CHAPTER 1
INTRODUCTION

1.1 GENERAL

This chapter deals with the general introduction about drought and different definitions of drought given by various agencies. Also, the various types of drought and impact of drought on environment, followed by the objectives of the present study.

1.2 CLIMATE CHANGE AND DROUGHT

Climate change is a natural phenomenon, but the increase in greenhouse gases due to human activities, which alters the climatic system, have become triggers for more rapid changes and influencing the occurrence of extreme climatic events. Climate change contributes to increased frequency of extreme weather events, such as drought, flood, earthquake and Tsunami. The severity of the drought is likely to increase in many parts of the world. Droughts are recognized as a natural environmental catastrophe and have attracted multidisciplinary attention across all researcher fields. Globally, demand for water and even water scarcity has risen owing to population increase and industrial development. Other factors, such as climate change, have added to the water shortage.

Drought is a prolonged period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield. Often, the difference between an estimated water demand and an expected water supply in a region becomes the basis to define a drought for that region.

Drought is not only a physical occurrence that can be defined by the weather conditions. A drought is defined as an extended period of unusually dry weather that causes water shortages and crop damage. The Intergovernmental Panel on Climate Change (IPCC) recognizes that climate change and the altered frequencies of associated extreme events such as drought and floods are expected to have negative impacts on human health.

According to IPCC's Fifth Assessment Report (AR5) based on many independent scientific analyses, new evidence, theoretical studies and computer simulations, there is greater certainty that the build-up of Greenhouse Gas in Earth’s atmosphere is changing the world’s climate and creating increasingly extreme and unpredictable weather. Because of these changes, the probability of extreme weather events is increasing. According to AR5, the computed linear trend of the globally averaged combined land and ocean surface temperature data show 0.85°C [0.65°C to 1.06°C] warming over the period 1880 to 2012, when multiple independently produced

datasets exist. In the period 1901-2012, climate has shown a warming of 0.89°C [0.69°C to 1.08°C] which is mainly attributed to anthropogenic activities (IPCC 2013). Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the case of India, increasing temperature trends of the order of 0.60°C during last 112 years (IMD 2012, Rathore et al. 2013) and increase in heavy rainfall events and decrease in low and medium rainfall events (Goswami et al. 2006) have been observed.

A world with 4°C rise in temperature would result in unprecedented heat waves, severe drought, and major floods in many regions, with serious impacts on ecosystems and associated services. Deltaic regions and coastal cities are particularly exposed to compounding climate risks resulting from the interacting effects of increased temperature, growing risk of river flooding, rising sea-level and increasingly intense tropical cyclones, posing a high risk to areas with the largest shares of poor populations. As per India's National Action Plan on Climate Change, parts of Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Northern Karnataka, Northern Andhra Pradesh, and Bihar are likely to be more vulnerable in times of extreme events.

Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change. Human and ecosystem vulnerability are interdependent. Regions and people with considerable development constraints have high vulnerability to climatic hazards. Increasing weather and climate extreme events have exposed millions of people to acute food in security and reduced water security, with the largest adverse impacts observed in many locations. Between 2010 and 2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability.

1.3 DEFINITIONS OF DROUGHT

The drought has no precise definition. Diversified hydro-meteorological variables, socioeconomic factors and different water demands in different regions have kept researchers away from compiling/modifying any precise definition of drought. The definition of drought which is good enough for one field does not help its implementation in another field. However, some broad definitions are sited below:

I. Linsley et al., (1959) defined "Drought as a sustained period of time without significant rainfall."

II. Gumbel (1963) defined "Drought as the smallest annual value of daily stream flow."

III. Palmer (1965) described "Drought as a significant deviation from the normal hydrologic conditions of an area."

IV. The Food and Agriculture Organization (FAO, 1983) of the United Nations defines a drought as a hazard, “The percentage of years when crops fail from the lack of moisture.”

V. The World Meteorological Organization (WMO, 1986) describes “Drought means a sustained, extended deficiency in precipitation.”

VI. The UN Convention to Combat Drought and Desertification (UN Secretariat General, 1994) defines “Drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.”

VII. The encyclopaedia of climate and weather (Schneider, 1996) defines a drought as “An extended period – a season, a year, or several years – of deficient rainfall relative to the statistical multi- year mean for a region.”

1.4 CLASSIFICATION OF DROUGHT

The classification system for the drought of four types is based on the nature of water deficiency. Meteorological, hydrological and agricultural droughts are considered environmental droughts according to this classification and are defined as periods with insufficient precipitation, river flow or groundwater, and soil moisture, respectively. The fourth type of drought is socio-economic drought, which is associated with water resource systems failing to meet water demands. Figure 1.1 presents the classification system for drought.

Being a slow process although drought often fails to draw the attention of the world community, its impact persists even after ending of the event. A single definition of drought applicable to all spheres is difficult to formulate since concept, observational parameters and measurement procedures are different for experts of different fields. Besides, the concept of drought varies among regions of differing climates. In general, drought gives an impression of water scarcity resulted due to insufficient precipitation, high evapotranspiration, and over-exploitation of water resources or combination of these parameters.

Conceptual Definitions of Drought

Conceptual definitions, expressed in general terms, help people understand the concept of drought. For example, drought is a protracted period of deficient precipitation resulting in extensive damage to crops, further resulting in loss of yield. Conceptual definitions may also be important in establishing drought policy.

Operational Definition of Drought

An operational definition of drought helps people to identify the beginning, end, and degree of severity of a drought. This definition is usually made by comparing the current situation to the historical average, often based on a 30-year period of record (according to World Meteorological Organization recommendations).

The following categories of drought are usually considered:

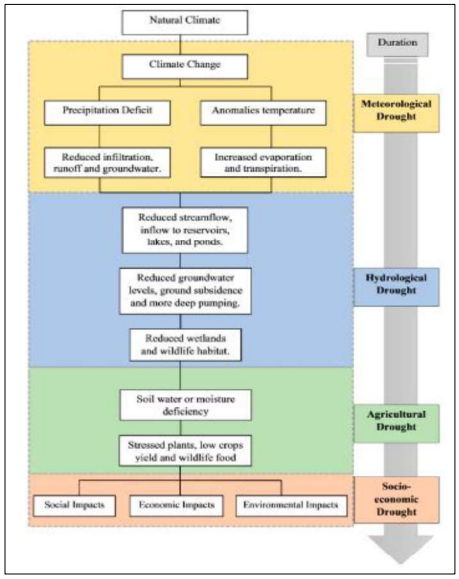

Figure 1.1: Categories of Drought and its Impact

I. **Meteorological Drought**

Meteorological drought is usually defined on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period.

Definitions of meteorological drought must be considered as specific to a region since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

II. **Hydrological Drought**

Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, groundwater).

III. **Agricultural Drought**

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth.

IV. Socioeconomic Drought

This occurs when physical water shortage starts to affect people, individually and collectively or, in more abstract terms, most socio-economic definitions of drought are associated with the supply and demand of an economic good.

The Relationship between various types of Drought is shown in below Figure 1.2

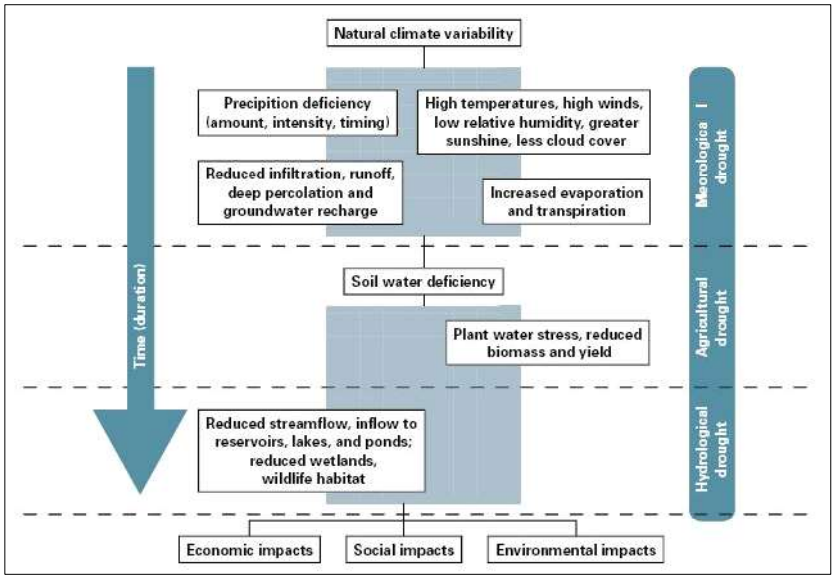

Figure 1.2: Relationship between various types of Drought

Fundamental Characteristics of Drought

In addition to type, droughts are fundamentally characterized in three dimensions: severity, duration, and spatial distribution. Further characteristics include: frequency, magnitude (cumulated deficit), predictability, rate of onset, and timing. Unfortunately, usage of the terms severity, intensity, and magnitude is not universal, and sometimes their meanings are switched.

Duration: Depending on the region, drought's duration can vary between a weeks' up to a few years. Because of drought's dynamic nature, a region can experience wet and dry spells simultaneously when considering various timescales. As such, in shorter durations the region experiences dryness or wetness, while in longer-term, it experiences the opposite.

Magnitude: The accumulated deficit of water (e.g., precipitation, soil moisture, or runoff) below some threshold during a drought period.

Intensity: The ratio of drought magnitude to its duration.

Severity: Two usages are provided for drought severity: the degree of the precipitation deficit (i.e., magnitude), or the degree of impacts resultant from the deficit.

Geographic extent: The areal coverage of the drought which is variable during the event. This area can cover one or several pixels (cells), watersheds or regions.

Frequency: The frequency or return period of a drought is defined as the average time between drought events that have a severity that is equal to or greater than a threshold.

1.5 DROUGHT: CAUSES AND EFFECTS

Drought is defined in many ways, like, 'a period of dry weather'; 'a condition of abnormal dry weather resulting in a serious hydrological imbalance, with consequences such as losses of standing crop and shortage of water needed by people and livestock'; 'a temporary reduction in water or moisture availability significantly below the normal or expected level for a specified period', and 'a creeping situation of scarcity without recharging of resources'.

Drought is a phenomenon that is widely considered as a 'creeping disaster' whose onset, end, and severity are difficult to determine. Unlike the suddenly occurring disasters, a drought may develop very slowly over several months affecting very large geographical area without causing little or no structural damage. The impacts depend on natural conditions, socio-economic situation, and the kind of land and water resources as well as the use patterns in the affected region.

The impact, response, and interventions would vary depending on at what point of time in a crop calendar there is acute water or soil moisture deficit. Generally, three situations are recognised:

- **Early season:** delayed rainfall (delayed onset of monsoon), prolonged dry spells after onset
- **Mid-season:** inadequate soil moisture between two rain events, and
- **Late season:** early cessation of rains or insufficient rains

Drought is responsible for many direct and indirect economic, social and environmental consequences throughout the world. Certain impacts are unavoidable but can be reduced significantly through planned interventions, whereas few other impacts can be mitigated by way of drought resistance. Common causes for drought in India are summarized in below Figure 1.3.

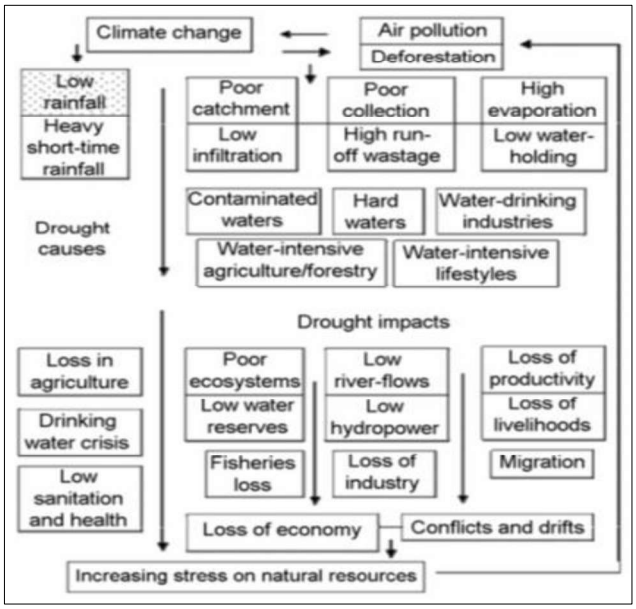

Figure 1.3: Common Causes for Drought in India

Increasing severity of drought can lead to a major livelihood crisis with crop losses and widespread unemployment. It is essential that along with a drought monitoring system, medium and long-term area specific plans be prepared for drought proofing of susceptible areas.

1.6 IMPACT OF DROUGHT

Drought is one of the most costly disasters as compared to other natural disasters. It has a negative impact on various parts of the society. Some of the major dire effects of drought are discussed below:

Impact on Environment

- The impact of drought to environment is seen as damages to flora and fauna including different species, wildlife habitat, forests, degradation of landscape quality, loss of biodiversity, and soil erosion.
- Normal conditions are re-established in case of short-term effects. But when these effects linger for long term, the damages may even become permanent. For example, increased soil erosion due to degradation of landscape quality, may result into an everlasting loss of biological productivity.

Impact on Economy

- The impact of drought on areas like agriculture, forestry and fisheries, can blow on economy of the country. These sectors have their basic requirements dependent on the surface and ground water supplies.
- The occurrence of a drought event can become the basis for the losses in yields in crop and livestock production.

Impact on Society

- The social impact of drought is due its length of persistency and extremity. The shortage of crop production resulting in suicides of farmers is a common nuisance around India. It can also cause loss of human lives due to food shortages, which can create panic and violence in the society as well.
- Water user conflicts are common during extreme drought, which are mostly political, social and industrial in nature. Social unrest can cause public dissatisfaction with government regarding drought response.

1.7 DISASTER MANAGEMENT FRAMEWORK

Drought is a unique natural hazard which through its multi-faceted characteristics causes damage to ecology and economy. Mitigation of drought requires a dedicated policy involving precautionary and combative measures. The state of Gujarat in India possesses an arid to semi-arid climate and suffers from recurrent droughts and perennial water scarcity problem. Droughts in Gujarat not only impart stress on the water resources but also on agriculture, economy and socio cultural spheres. Although several policies have been prescribed and numerous measures have been prescribed to counter droughts and to reduce drought impacts, drought still revisits Gujarat in every three years and creates havoc to peoples' life.

The National Disaster Management Act, 2005 (NDM Act 2005) lay down institutional and coordination mechanism for effective Disaster Management (DM) at the national, state, district and local levels. Government of Gujarat has also enacted Gujarat State Disaster Management Act, 2003 (GSDM Act 2003) which preceded the NDM Act 2005 and created a multi-layered institutional system consisting of Gujarat State Disaster Management Authority (GSDMA). The institutional arrangements have been set up consistent with the paradigm for Disaster Risk Reduction (DRR) by way of strengthening disaster, mitigation, preparedness and response.

Owing to its geo-climatic, geological and physical features, Gujarat is vulnerable to all major natural hazards namely, drought, flood, cyclone, earthquake, tsunami, Heat wave, etc. The State is also under constant threat of various human made hazards like that of Industrial chemical hazards, fire, transportation accidents, epidemic, accidents, etc. Gujarat State Disaster Management Authority (GSDMA) developed Gujarat Hazard Risk &Vulnerability Atlas.

As per the same, following are the major hazards in the State: Daily temperature of the State ranges from a minimum 13°C to 27°C in January to 27°C to 45°C in the summer during May. The South-West winds mostly bring rain between June to September and approximately 90 to 95% of precipitation is registered in these three months. From the North-West areas to South Gujarat areas, the rainfall varies from 300 mm to 2000 mm per annum. In Gujarat, 60% of rainfall is uncertain, unprecedented and unequal and the regions of Saurashtra, Kutch and North Gujarat

face famine every third year. Since 1900, the state has faced scarcity of water and food almost 30 times.

Gujarat is one the chronic drought prone state of India, with an average annual rainfall about 816 mm with more than half of the Talukas of Gujarat receiving rainfall within the range of 200-400 mm. The Government of India has devised many short, medium and long-term strategies to mitigate and overcome adverse effects of drought, and has implemented relief and development programmes in cooperation with the concerned states.

In the last 20 years, India has evolved many new strategies to cope with droughts by a change from a purely relief focus to the present drought management strategy. Monitoring and declaration are important components of disaster management and governance in India. Drought declaration is announced when the rainfall is –20% to –59% (early warning), –60% to 99% (drought) and –100% of normal (severe drought) conditions. Current drought management mechanism includes institutional mechanisms, employment generation and social welfare practices, assistance/support by Central and State Governments, and operation of EWS.

1.8 DROUGHT SCENARIO IN INDIA

One of the worst natural calamities that affect India is the large scale incidences of droughts during the southwest monsoon season (June to September). The period between the years 1901 to 1930 was a period of frequent droughts, the frequency being once in four years. During the following 30 years, there were only two drought years, 1941 and 1951.However, the next 30 years saw 10 instances of droughts, a drought occurring once in three years on the average. The worst drought affected States are Karnataka, Tamil Nadu, Rajasthan, Gujarat, Andhra Pradesh and Maharashtra. During the seventies, about 80% of world's victims affected by drought lived in India.

The National Commission on Agriculture (1976) reported that about one third of the geographical area of the country i.e.107 million hectares spread over 99 districts in 13 States, were affected by droughts. The 1987 drought was one of the worst droughts with an overall Rainfall deficiency of 19%. It affected 59-60% of the crop area and a population of 285 million.

An assessment of droughts in Tamil Nadu State from 1977 to 1991 reveals recurrent drinking water shortages in major parts of the state - the city of Madras in particular. The worst drought years in the past 15 years are identified as 1980, 1982, 1983, 1987 and 1989. The 1987 drought which has crippled the state's economy. The 1987 drought serves as a model chronic drought year in Tamil Nadu, and it is interesting to study its redeeming features and its management.

The catchment areas did not receive any water, and there were 290 poor rainy days, 48 marginal rainy days and 27 good rainy days. The ground water level fell steeply up to 11 meters. The drought scenario of 2000 over the country is still fresh in the minds of all. More than 150 districts covering 8 States were affected by droughts. The most recent drought of 2002, ranks fifth in terms of magnitude but is unique when examined in overall terms of magnitude, spacing, Dispersion and duration. In July 2002, rainfall deficiency increased to 51%, surpassing all previous droughts. The impact of drought spread over 56% of land mass and threatened the livelihoods of 300 million people living across 18 States.

In past century, the country has experienced twenty-one large-scale droughts in the years 1891, 1896, 1899, 1905, 1911, 1915, 1918, 1920, 1941, 1951, 1965, 1966, 1972, 1974, 1979, 1982, 1986, 1987, 1988, 1999 and 2000 with greater frequencies during the periods 1891-20, 1965-90 and 1997-2000.The monsoon of 2000 was the 13^{th} consecutive normal monsoon considering country as a whole, but on a regional basis, this was the third consecutive drought year in areas covered by the states of Rajasthan, Gujarat and Andhra Pradesh.

The drought of 1987 was one of the worst in the century. The monsoon rainfall was normal only in 14 out of 35 meteorological sub divisions in the country. The overall deficiency in rainfall was 19% as compared to 26% in 1918 and 25% in 1972 being worst years. Agricultural operations were adversely affected in 43% (58.6millionha) of cropped area in 263 districts in 15 States and 6 Union Territories. In the two worst affected states of Rajasthan and Gujarat, the rainfall was less than 50% from normal. In these states, the drought of 1987 was the third or fourth in succession resulting in distress to an unprecedented level. Gujarat is one such state where drought occurs with unfailing regularity

1.9 DROUGHT SCENARIO IN GUJARAT

Major parts of the state of Gujarat fall under arid and semi-arid climatic zone, and suffer from recurrent droughts. It has also been observed that the frequency and intensity of droughts have increased in the state over the years, resulting in serious drinking water scarcity. As per the records of the India Meteorological Department (2015), Gujarat was hit by 15 major droughts (years: 1982, 1985, 1986, 1987, 1990, 1991, 1993, 1995, 1998, 1999, 2000, 2001, 2002, 2004 and 2009) during the last three decades (1981–2010). In most of these drought years, occurrence of heat waves and high temperatures are also noticed, particularly in northern Gujarat.

During this period, moderate and severe heat waves burnt the region in the years 1990, 1995, 2001, 2002, 2004 and 2010. Meteorological drought and heat waves affect water resources and water supply, damages vegetation health and reduces agricultural productivity. From the short term and long term impacts, it was found that deficient rainfall and gap between consecutive rainy days lead to the rise in

temperature, increase in heat waves, while high evapotranspiration results in high moisture deficiency. The temporal and spatial drought pattern revealed that vegetative drought is slow to begin but quicker to withdraw.

The probability of occurrence of intense drought only due to inadequacy of monsoon rainfall or from high temperature alone is found to be low. Intense drought occurs only when rainfall deficiency is accompanied by heat waves and extremely high temperature. Also, drought may occur even in non-El Niño years as is evident in the case of Gujarat. All drought years in Gujarat are found to be El Nino years, but all EL-Nino years are not drought years.

The Indian sub–continent is influenced by South–West (S–W) monsoon during June–September and North–East (N–E) monsoon during October–December. Nearly 70% of the annual rainfall in India is received during the S–W monsoon. In Gujarat, rainfall is uncertain, unprecedented and unequal spatially and temporally, and the regions of Saurashtra, Kutch and northern parts of the state face famine every third year. Since the year 1900, the state has faced scarcity of water and food almost 30 times. Gujarat is one of the chronic drought prone state of India, with an average annual rainfall about only 700 mm with more than half of the district sub-divisions of Gujarat receiving rainfall within the range of 200–400 mm. Substantial portions of the state are arid to semi-arid. With large parts of northern Gujarat and Saurashtra have no source of alternate irrigation, over-extraction of the limited ground water resource thus resulted in the decline of the water Table, which in turn has added stress on cultivated crops and water supplies (Gujarat State Disaster Management Plan, 2016–17).

Droughts are frequent in North Gujarat regions viz., Banaskantha, Gandhinagar, Mehsana, Patan and Sabarkantha districts due to poor and erratic rainfall distribution. The climate varies from humid in the district through sub-humid in the central part to semi-arid and arid in the northern and western parts. In 1999, Gujarat faced the worst drought of the past 100 years. Some 7,500 villages spread over 145 blocks in 15 districts were severely affected. The state has been hit by the worst drought in 100 years.

During the last three decades (1981–2010), the number of heat waves in Gujarat and some part of North Gujarat has been considerably high with moderate and severe heat waves affecting lives in the years 1990, 1995, 2001, 2002, 2004, and 2010. In major parts of Northern Gujarat, an appreciable rise in temperature coupled with deficient rainfall has been observed in the last decade (2001–2010). It has also been observed that the frequency and intensity of droughts have increased in the region over the years, resulting in serious drinking water scarcity. Out of every 5 years, 2–3 are drought years in Gujarat, and drought becomes severe and widespread in 2–3 out of every 10 years. Occurrence of heat waves and high temperatures is also noticed inmost drought years. As a

result of extreme climate, fall in groundwater table has been observed over a period of last thirty years putting immense pressure on groundwater table and demand for fresh water for drinking and household.

1.10 NEED OF THE PRESENT STUDY

North Gujarat is located in the western part of India and is largest part of Gujarat state. Its geographical location makes it vulnerable to variations in the monsoon patterns, with rainfall being critical for agriculture in the region. North Gujarat has a history of experiencing drought conditions, making it a region of interest for drought assessment. It has faced recurring droughts due to its arid and semi-arid climate, which makes it susceptible to water scarcity and agricultural challenges.

Drought can have a severe impact on various crops like cotton, groundnut, and millet, and consequently, on the livelihoods of the people in the region. The region depends heavily on irrigation for agriculture, and drought can exacerbate water scarcity issues.

Drought assessment is essential for understanding the impacts of climate change, improving water resource management, and implementing drought mitigation strategies. Agricultural drought in North Gujarat, like in other drought-prone regions, can have a significant impact on various aspects of the local economy, environment, and society. This makes its important to study North Gujarat districts in monitoring and assessment of drought conditions.

1.11 OBJECTIVES OF THE PRESENT STUDY

1. Estimation of various meteorological drought indices over the study area i.e., north Gujarat region.
2. Estimation of drought by different climatic index over the study area.
3. Estimation of various aridity index over the study area.
4. To determine frequency of meteorological drought indices.
5. Estimation of various hydrological drought indices.
6. To determine frequency of hydrological drought indices over the study area.
7. To estimate different agricultural drought indices.
8. Computation of vegetation stress by remote sensing techniques.
9. Trend and correlation analysis of drought indices.
10. Generation of drought severity maps.
11. To construct comparisons matrix of various developed drought indices over study area.
12. To develop drought forecasting model of area considered for the study.

1.12 OUTLINE OF THE THESIS

This thesis is organized in to five different chapters. The first chapter gives introduction and objectives the study, the second chapter gives reviews related literature. The third chapter deals study area and data collection. Chapter four presents and discusses the methodology of drought indices. To conclude, chapter five draws conclusions and makes appropriate recommendations.

Chapter 1 describes definition of drought and types of drought. Also, introduction about brief history of droughts, types of drought, impact of drought and disaster management framework of drought in Gujarat. Also, history of drought in India & in Gujarat. Finally, the objectives of the present study.

Chapter 2 presents a complete review of research related to different types of drought and drought forecasting techniques. This chapter also deals with Literature Review of previous research carried out in the field of drought assessment as well as role of remote sensing and GIS technology in the arena of monitoring and assessment of droughts for meteorological drought indices, hydrological drought indices and agricultural drought indices.

Chapter 3 provides a description of relevant information on North Gujarat agro climatic zones which includes climate and water resources in study region. Also, various climatological data and satellite images data used in present study.

Chapter 4 presents methodology related with different meteorological drought indices, hydrological drought indices and agricultural drought indices. Also, different climatic indices and aridity indices. Along with, methodology the trend analysis of different drought indices by non-parametric tests is shown. The methodology related to various soft computing techniques used for estimation drought indices using ANFIS and Fuzzy Logic.

Chapter 5 contains results and analysis of different years under various drought category using different meteorological drought indices, Hydrological drought indices and Agricultural drought indices. Also, results of arid zones and semi-arid region using different aridity indices and climatic indices. Also, soft computing results shows various developed model using various combinations and best model is estimated using different performance indices.

Chapter 6 This chapter concludes the overall the results of North Gujarat districts which shows conclusion of drought indices and trend analyses by summarizing their results, then highlights the importance of this thesis in the study area.