakh, in north India, can be differentiated using morphometric analyses of longitudinal valleys.

Morphometric analysis through remote sensing and GIS techniques have been attempted by a number of researchers (Nautiyal, [52]; Srivastava, [53]; Nag, [54]; Agarwal, [55]; Singh et al., [56]; Vittala et al [57]; Obi Reddy et. al., [58]) and all have arrived to the conclusion that remote sensing and GIS are the powerful tools for studying basin morphometry and continuous monitoring.

Ajoy Das et. al., [60] have used remote Sensing and GIS techniques for generation of various thematic maps such as geomorphology, drainage, watershed and surface water, land use/land cover, soil and slope. These maps were used for prioritization of mini watersheds through morphometric analysis.

Zende et. al., [61] have studied Krishna basin for the quantitative analysis of morphometric parameter, using GIS software and utilized for watershed prioritization for soil and water conservation, flood prediction and natural resources management.

Shakil Ahmad Romshoo et al., [62], have studied Geo-informatics for assessing the morphometric control on hydrological response at watershed scale in the Upper Indus Basin. From the morphometric analysis, it is evident that the hydrologic response of sub-watersheds changes significantly in response to spatial variations in morphometric parameters.
Table 2-7: Primary topographic attributes that can be computed by terrain analysis from DEM data [59]

<table>
<thead>
<tr>
<th>ATTRIBUTE</th>
<th>DEFINITION</th>
<th>SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>Elevation</td>
<td>Climate, vegetation, potential energy</td>
</tr>
<tr>
<td>Upslope height</td>
<td>Mean height of upslope area</td>
<td>Potential energy</td>
</tr>
<tr>
<td>Aspect</td>
<td>Slope azimuth</td>
<td>Solar isolation, evapotranspiration, flora and fauna distribution and abundance</td>
</tr>
<tr>
<td>Slope</td>
<td>Gradient</td>
<td>Overland and subsurface flow, velocity and runoff rate, precipitation, soil water content, vegetation, geomorphology, land capability</td>
</tr>
<tr>
<td>Upslope slope</td>
<td>Mean slope of upslope area</td>
<td>Runoff velocity</td>
</tr>
<tr>
<td>Dispersal slope</td>
<td>Mean slope of dispersal area</td>
<td>Rate of soil drainage</td>
</tr>
<tr>
<td>Catchment slope</td>
<td>Mean slope of the watershed</td>
<td>Time of concentration</td>
</tr>
<tr>
<td>Upslope area</td>
<td>Catchment area above a short length of contour</td>
<td>Runoff volume, steady-state runoff rate</td>
</tr>
<tr>
<td>Dispersal area</td>
<td>Area downslope from a short length of contour</td>
<td>Soil drainage rate</td>
</tr>
<tr>
<td>Catchment area</td>
<td>Area draining to the catchment outlet</td>
<td>Runoff volume</td>
</tr>
<tr>
<td>Specific drainage area</td>
<td>Upslope area per unit width of contour</td>
<td>Runoff volume, steady-state runoff rate, soil-water content, geomorphology</td>
</tr>
<tr>
<td>Flow path length</td>
<td>Maximum distance of water flow to a point in the catchment</td>
<td>Erosion rates, sediment yield, time of concentration</td>
</tr>
<tr>
<td>Upslope length</td>
<td>Mean length of flow paths to a point in the catchment</td>
<td>Flow acceleration, erosion rates</td>
</tr>
<tr>
<td>Dispersal length</td>
<td>Distance from a point in the catchment to the outlet</td>
<td>Impedance of soil drainage</td>
</tr>
<tr>
<td>Catchment length</td>
<td>Distance from highest point to the basin outlet</td>
<td>Overland flow attenuation</td>
</tr>
<tr>
<td>Profile curvature</td>
<td>Slope profile curvature</td>
<td>Flow acceleration, erosion and deposition rate, geomorphology</td>
</tr>
<tr>
<td>Plan curvature</td>
<td>Contour curvature</td>
<td>Converging/diverging flow, soil water content, soil characteristics</td>
</tr>
<tr>
<td>Tangential curvature</td>
<td>Plan curvature multiplied by slope</td>
<td>Provides alternative measure of local flow convergence and divergence</td>
</tr>
<tr>
<td>Elevation percentile</td>
<td>Proportion of cells in a user-defined circle lower than the center cell</td>
<td>Relative landscape position, flora and fauna distribution and abundance</td>
</tr>
</tbody>
</table>
Shagufta Akbari et al., [63] have estimated Geomorphology Parameters for Small Catchment using GIS study focuses on Nima-Wira catchment situated in the Krishna river basin, Andhra Pradesh, India. In this study SRTM and Cartosat image were procured for year 2001 and 2009 respectively.

Danilo Godone et. al., [64] have studied, the role of morphometric parameters in Digital Terrain Models interpolation accuracy: a case study. The investigated dataset is a helicopter-borne laser scanner survey carried out on a mountain slope. It has been interpolated at various resolutions, and a percentage of the entire set has been employed to evaluate the interpolation accuracy.

Jadhav Snehal et. al., [65] have tried, the morphometric analysis of Domri river sub-basin is carried out in order to hydrological implication. Total area of the sub-basin is 274.68 km². Drainage texture in the investigated sub-basin indicates massive and resistant rocks cause coarse texture. Drainage morphometry is useful to signifying the construction sites for artificial recharging structures for implication of hydrology.

Shanghong Zhang, et al., [66] have employed, DEM for flat region Extraction of watershed characteristics using a digital elevation model (DEM) is an important prerequisite of hydrologic analysis. A new method, water depth gradient burning (WDGB) is proposed herein to extract watershed characteristics and subsequent terrain analysis in a flat region.

Aher, et al. [67], have used remote sensing and GIS approach. Planning of watershed at micro-level is indispensable for sustainable development, particularly in the fragile semi-arid tropics. Geospatial–statistical techniques were used for identifying critical and priority sub-watersheds in water scarce region of India.

Thapa R. et al., [68] in their study they utilized aerial photographs, satellite images and topographic maps for the study of morphotectonics and hydrogeology for groundwater prospecting using remote sensing and GIS in the North West Himalaya. The study reveals that the study area has a network of interlinked subsurface fractures.
Nageswara Rao K. et al., [69] were adopted GIS and image processing techniques for the identification of morphological features and for the analysis their properties of the lower Gostani River Basin area in Andhra Pradesh State. The study shows that the drainage density value is low which indicates the basin is highly permeable subsoil and thick vegetative cover.

Mahadevaswamy G. et al., [70] made an attempt to study drainage morphometry and its influence on hydrology of Nanjangud taluk of Karnataka State. Quantitative morphometric analysis has been carried out for linear, relief, and aerial aspects for all the sub-basin. This study reveals that the elongated shape of area is mainly due to guiding effect of thrusting and faulting. Some sub-basins having highly permeable subsoil materials under dense vegetation cover.

Lakshmamma et al., [71] carried out the Morphometric analysis of Gundal watershed of Chamarajanagar district of Karnataka. The analysis clearly indicates some relations among the various attributes of the morphometric aspects of the watershed and helps to understand their role in sculpturing the surface of the region.

Rajiv Chopra et al., [72] used Remote Sensing and GIS techniques for the Morphometric Analysis of sub-watersheds in Gurdaspur district of Punjab. Detailed drainage map prepared from aerial photographs and SOI toposheets was updated using IRS-1D PAN sharpened LISS-III analog data. Updated drainage maps were used for the morphometric analysis of the sub-watersheds. In spite of mountainous relief, low drainage density values indicate that the area is underlain by impermeable sub-surface material.

Akram Javed et al., [73] carried out Prioritization study of Sub-watersheds based on Morphometric and Land Use Analysis using Remote Sensing and GIS Techniques. The study demonstrates the utility of remote sensing and GIS techniques in prioritizing sub watersheds on morphometric and land use change analysis as well as with the integration of these two. The study involved identifying and delineating changes which have taken place in the watershed.
Amee K. et al., [74] in their study, morphometric analysis and prioritization of the eight miniwatersheds of Mohar watershed, located between Bayad taluka of Sabarkantha district and Kapadwanj taluka of Kheda district in Gujarat State, India is carried out using Remote Sensing and GIS techniques. The compound parameter values are calculated and prioritization rating of eight miniwatersheds in Mohar watershed is carried out. The miniwatershed with the lowest compound parameter value is given the highest priority and determined the watershed with highest priority having maximum soil erosion.

2.6 REVIEW OF LITERATURE OF INTENSITY DURATION CURVES

Rainfall Intensity Duration Frequency (IDF) relationship is one of the most important tools in water resources engineering for accessing the risk and vulnerability of water resources structures as well as for planning, design and operation [75]. The IDF is a mathematical equation representing the relationship between maximum rainfall intensity as a dependable variable, the rainfall duration and the return period as independent variable [76]. There are several commonly used IDF functions found in the literature of hydrology applications ([77] and [78]) and Mathematically, the IDF relation can be presented as a function of the return period and the duration of rainfall

\[ I = F (T, D) \]  

Where \( i \) is the rainfall intensity, \( T \) is the return period (years) and \( d \) is the rainfall duration (hr)

Koutsoyiannis et al., [79] reported the rainfall intensity-duration-frequency (IDF) relationship, consistent with the theoretical probabilistic foundation of the analysis of rainfall maxima. It allows incorporating data from non-recording stations, thus remedying the problem of establishing IDF curves in places with a sparse network of rain-recording stations, using data of the denser network of non-recording stations.

Le Minhnhat et. al., [80] studied IDF curves in the monsoon region of Vietnam. This research is to construct IDF curves for seven stations in the monsoon area of
Vietnam and to propose a generalized IDF formula using base rainfall depth, and base return period for Red River Delta (RRD) of Vietnam

Okonkwo et. al., [81] developed IDF Curves for seven states of Southeastern Nigeria. The Graphical and Statistical methods were used and the results were compared. The annual maxima series was used. In the statistical method, the Type I extreme-value distribution (Gumbel) was applied to the annual maximum series for each of the seven stations to estimate the relevant parameters of the IDF model. The non-parametric Kolmogorov-Smirnov test and the $\chi^2$ test were used to confirm the appropriateness of the fitted distributions for the locations.

Eman Ahmed et. al., [82] developed IDF relationship through statistical analysis of samples of records at proper meteorological stations. Sinai Peninsula in the North East part of Egypt has a network of daily rainfall recording rain gauges. A total of six different durations ranging from 5 minutes to 24 hours for return periods of 2, 5, 10, 25, 50, 100 and 200 years were analyzed. The IDF curves and isopluvial maps for the region are developed using the available rainfall data.

Norlida et al [83] used Generalized Pareto Distribution (GPD) to derive the Intensity-Distribution-Frequency curve for an urban area located in the tropical region using partial duration series (PDS). The Method of L-Moments (LMOM) is used to fit the distribution while the Kolmogorov-Smirnov (K-S) is used for goodness-of-fit test. The procedure was repeated for eleven rainfall durations, which range from 5 minutes to 4320 minutes. Five urban rainfall stations where the data was extracted were used in the study. For comparison purpose, the Log-Logistic 3(P) and the Generalized Extreme Value (GEV) were used.

Zainudini et. al., [84] used rainfall intensity-duration-frequency (IDF) curves as a prediction tool to identify the likelihood with which a certain rainfall rate or a specific volume of flow will recur in future, that will create flooding havoc in an area. In the study, IDF curves using rainfall data from Sistan and Balochistan, different durations have been developed and presented. The results have been compared with analysis of data from other countries. The results based on shorter duration rainfall data are plausible and can potentially be useful for design purposes; however, a detailed analysis using comprehensive data sets is needed.
Ibrahim, H. Elsebaie [85] used two common frequency analysis techniques i.e., Gumbel and the Log Pearson Type III distribution (LPT III) to develop the IDF relationship from rainfall data for the regions of Najran and Hafr Albatin in the kingdom of Saudi Arabia (KSA). The results obtained using Gumbel distributions are slightly higher than the results obtained using the LPT III distribution. The chi-square goodness of-fit test was used to determine the best fit probability distribution. The parameters of the IDF equations and coefficient of correlation for different return periods (2, 5, 10, 25, 50 and 100) are calculated by using non-linear multiple regression method.

Rashid et al [86] developed an IDF empirical formula to estimate the rainfall intensity for any duration and any return period with minimum effort. Various distribution functions were used for analysis and chi-square goodness to fit test were used to identify the best statistical distribution among them. Study showed that Person Type III is the best probability distribution and the best IDF empirical formula was in the form, intensity \( I = x^* (l_d)^{-y} \) where \( x \) and \( y \) are fitting parameters and \( td \) the required time duration.

C.B.Jagadeesh, et. al., [87] reported flood event at Gali Anjaneya Temple in Vrishabhavathi sub watershed disrupts the normal life and cause loss to economy.

Munshi et. al., [88] reports proliferation in greenhouse gases hydrologic cycle is changing day by day which is causing variations in intensity, duration and frequency of rainfall events. By pinpointing the potential effects of climate change and acclimating to them is one way to reduce urban susceptibility. Since rainfall characteristics are often used for planning and design of various water resources project, reviewing and updating rainfall characteristics (i.e., Intensity–Duration–Frequency (IDF) curves) for future climate situations is necessary. The target of this study was to develop Rainfall IDF empirical equations and curves for seven divisions of Bangladesh to estimate the rainfall intensity for any duration and any return period with least effort.
2.7 REVIEW OF LITERATURE OF RUNOFF ESTIMATION

Runoff is one of the most important hydrological variables used in most of the water resources applications. Reliable prediction of runoff from land surface into streams and rivers is difficult and time consuming to obtain for ungauged basins. However, Remote Sensing (RS) and Geographic Information System (GIS) technologies can augment to a great extent the conventional methods used in rainfall-runoff studies. These techniques can be used to estimate the spatial variation of the hydrological parameters, which are useful as input to the rainfall-runoff models.

Rainfall runoff is an important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system. Estimation of the same is required in order to determine and forecast its effects. Estimation of direct rainfall runoff is always efficient but is not possible for most of the location at desired time. Use of remote sensing and GIS technology can be used to overcome the problem of conventional method for estimating runoff caused due to rainfall.

Many methods are used to estimate the runoff from a watershed. The Soil Conservation Service (SCS) Curve Number (CN) rainfall runoff technique is a well-known method, widely used to estimate runoff, and thus, water recharge, stream flow, infiltration, soil moisture content, and landfill leachate production, from precipitation. Many research works have been reported on SCS and GIS based runoff estimation.

Sharma K. D et al., [89] estimated the runoff using Landsat Thematic Mapper data and the SCS model. The conclusion from their study reveals that, the visual interpretation procedures are very useful for hydrological studies using Landsat TM photographic products. Use of post-monsoon landsat TM false colour composites of bands 2, 3, and 4 to evaluate and map landforms and associated features, viz. soil, vegetation, drainage pattern and land use/land cover is reasonable in an environment. The runoff curve numbers estimated from those remotely sensed parameters, in combination with observed rainfall, predict runoff depth and peak flow within a high degree of accuracy in deserted regions.
Samah Al-Jabari et al., [90] in their study, SCS method was used with GIS to estimate the runoff from Wadi Su’d watershed as a case study for agricultural watershed. The Wadi is located in Dura area of the Hebron District-West bank. The rainfall and land use data were used along with the experimental data of soil classification and infiltration rate for the estimation of the runoff for the study area. The result of the study shows that the average annual runoff depth for the study area was 7.3% of the total annual rainfall.

Amutha R et al., [91] is carried out estimation of surface Runoff in Malattar Sub-watershed using SCS-CN method. Malattar sub-watershed lies in the region Gudiyattam Block, Vellore District, Tamil Nadu. The daily rainfall data was collected and used to predict the daily runoff from the watershed using Soil Conservation service-Curve Number (SCS-CN) method (USDA, 1972) and GIS. The developed rainfall-runoff model is used to understand the watershed and its runoff flow characteristics.

Veeranna B et al., [92] calculated the runoff volumes of the Ashti sub-basin on river Godavari by SCS Curve Number and GIS. For determining the results the data sets such as IRS AWiFS satellite image, 1:5000 standard topographic map, drainage map and soil map on 1:5000 are used. AWiFS image is classified by using digital image techniques for extracting Land Use and Land Cover and integrated into GIS with hydrological soil map. Soil Conservation Curve Number method is used to determine Curve Number and runoff volume distribution of the basin area.

Soulis K. X et al., [93] carried out an investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability in a Mediterranean experimental watershed in Greece. The watershed was characterized by the presence of a constant “impervious runoff source area fraction”. The remaining area of the watershed was covered by relatively high hydraulic conductivity soils. Their analysis concluded, that using the CN values produced by the standard procedure the SCS-CN method overestimates systematically runoff for high rainfall depth events, whereas it underestimates runoff for low rainfall depth events. Furthermore, the analysis indicated...
that there is a strong correlation between the CN values and the rainfall depth, with the CN values decreasing when the rainfall depth increases.

Ratika Pradhan et al., [94] studied modified Soil Conservation System (SCS-CN) model were used for rainfall-runoff estimation of the area in and around Singtam, East Sikkim. Estimated runoff was compared with the runoff calculated with the actual rainfall data for the year 2009, in general good correlation has been found between observed and computed runoff.

Geena et. al., [95] used Soil Conservation Service number (SCS-CN method) (SCS:1972) also known as hydrologic soil group method was used, this method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate results. Generally the model is well suited for small watersheds of less than 250 km². In their study, the runoff from SCS curve number model modified for Indian conditions has been used by using conventional database and GIS for Red hills watershed.

Lange [96] mentioned that Geomorphological Instantaneous Unit Hydrograph (GIUH) model has been used by Allam [97], Nouh [98] and Al-Turbak [99] to develop unit hydrograph for several catchments in the Kingdom of Saudi Arabia. In the semiarid experimental catchment of Walnut Gulch, Arizona, USA, the long history of research provides good runoff records, which facilitated the successful application of calibrated models (Goodrich et al. [100], Renard et al., [101] and Thormahlen, [102]). The long history of research also allowed a non-calibrated model run of KINEROS, a complex distributed model developed for semiarid catchments. Lange et al. [103] develop a model not depending on calibration but accounting for the dominant processes of arid zone flood generation.
2.8 LITERATURE REVIEW OF GROUNDWATER PROSPECT ZONES

The rapid development of ground water resources for varied usage has contributed in expansion of irrigated agriculture, overall economic development and in improving the quality of life in India. Ground water, which is the source for more than 85 percent of rural domestic water requirements of the country, is depleting fast in many areas due to its large-scale withdrawal. The significant contribution made for Green Revolution and also as primary reliable source of irrigation during drought years has further strengthened the people’s faith in utilization of ground water as dependable source (CGWB, [104]).

The advent and development of new technologies, such as remote sensing with its advantages of spatial, spectral and temporal availability of data have proved to be useful for quick and useful baseline information about the factors controlling the occurrence and movement of groundwater like geology, geomorphology, land use/cover, drainage patterns, lineaments etc. (Meijerink, [105]). Further, remote sensing techniques provide a synoptic view of large areas, facilitating better and quicker assessment, development and management of water resources with collateral information.

Excellent reviews of remote sensing applications in groundwater hydrology are presented in Waters et al. [106], which concluded that remote sensing has been widely used as a tool, mostly to complement standard geophysical techniques. In the recent years, modern technologies like Geographic Information System (GIS) is being used for various purposes such as groundwater investigations and many authors (Shahid et. al., [107]; Singh, and Prakash [108]) have attempted to delineate groundwater potential zones. GIS techniques facilitate integration and analysis of large volumes of data, whereas, field studies help to further validate results.

Krishnamurthy et. al., [109] applied digital enhancement techniques for groundwater in a hard rock terrain of parts of the Raichur district, Karnataka. The geological structures were highlighted by filtering. Band subtraction brought out the vegetation along valley fills and moisture-laden lineaments. Based on the results, a package was
suggested which could be used on an operational basis for groundwater targeting in typical hard-rock crystalline formations.

Kamaraju et al., [110] evaluated groundwater potential of west Godavari district, Andhra Pradesh state, India. Information on the parameters controlling groundwater such as lithology, geomorphology, structure and recharge condition of the study area was analyzed using Arc Info GIS software. An evaluation of groundwater potential and generation of a map showing three hydro geological conditions with district groundwater prospects which would serve as a basic tool in exploitation of groundwater resources of the district was presented.

Tiwari and Rai [111] evaluated the groundwater potential zones of Dhanbad district in Bihar. Landsat-5 data was interpreted visually to differentiate different hydro morphological units and to delineate the major trends of lineaments. Different geomorphic features identified were linear ridges, residual hills, pediplain, buried pediment and dissected pediplain besides lineaments. The study showed that the buried pediments were promising zones for groundwater prospecting.

Saraf and Choudhury [112] utilized IRS-LISS-II data along with other data sets extract information on the hydrogeomorphic features of a hard rock terrain in the Sironj area of Vidisha district of Madhya Pradesh, India. The study exhibited reservoir induced artificia. IRS LISS-II data were supported with information derived from DEM, drainage and groundwater data analysed in a GIS framework.

Subba Rao et. al., [113] assessed groundwater prospects in a developing satellite township of Visakhapatnam Metropolitan Complex, Andhra Pradesh, India using the Remote sensing Techniques and conventional method. The study indicated that the fluvial and rolling plains were promising zones for groundwater occurrence and the denudational landforms were not considered as groundwater potential zones.

Srinivasa Rao et al. [114] investigated groundwater potential in the hard rock terrain and drought-prone area in the Niva river basin in Andhra Pradesh state. Landsat 5 photographic data were used prepare an integrated hydrogeomorphology map. Larsson’s integrated deformation model was applied to identify the various fracture systems, to pin point those younger tensile fracture sets which are the main
groundwater reservoirs and to understand the importance of fracture density in groundwater prospecting. Groundwater potential zones were delineated and classified as very good, good to very good, moderate to good, and poor.

Pankaj et al. [115] delineated various groundwater potential zones for the assessment of groundwater availability in hard rock terrain with the help of hydro-geological parameters using satellite IRS-1B LISS-II digital data. Area selected for this study was a part of Bargarh district, Orissa, India. Various thematic maps were integrated with the help of GIS to demarcate the poor to excellent groundwater potential zones. The results showed that lineaments and drainage density were the most important contributory factors in the groundwater potential of various geomorphic units in the area of investigation.

Murthy [116] discussed an approach to investigate groundwater potential over extensive geographical areas and illustrates its potential with reference to watershed planning in the large Varaha river basin, Andhra Pradesh, India. The method involved in creation of a systematic database of information from satellite data for reconnaissance survey before going for field exploration. The thematic and topographic information was digitized and ERDAS imagine GIS software was used to analyze this information.

SreeDevi et al. [117] carried out hydrogeomorphology and lineament studies by using satellite data for the Pageru river basin in Cuddapah district, Andhra Pradesh, India through visual interpretation of remote sensing data. From these studies, various geomorphic units were classified as favorable, moderately favorable, and poor zones of groundwater.

Gopinath et al. [118] investigated the role of hydrogeomorphological units and lineaments in the storage of groundwater from the Muvattupuzha river basin using IRS 1D-LISS III data. Other than the usual water bodies such as river course, reservoirs and ponds, the major hydrogeomorphological units identified in this basin in the descending order of their groundwater potential were valley fills, moderately dissected plateau, pediments, residual mounts, residual mount complex, linear ridges, residual hills, and structural hills. The pump test analyses of dug well from different hydrogeomorphic units also confirmed that valley fills were the most promising unit for groundwater prospecting than the rest.
Srinivasa Vittalla et al. [119] discussed the evaluation of groundwater potential zones in the sub-watersheds of North Pennar river basin around Pavagada in Karnataka, India using Remote Sensing and GIS techniques. Integrated map comprising groundwater potential zones prepared using GIS indicated that valley fills and moderately weathered pediplains were very good to good, shallow weathered pediplains were good to moderate, pediment inselberg complex and pediments were moderate to poor and denudational hills, residual hills and inselbergs were poor to very poor groundwater prospect zones.

Kishore and Jugaran [120] developed and tested integrated remote sensing and GIS based methodology for the evaluation of groundwater resources of Bata watershed in Sirmour district, Himachal Pradesh. Remote Sensing data along with other data sets like existing geological maps and field observed data have utilized to extract information on the hydrogeomorphic features of the hilly terrain area. Area in investigation of all attributes provides more accurate results in groundwater prospect zones identification.

Asadi et al., [121] carried out a model study to increase groundwater levels in part Medak and Hyderabad districts of A.P. Delineation of groundwater prospect zones was done using IRS-ID PAN and LISS-III geocoded data on 1:50000 scale. Information on base, drainage, lithology, structure, landuse/landcover, slope, geomorphology and hydrology maps are generated and integrated to prepare groundwater prospect map for the study area.

In all these research studies, the commonly used thematic layers are lithology, geomorphology, drainage pattern, lineament density, soil and topographic slope (Binay Kumar et al., [122]; Saravanan, [123], Sumit Dabra et al., [124]). All the studies have been carried out in India; the majority of which focus on soft rock and hard-rock terrains.

Rambabu Palaka et al., [125] studied Kosigi, which is one of drought prone mandal of Kurnool district was taken up to identify potential zones for groundwater recharge using GIS techniques. By considering suitability of terrain surface, soil and its depth;
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Thematic maps such as geomorphology, drainage density, lineament density, and land use / land cover were prepared for Weighted Overlay Analysis (WOA) using ArcGIS 10.2 desktop software. The weights of selected themes were computed using Analytic Hierarchy Process (AHP) method. From the results, the groundwater potential zones with poor (34.76 km$^2$), moderate (227.91 km$^2$), good (117.02 km$^2$), very good (36.37 km$^2$), and excellent (5.20 km$^2$) prospective zones were identified.

2.9 REVIEW OF LITERATURE OF SOIL EROSION ESTIMATION

Erosion removes organic matter from soil and contributes to breakdown of the soil structure that will in turn affect soil fertility and the crop yields. Soil erosion causes siltation of reservoirs, which ultimately reduces the life of the project and affects generation of hydroelectric power. It also affects the flora and fauna of the earth. Eroded sediment can carry nutrients particularly phosphates to waterways, and contribute to eutrophication of lakes and streams. Adsorbed pesticides carried with eroded sediments, adversely affect surface water quality. Soil erosion occurs as a result of changes in agricultural practices, agricultural intensification, land degradation and global climate change [126]. Inter-rill and gully erosion are the results of the removal of soil particle from its parent place of origin by the raindrops. These detached particles of soil are then transported ultimately to the river basin that enrich the suspended sediment yield, bed load and sediment delivery ratio of the river basin [127]. The total land area subjected to human-induced soil degradation is estimated at about 2 billion hectares. By this, the land area affected by soil degradation due to erosion is estimated at 1100 Mha by water erosion and 550 Mha by wind erosion [128]. Soil erosion in India has a major effect on the agricultural sector, siltation of reservoirs and degradation of soils. In India, almost 130 million hectares of land [129], i.e., 45% of the total geographical surface area, is affected by soil erosion. Soil erosion estimated by Narayan and Babu [130] in India is 16.4 t ha$^{-1}$ (5334 m-tonnes) of soil detaches annually due to various reasons, 29% of soil loss is carried away by the river into the sea and 10% into the reservoirs that lead to reservoir sedimentation. Soil is detached mainly by rainwater erosion (56 %) and wind erosion (28 %), physical deterioration (12 %) and chemical deterioration (4 %) [131].
Chandramohan et al., [132] have attempted to estimate the soil erosion using USLE for a drainage area in Koppal district in Karnataka state. The average loss from the study area was computed as 25.98 tons/ha/year. Thematic maps such as landuse and soil texture were prepared using base map, remote sensing data. The digitized contour map and spot height information was used to obtain the DEM. This DEM was used for the calculation of LS factor. The effectiveness of various types of management and surface practices can be evaluated by changing the CP factor and the most effective (the one which gives minimum sediment yield) effective management strategies can be worked using GIS data base.

Srinivas et al., [133] have assessed soil erosion of Nagpur district, India, using USLE. They express that the assessment of soil erosion for a large area such as district can be deduced by deterministic relationship of complex factors such as rainfall erosivity, soil erodibility, slope and land use/land cover. They feel that remote sensing and GIS techniques prove to be of immense help in land cover mapping. They have suggested suitable agronomic and mechanical measures for soil conservation in their study area.

2.10 REVIEW OF LITERATURE OF EVAPOTRANSPIRATION

Scientists have developed a number of meteorological procedures for estimating reference evapotranspiration (ET) over the past six decades. The Penman and the Penman Monteith equations represent the two most commonly used methods today. Both procedures have been subjected to modifications in an effort to improve the estimates of reference ET. Unfortunately, this proliferation of “modified” Penman and Penman-Monteith Equations has led to considerable confusion, particularly when using reference ET in operational irrigation management where the use of crop coefficients is required. The scientific community has addressed this issue in recent years and has developed a standardized computation procedure for estimating reference ET that is based on the Penman-Monteith Equation [134]. This standardized computation procedure has been adopted by the research community, most manufacturers of weather stations and the public weather networks that disseminate reference ET data. Turf Managers should be aware that older weather stations manufactured by Rain Bird, Toro and other irrigation companies may still use the older, non-standardized procedures for estimating reference ET. These older procedures may
produce reference ET values with a bias relative to the new standardized procedure. Turf Managers are encouraged to upgrade their weather stations and/or irrigation management software to provide reference ET computed using this new standardized procedure so they can more effectively utilize future research on irrigation scheduling and management.

Many tests for the detection of significant trends in hydro climatologic time series can be classified as parametric and non-parametric methods ([135], [136]). Parametric trend tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed. In comparison, non-parametric trend tests require only that the data be independent and can tolerate outliers in the data. On the other hand, they are insensitive to the type of data distribution ([137], [138]). The Mann-Kendall (MK) and Spearman’s Rho (SR) tests are examples of non-parametric tests that are applied for the detection of trends in many studies ([139], [140], [141], [142], [143]). A comparison of the power of the MK and SR tests and their results showed the same power in detecting monotonic trends ([144], [145]).

Recent applications of hydrologic modeling in tropical data-scarce catchments (Ndomba and Birhanu, [146]; Birhanu et al., [147]; Mulungu and Munishi, [148]) suggest a wide use of the SWAT model (Arnold et al., [149]). Moreover parameters like curve number in SWAT model may be appropriate to reflect the impact of changes in land use or land management on agricultural watersheds (Van Liew et al., [150]). Accounting for heterogeneity of environmental variables such as soil types, land uses, topographic features, and weather parameters is essential in order to properly simulate the effect of spatially varying properties (Muleta and Nicklow, [151]). In SWAT model spatial data base of model parameters; that is, land use, soil and crop management files are developed using physically-based approach and sensitive parameters are identified using the sensitivity analysis based on the Latin Hypercube one factor at a Time method (Van Griensven and Srinivasan, [152]). The LH-OAT method was identified as more strategic, efficient, and effective sampling approach that can significantly reduce computational demand. Parameter optimization is based on the shuffled complex evolution method which was more effective and efficient compared to other optimization methods (Duan et al., [153]; Yapo et al., [154]).
2.11 LITERATURE OF LAND SUITABILITY FOR IRRIGATION

It is essential to select crops for cultivation according to the soil suitability, so that maximum profit may be achieved while maintaining the ecological sustainability. The crop land use planning involves decisions about land use and the environment. Soil information is a vital component in the planning process, reflecting directly upon land-use suitability [155]. The Land suitability is the process of assessing the suitability or ability of a given type of land, evaluation and grouping of specific areas of land in terms of their suitability for defined agricultural use. It involves evaluation of the factors like climate, terrain, soil etc. Land suitability is a function of crop requirements and soil/land characteristics. Matching the land characteristics with the crop requirements provides suitability. So, “suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use” [156]. In many cases, especially in semi-arid regions, the limited availability of agricultural land is a critical factor. This increased pressure on the available land resources may result in land degradation [157]. Reliable and accurate land evaluation is therefore indispensable to the decision-making processes involved in developing land use policies that will support sustainable rural development. If self-sufficiency in agricultural production is to be achieved in developing and transitional countries, land evaluation techniques will be required to develop models for predicting the land’s suitability for different types of agriculture [158]. Land could be categorized into spatially distributed agriculture potential zones based on the soil properties, terrain characteristics and analysing present land use [159]. Production could be met through systematic survey of the soils, evaluating their potentials for a wide range of land use options and formulating land use plans which were economically viable, socially acceptable and environmentally sound [160]. Albaji et al. [161] compared the different irrigation methods based on the parametric evaluation approach in Shoibieh plain, Iran, using a parametric evaluation system. The results demonstrated that by applying sprinkler irrigation instead of surface and drip irrigation methods, the arability of 48805.43 ha (98.3%) in the Shoibieh Plain will improve. Hired et al. [162] and Bond [163] developed classification systems for assessing site suitability for effluent irrigation and suitability of land for irrigation water [164]. Both
systems include topographic criteria as well as soil attributes that are taken into consideration when assessing the overall land suitability for irrigation.

2.11.1 CONCEPT OF IWRM

Integrated water resources management (IWRM) was defined by the Global Water Partnership [165] as “a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.”

Jonch-Clausen [166] offered a good general description of IWRM (why, what, and how). He explained necessity of IWRM Plans (pressures and competition for water requires improved management), the main targets and the way reaching the main aims. To assure political interest and public support, the initial focus should be on crucial, urgent issues: flood management, irrigation water disputes or other such issues may be entry points.

IWRM is about:

- A systematic process for managing water, land and related resources in a way that meets society’s long-term need for water while ensuring that economic and social welfare are not compromised and that there is no harm to the environment.
- A coordinating framework for integrating and implementing sectoral needs, water and water-related policy, resource allocation, and management of natural resources and environmental systems; within the context of social, economic, and environmental development objective.
- Managing water resources at the lowest possible level.
- Managing demand for water and optimizing the supply.
- Providing equitable access to water resources by a participatory approach.
- Establishing policies to help manage water resources.

FIGURE 2-3 shows schematic diagram of IWRM process. Figure 2-4 shows the dimensions of IWRM.
2.12 IWRM FOR SUSTAINABLE IRRIGATION

The increase in water consumption obviously reduces available water to downstream users. Upstream water use influences the flow regime and has impacts downstream, both in terms of quantity and water quality. As stated by Van der Zaag and Savenije [167], my water use always implies ‘looking upstream’ in order to assess water availability, and ‘looking downstream’ in order to assess possible third party effects of my activity (Figure 2-5). The vital nature of water gives it characteristics of a public good. Its finite nature confers to it properties of a private good, as it can be privately appropriated and enjoyed. The fugitive nature of water, and the resulting high costs of exclusion, confers to it properties of a common pool resource.

Water resource management aims to reconcile these various attributes of water. This is obviously not a simple task. At the heart, Integrated Water Resources Management aims to reconcile economic efficiency, equity, and environmental preservation goals (Molle et al., [169]). This is reflected in the first Dublin Principle, formulated at the International Conference on Water and the Environment, held in Dublin in January 1992, which states that ‘since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer’ (ICWE, [170]).

Watershed management generally aims at establishing an enabling environment for the integrated use and management of water and land resources of a watershed to accomplish resource conservation and biomass production objectives [171]. Although frequently advocated as a key to achieving effective water management (Rogers and Hall [172]2003), stakeholder participation in river basin management is not straightforward and actually including the poor and achieving substantive stakeholder representation has proven elusive in practice.

Jonch-Clausen [173] offered a good general description of IWRM (why, what, and how). He explained necessity of IWRM Plans (pressures and competition for water requires improved management), the main targets and the way reaching the main aims (the IWRM process: start with the national context and urgent issues).
FIGURE 2-3: SCHEMATIC DIAGRAM OF IWRM PROCESS

Dimensions of IWRM

Figure 2-4: Different dimensions of IWRM

Figure 2-5: Everybody lives downstream and looks upstream
(Van der Zaag, [168]).
Biswas [174] stated that there is no agreement on its fundamental issues like what aspects should be integrated, how, by whom, or even if such integration in a wider sense is possible. In a “second look” Biswas [175] analysed the current directions of IWRM and repeated his critical view of the popular concept and the problems of implementation in the real world.

Grigg [176] gave a more detailed description of the complexity and the difficulties of implementation at different levels. After his analysis of actual problems he offered another concept for integration of IWRM in different sectors. Coordination across geographic areas is recognized as a special challenge of integration.

2.13 RESEARCH GAPS

Mohan and Nguyen [177] carried out Fuzzy Programming to reservoir operation. Pesti et al. [178], Bardossy and Duckstein [179], Shreshta et al. [180]. Excellent descriptions of fuzzy linear programming (FLP) are reported by Korhonen et al. [181] and Slowinski [182]. The flexibility to convert the fuzzy model into existing optimization software makes the approach more attractive. But no efforts have been made to study the application of multi-objective fuzzy linear programming (MOFLP) to irrigation planning scenarios.

The research gaps may be summarized as the following:

- There is a significant lack of integration among different procedures applied in data collection and in transfer of data into information.
- The quality of available environmental data varies significantly from one region to another and from one country to another. Such variations may be attributed to the presence of different sources of pollutant loads and different geological (or geochemistry) conditions.

Thus, balancing environment and production objectives and the interests and roles Sustainable Irrigation Development in the study area T G Halli Watershed of various stakeholders of the socio-political hierarchy, based on the principles of collective action and management at the lowest appropriate level, has become a core approach of watershed management.

This research quantifies the impact of irrigation development and provides some recommendations concerning future development of Integration of Water Resources Management for Sustainable Irrigation in the Study Area T G Halli Watershed.