# Chapter 1

# Introduction

## 1.1 Background Information

Water is a must for sustaining all life forms, and it is a precious natural resource. Nature has bestowed India with huge, but not unlimited amount of water resources; yet the country continues to be plagued by water problems. The genesis of the problem is due to natural factors because of extreme unevenness of available water over space and time. The problem is further complicated by the unabated growth of population, causing increasing demand of water for domestic use, irrigation and industrial sector.

### 1.1.1 India and Gujarat Water Resources Availability

Water use has increased manifold in India. National Water Policy (2002) states that in India, out of total precipitation, including snowfall, of around 4000 billion cubic meter, the availability from surface water and replenishable groundwater is put at 1869 billion cubic meters. Because of topographical and other constraints, about 60 percent of this i.e. 690 billion cubic meters from surface water, and 432 billion cubic meters from ground water can be put to beneficial use.

The total geographical area of Gujarat state is 19.6 million hectare from which cultivable area is 12.5 million hectare, and it has a population of about 60.44 million (Census of Gujarat, 2011) which is growing at an annual rate of 1.92 percent. The state's water resources are just 2.28 percent of India's total water resources, while the state constitutes 4.88 percent of national population, indicating the low availability per-capita water (Vyas, 2000).

The ultimate irrigation potential of state is 6.92 million ha, and created irrigation potential is 3.90 million hectare; out of which utilized irrigation potential is 3.48 million hectare i.e. 27.84 percent (GWSSB, 2005). The total available water resources of the state have been estimated at 42666 Million Cubic Meter (MCM), which includes 11100 MCM that would be available from Narmada. Utilizable surface water in the state is 31500 MCM, including 11100 MCM (35 percent) from Narmada. Out of the total 185 river basins in the state of Gujarat 17 basins are in the North and South Gujarat; whereas 71 and 97 basins are in Saurashtra and Kutch region respectively. The availability of quantum of water resources in the north and south Gujarat is 82 percent of total water resources; whereas total water available in

Saurashtra and Kutch region is 15.80 percent and 2.20 percent respectively. Per capita availability of fresh water estimated in 2001 in Gujarat was 1137 $m^3$ per annum as against national renewable fresh water standing of 2000 $m^3$. In view of this Gujarat can be identified as “Water Scarce State” (GWSSB, 2005).

Natural distribution (availability) of the water resources in the Gujarat state is uneven over the different regions due to kaleidoscopic diversity in topography. The Gujarat state has four distinct regions namely: 1) South of Sabarmati River is South Gujarat (which is inclusive of Central Gujarat), 2) North Gujarat, 3) Saurashtra, and 4) Kutch. The rainfall is erratic and unevenly distributed about 95 percent total rainfall occurs during monsoon period (June to September). The South Gujarat receives highest rainfall greater than 2000 mm, whereas it ranges from 300 mm to 500 mm in the North Gujarat and Saurashtra. Kutch receives the minimum rainfall ranging from 200 mm to 300 mm.

The States’ geographical area has 55.8 percent rocky strata and 44.2 percent alluvial strata. As there is no perennial river in North Gujarat, Saurashtra and Kutch, surface water is not available in sufficient quantity; hence ground water is utilized as the main source for irrigation. The ground water table is being depleted at the rate of 3 to 5 meter per year, as the extraction (exploitation) of groundwater is more than the recharge in these regions. There is 1600 km long coastline. The coastal regions of Saurashtra and Kutch are extracting ground water more than its natural recharge resulting into sea water intrusion. In contrary to this, more surface water is utilized / supplied through canals for irrigation; resulting in water logging, increase in salinity etc.

## 1.2 Issues Related to Irrigation Management

Irrigation alone needs about 80 percent of the total water requirement. The limited availability of utilizable water, and growing need of water for irrigation, and other purposes has given irrigation management a special importance. Water is a scarce resource, especially in arid and semi arid regions. It is essential that the efficiency in use of water must be maximized. An irrigation system has to ensure that water is distributed in adequate quantities, and at right moment throughout the command area to meet the crop water requirements. Poorly managed irrigation can lead to water logging, salinity, sea water intrusion, lag between creation of potential and its utilization. It also leads to unreliable, insufficient supplies and inequitable distribution of available water; absence of conjunctive use of groundwater and surface water, absence of farmer’s participation in the management and non recovery of the project cost. To match supply and demand for irrigation scheduling, it is necessary to compute crop water requirement, which needs precise estimation of evapotranspiration.

## 1.3 Evapotranspiration and Irrigation Scheduling

Evapotranspiration is the combined process, through which water is lost by evaporation from the soil surface and from the crop by transpiration. The crops require a fixed quantity of water to meet the water losses through evapotranspiration, for bumper crop production under standard conditions. The crop evapotranspiration ($ET_c$) under standard conditions refers to crops that are disease-free, well fertilized, and are grown in large fields under optimum soil water with excellent management and environmental conditions, so as to attain full production, under the given climatic conditions (Allen et al., 1998). $ET_c$ measurement is not easy and requires sophisticated, expensive equipment and trained research personnel with varied range of systems. Evapotranspiration data could be obtained from varied range of measurement systems which included lysimeters, eddy covariance, Bowen ratio, scintillometry, sap flow, satellite-based remote sensing, direct modeling and soil water balance, such as gravimetric, neutron probes, electromagnetic types of soil sensors, time domain reflectometry etc. (Phene et al., 1990; Cammalleri et al., 2010; Allen et al., 2011; Evett et al., 2012). Direct measurement techniques are not feasible for estimating evapotranspiration in large irrigated area. Mostly they are used for research purposes by trained personnel. The measurement techniques just provide the point value of moisture content, and it cannot be used to estimate the crop water requirement of large irrigated area with varied climate. Evapotranspiration is generally estimated by using different methods, which requires measurements of climatological parameters. The factors that affect estimation of potential evapotranspiration are radiation, temperature, relative humidity and wind speed. The empirical and temperature based methods perform suitably under specific climatic and agronomic conditions, for which they are originally developed and cannot be used under different conditions, other than that for which they were developed. The radiation methods provides better estimates in humid climate, but are less precise in advective conditions in arid and semi arid climates, and hence it needs adjustment or correction. The combination methods take into account the radiant energy term as well as aerodynamic term the ability to remove water vapour hence it improves upon the evapotranspiration estimation. FAO-PM is considered to be the sole standard method to estimate reference evapotranspiration in case all the climate data are available. This method can provide important tool, for developing decision support system for irrigation scheduling.

Methods that are used to estimate crop evapotranspiration are one step (direct) or two step (indirect) i.e. crop coefficient approach. The crop coefficient approach is widely used, because of its simplicity in which crop coefficient values are multiplied with potential (reference) evapotranspiration, to obtain crop evapotranspiration. Crop coefficient is further classified as single crop coefficient and dual crop coefficient. Amongst the two crop coefficient approach, single and dual; the dual crop coefficient gives precise estimates of crop water requirement, especially during light and frequent wetting events. Dual crop coefficient could play a vital role in moisture deficit fields due to climate change in tropical regions. There are many simple and popular models used by researchers, which use single crop coefficient approach such as CROPWAT. Some advanced models like WEAP, SIMDualKc etc. use dual crop coefficient to precisely estimate crop water requirement. As, water is becoming scarcer, the effect of climate change resulting in moisture deficit in tropical regions is compelling irrigation managers to resort to water saving technologies, wherein dual crop coefficient approach could play an important role. The daily variation in soil surface wetness, soil moisture profile due to frequent or light wetting, because of rainfall and irrigation can have a significant impact on crop evapotranspiration. Soil water balance techniques can be applied over large areas to estimate evapotranspiration. Irrigation is one of the input parameters in soil moisture balance model, which is derived from adopted irrigation scheduling techniques. In irrigation scheduling we determine the timing and the quantity of water required to be applied for irrigation. The irrigation scheduling can be accomplished for full or partial crop water requirement. The purpose of irrigation scheduling is to efficiently use the water, and assist the farmer in maximizing the crop yield. Various approaches, which are employed in irrigation scheduling, are transpiration ratio approach, soil moisture deficit approach, irrigation depth-interval-yield approach, water-balance accounting approach, critical stage approach, visual plant symptoms approach, simulating evapotranspiration by models etc. The conventional approach is to apply irrigation water of fixed depth at fixed interval, which is popular among the masses due to its simplicity and ease in application, at the same time ensuring significant yield. However, this approach leads to either over irrigation or water stress. Deficit irrigation or partial crop water requirement is practiced, when there is water scarcity, or when irrigation system capacity is limited. Critical stage approach, visual plant symptoms approach are practiced, when sufficient water availability is an issue, or cultivators do not own their wells/ tube wells. Soil moisture deficit approach, and water balance accounting approach requires monitoring of soil water status with sophisticated equipments; and the irrigation is applied according to crop water requirement, and availability of water is practiced mostly by research personnel.

Simulating daily/ hourly evapotranspiration with aforementioned models is possible with the advent of automatic weather stations, and using climate parameters for Penman-Monteith method. Large numbers of models that are available nowadays for computing soil water balance techniques could be of great help, for developing and evaluating alternative irrigation strategies in Sardar Sarovar Project.

## 1.4 Sardar Sarovar Project

Sardar Sarovar Project (SSP) is one of the biggest multipurpose projects of India. SSP is having gross command of 3.43 million hectare, while CCA of 2.12 million hectare in Gujarat state. The entire command has been divided into 13 different homogeneous agro climatic regions based on topography soil classification, rainfall and weather. The climate of area is semi arid; the rainfall is erratic and non uniform. Type of surface soil prevalent is deep black, goradu sandy loam, coarse soil from granite and coastal alluvial. The study area lies between $21^0$ 45'to $22^0$ –53' N latitudes and $72^0$–31' to $73^0$ – 43' E longitudes in SSP command area phase- I Gujarat state. The study area constitutes, 16 blocks of Region I (CCA = 161900 hectare) and four blocks of Region II (CCA = 35731 hectare) of Sardar Sarovar Project (SSP). Availability of water is limited spatially and temporally in Gujarat state and many regions are facing formidable water management challenges, thus water needs a proper use.

## 1.5 Need for the Study

Optimum utilization of water available for agricultural is a great concern, as it being the limited resource. The irrigated agriculture uses large chunk of water, thus a big responsibility lies with irrigation managers to efficiently use the water. Irrigation is supplied to compensate the moisture deficit in soil occurred due to evapotranspiration. The large quantity of water is lost as evaporation and transpiration from the fields. To match the irrigation supply with demand, estimation of the evapotranspiration is required to be done with appropriate methods, which can give reasonably good accuracy. FAO presented two publications to describe various model for estimating crop water requirements (Doorenbos & Pruitt, 1977; Allen et al., 1998). In view, of the recent development in data acquisitions, variability of climate, soil and crop in command area, we need efficient techniques for precise estimation. Different water application strategies are possible, and evaluation of each one is required to suggest the best suitable technique to model soil water crop interaction, thus detail studies are required to identify the suitable irrigation strategies.

## 1.6 Motivation of the Study

The complexities involved in estimation of crop water requirement with different parameters to be considered, has made it a challenging task. Evaluation of effective rainfall involves the gross assumptions in estimating other processes such as surface run off, deep percolation, soil moisture storage capacities, crop water use etc. Recent development in automated instruments has enabled the availability of meteorological data on daily as well as hourly basis. Using this data, it is also possible to precisely estimate reference evapotranspiration applying advance model such as Penman Monteith. Such model can be further extended to build soil moisture balance model to precisely monitor the irrigation process. It is also required to evaluate crops sensitivity to the climate variability, for estimating crop water requirements. Availability of limited surface water poses threat to crop yield. Examining the yield response in field, and / or controlled experiments to varied water applications is laborious, expensive and time consuming. Neither, it is possible to carry out all combinations of scenarios like normal, wet and dry season and their effect in yields. In view, of this background, modeling as a tool in assessing various irrigation strategies is very useful. A comprehensive soil moisture balance model integrating various processes can provide decision support tools, for evolving irrigation strategies under varied situations**.** Many a times, conventional irrigation practices result into over irrigation or moisture stress condition leading to poor performance. Evaluating alternative irrigation strategies and selecting the irrigation schedule, which maximizes yields with given water supply in region I and II, for Sardar Sarovar Project is very much required as water availability is fairly limited.

## 1.7 Research Objectives

The main purpose of present study was to compute crop evapotranspiration for selected major crops grown in the study area. Crop evapotranspiration under pristine, and water stress conditions are to be estimated with help of daily reference evapotranspiration and crop growth models available. Further, to develop and evaluate the alternate sets of irrigation strategies to maximize yields, under varied scenarios of rainfall using soil moisture balance model. The present study was undertaken in agro- climatic region I and few blocks of region II of, Sardar Sarovar Project command area with the following main objectives:

1. Developing crop water use model, using dual crop coefficient approach.

2. Coupling crop water use model into soil moisture balance model.

3. Predicting water demand and yield by constructing various scenarios, of alternative sets of irrigation strategies.
4. Evolving irrigation management strategies with a conjunctive use approach.
5. Evaluating scenarios with regard to water sufficiency.
6. Suggesting information system model framework to support management, of water demand and supply.

The present study was limited to compute crop water requirements for selected fourteen major crops grown in Kharif /Rabi /Two seasonal, under region I and few blocks of region II. For prediction of crop water requirements the climate and rainfall data of year 2003 to 2010 were used.

## 1.8 Organization of the Thesis

Thesis has been arranged in six chapters.

- Chapter 1 consists of general background signifying the importance of topic, water resources availability in India and Gujarat, issues related to irrigation management, evapotranspiration and irrigation scheduling, Sardar Sarovar Project, need for the study, motivation for taking up the study and outlining the objectives of research work.
- In Chapter 2, detailed review of literature is organized and presented according to the various categories, related to research topic, such as prevailing methods for estimating evapotranspiration, different approaches adopted, different tools for assessing soil moisture balance models, irrigation scheduling and irrigation strategies to promote conjunctive use.
- Theoretical aspects of the study, has been incorporated in Chapter 3. It discusses about the various models adopted for crop growth, yield and soil moisture balance. SCS method to estimate effective precipitation, which is used as an input for soil moisture balance, and process followed to find evapotranspiration, under standard and water stress conditions in the study area have been discussed in this chapter. Further; the chapter includes the procedure for finding efficiencies for water use, irrigation water use, and evaluating irrigation strategies by empirical and statistical analysis.
- Chapter 4 is pertaining to study area, data collection, and fourteen crops used in the research.

- In Chapter 5 the developed irrigation strategies are evaluated crop wise for all blocks during the study period, water demand is estimated as per strategy and scenario.
- Chapter 6 includes the specific conclusions and recommendations arrived on the basis of research work; limitations of the study, and scope for the future work.
- Quoted references in the text have been listed under "References" and other studies not referred in text have been listed under "Bibliography".
- Appendix includes structure of WEAP model, flow chart of the WEAP model, input files, sample calculations, Ph.D. course work certificate, and research contributions.