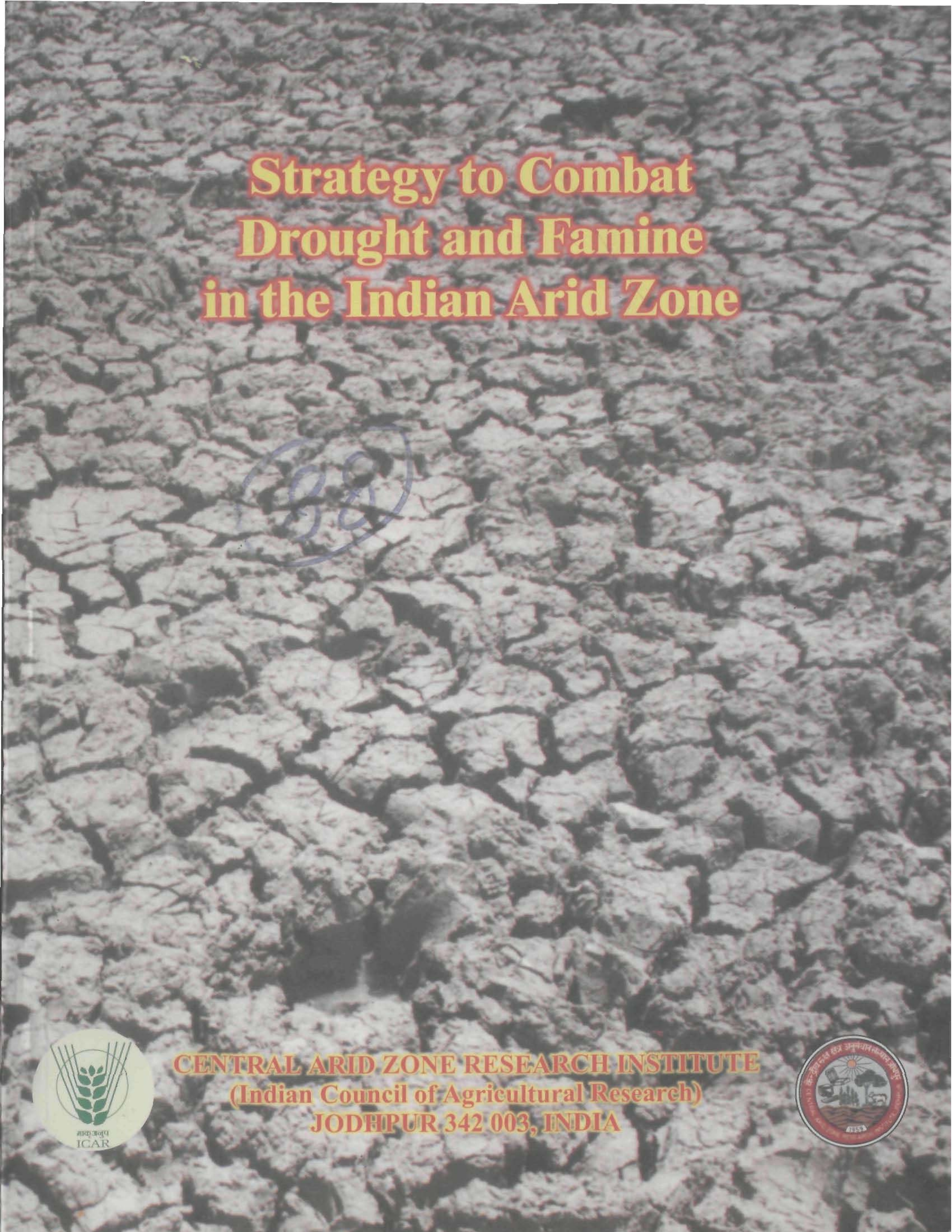

Strategy to Combat Drought and Famine in the Indian Arid Zone

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STRATEGY TO COMBAT DROUGHT AND FAMINE IN THE INDIAN ARID ZONE

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FOREWORD

The Indian arid zone extending to about 12% of the geographical area of the country (32 million ha), is highly prone to droughts and famines. During the twentieth century, the region experienced agricultural drought once in three years to every alternate year in one or the other parts. Failure of monsoon leaves the arid region totally dependent for food and fodder on buffer stocks to sustain its 19.8 million human and about 28 million livestock population. Migration in search of fodder, food, work and water is a common feature imposing hardships upon desert dwellers, casualties of livestock and famines in extreme drought situations.

The present drought is primarily due to the failure of Southwest monsoon during 1999 and food and fodder crises in the region due to accumulated shortage in rainfall during 1997 and 1998. Although 12 States are in the grip of severe drought but the most affected States are Rajasthan, Gujarat, Andhra Pradesh and Madhya Pradesh. Situation, however, is quite serious in the Thar Desert encompassing both Rajasthan and Gujarat. It is essential to evolve a long-term strategy to mitigate the drought condition and ensure required relief through adoption of appropriate desert management techniques.

I appreciate the efforts of Central Arid Zone Research Institute, Jodhpur for undertaking the stock of situation through a field survey in the severely drought affected districts in Rajasthan and Gujarat by a multidisciplinary team and bringing out a timely publication. The bulletin covers short and long-term strategies to provide drought proofing in the Indian arid zone. Although the immediate relief measures are mainly in the purview of State Governments utilizing Central or any kind of relief aid, yet CAZRI could offer advisory services on action plan of food for work, training on enriching low grade fodder, prevention of disease outbreak and a contingent planning for aberrant rainfall conditions. Strategies developed and advocated by CAZRI for arid region are of great relevance for long-term drought combating programme. Development of water resources, rainwater harvesting, water conservation, integrated watershed management, groundwater recharge, alternate land use planning, breeding drought tolerant varieties, and drought warning and monitoring would go a long way to combat drought in the region.

I hope that this bulletin will form a good document on the drought study in the country and act as a guide for various State and Central agencies involved to mitigate drought in the Indian arid region. My complements to team members for this timely effort.

(R. S. PARODA)
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May 19, 2000

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EXECUTIVE SUMMARY

Though the term drought is associated with scarcity of water, it means different things to different people. To the agriculturist, it means the deficit of rainfall and soil moisture to support healthy crop growth: to the meteorologist, it indicates the deficiency of rainfall compared to normal rainfall of the region and to the hydrologist it is the scarcity of water in surface and groundwater resources. According to the National Commission of Agriculture (1976), if the drought occurs in more than 40% of the years in an area, it is classified as chronically drought prone area. As per this classification, Indian arid zone is a chronically drought prone area. This fact is substantiated by a popular saying in the region that in the course of a decade, one year would be of bumper harvest, five years of moderate produce, three years of scanty harvest and one year of disastrous drought. Analysis of rainfall data (1901-1999) indicated that out of 99 years, the Indian arid zone experienced agricultural drought in one part or the other during 33 to 46 years, which suggests a drought once in three years to alternate year, Often drought persists continuously for 3 to 6 years, as prolonged droughts faced by this region during 1903-05, 1957-60, 1966-71, 1984-87 and 1997-1999. Such prolonged droughts put tremendous stress on natural resources and lead to severe scarcity of food, fodder and water.

The major causes of agricultural droughts in the Indian arid zone are its geographic location not favouring abundant monsoon rainfall, poor quality and excessive depth of groundwater limiting its use for irrigation, absence of perennial rivers and forests, poor water holding capacity of soils, and huge drawl of limited groundwater resources. Because of lack of substantial irrigation facilities, the agriculture is mostly dependent on rainfall. The increased pressure of both human (400%) and livestock (127%) population during twentieth century has put tremendous pressure on land, and surface and groundwater resources. Therefore, the impact of drought is felt much more severely in the arid region compared to other parts of the country.

As the water storage is dependent on the scanty and erratic rainfall, the duration of availability of water in surface water resources is reduced significantly in drought years. Groundwater table is declining @ 0.2 to 0.4 m/annum in almost three-fourth of the region, consequently shallow wells dry up during droughts and deep wells became deeper. Quality of groundwater deteriorates and sometimes the concentration of undesirable substances such as fluoride and nitrate increase to harmful/toxic levels. Grazing herds of animals quickly remove the scanty grass cover that come up with meagre rainfall, thus aggravating the problems of soil erosion and desertification. Widespread crop failures lead to acute shortage of food and fodder. Both human and livestock suffer from malnutrition and consequently become victim of host of diseases. As most of the people of this region depend on agriculture and pastoralism, drought leads to decline in income and employment opportunities. Large-scale migration with livestock or in search of employment is a common feature during prolonged droughts.

To minimize the suffering of human and livestock, relief measures are taken up by the respective State Governments and NGOs' on a large scale. These measures mainly aim at provision of drinking water, supply of food grains through Public Distribution System at subsidized rates, supply of feed and fodder for livestock and subsidy to approved *Gosalas*, human and livestock healthcare, etc. Efforts to create direct and indirect wage employment through food for work barely sustain the living of the rural poor who suffer most due to drought. However, some long-term preventive measures need to be given increased attention for integrated development of drought-prone areas and to tackle the problem on permanent basis. Some of these direct measures are long-term forecast of monsoon, suitable land use system, water harvesting, soil and water conservation, contingency crop planning, adoption of improved technologies for dryland crops, efficient irrigation methods, enrichment of cereal straw as fodder, etc. In addition to these, human and livestock population pressure needs to be reduced through education, alternative ways of employment generation and disposal of unproductive livestock.

The root cause of weak monsoon in India is related to the widespread, persistent atmospheric subsidence, which results from the general circulation of atmosphere. Better understanding and mathematical modeling of the monsoon phenomenon would be very helpful in early long-term forecast of monsoon to enable planners and farmers to plan accordingly.

No one understands the value of single drop of water better than the desert dwellers. Rainwater harvesting is traditional way of life in arid regions. Various techniques of rainwater harvesting have been developed/refined by research workers. Improved designs of N*adis*, T*ankas*, *Khadins*, etc. have also been developed. These technologies should be popularized among the people of this region. Utilizing flash floods/surplus rainwater for artificial recharge of groundwater to augment the dwindling water table is need of the hour. Integrated watershed management, which aims at utilizing the rainfall wherever it falls should be the unit for planning and implementation of the development programmes. The measures like afforestation, pasture development, livestock management, field crops, water storage, etc. are undertaken in the watershed areas identified as suitable for such measures.

With the increased pressure on land, marginal lands are being brought under cultivation, which is a disastrous trend. Concerted efforts have to be made to adopt suitable land use systems keeping in consideration the rainfall, soil type and need of the people. Growing of crops, fruits, trees and grasses in various combinations minimize the risk of crop failure and provide stability to farm income. Suitable combinations of these components for different rainfall zones and soil types have been developed by the scientists which should be preferred over crop cultivation alone.

As water is the scarce resource in the Indian arid zone, efficient irrigation technologies like sprinkler and drip system should be popularized which aim at maximizing production per unit of irrigation water. Adoption of improved agronomic practices like use of improved varieties, timely weed control, use of fertilizers along with farm yard manure. *in-situ* rainwater harvesting, etc. can give good yields even in below normal rainfall years. Cultivation of water intensive crops should be discouraged.

Besides natural resources, livestock and permanent vegetation such as grasses and trees are strengths for survival of mankind in the arid regions. Management of grasslands with *Lasiurus sindicus, Cenchrus ciliaris* and *Cenchrus setigerus* and top feed species such as *Prosopis cineraria, Acacia senegal* and *Tecomella undulata* need priority attention. Such a silvi-pasture system survives annual droughts and provides rich fodder. Quality of fodder particularly the wheat straw given to cattle during drought is usually very poor. The fodder quality can be improved through urea/molasses treatment, thus improving animal health and productivity with very little investment. Management of common property resources such as grazing lands, *Orans,* village ponds, etc. needs top priority by the people for themselves to combat drought in arid regions.

STRATEGY TO COMBAT DROUGHT AND FAMINE IN THE INDIAN ARID ZONE

INTRODUCTION

Because of the inherent variable character of rainfall there are often occasions when the actual rainfall in arid region falls appreciably below the 'normal' expected on a long-term basis. This causes drought, which is manifested in terms of crop failure, unreplenished ground and surface water resources, and lowered levels/drying of lakes and reservoirs. Tannehill (1947) has underlined the uniqueness of drought among weather phenomena by pointing out how 'it creeps on us gradually, almost mysteriously, but its consequences are a terrible reality'. Unlike floods, droughts do not make their onset obvious, nor is it at all easy to say with certainty when does a drought withdraw. The Encyclopedia of Cliamatology (Oliver and Fairbridge, 1987) opens its article on drought thus: drought has been defined in many ways, including (a) a period of rainfall deficiency, (b) a relative state of forest flammation, (c) occurring when a specific agricultural crop or pasture yields less than expected amounts, (d) denoting a critical level of soil moisture or groundwater depletion, and (e) poetically as a 'valley of rain deficiency in the broad sweep of time and weather'. Current theory identifies the phenomenon of drought as a temporary negative deviation in environment moisture status. Acute water shortage arising from lack of rainfall or its proper distribution in time and space is the prime cause of drought. Catastrophic drought events in a row may lead to famines in arid region causing large scale migration, loss of livestock and human lives due to severe scarcity of water, food and fodder.

Causes of drought

Droughts in the Indian sub continent are mainly due to failure of rainfall from southwest monsoon. The root cause for failure of monsoon rainfall is due to the widespread, persistent atmospheric subsidence, which results from the general circulation of the atmosphere. Recent studies on interactions between global circulations and drought showed that the El Nino phase of the Southern Oscillations (ENSO) has the largest impact on India through drought. While ENSO events cause summer drought with a reduction in food grain production during monsoon period, the winter rainfall usually enhanced consequently with an increase in the winter crop production (Sinha 1987, WMO 1994, Rao and Miyazaki, 1997). If the monsoon rainfall is not adequate to support the crop throughout its growing cycle, aridity or agricultural drought occurs.

The frequency of droughts and floods are also influenced by climatic changes as a result of increased concentration of the atmospheric CO_2, methane and nitrous oxide. The indiscriminate use of gases like chlorofloro carbon (CFC) and use of cock in thermal power plants have altered the radiation balance of the earth's atmosphere resulting in increased temperature due to Green House effect. The Inter-governmental Panel on Climate Change (IPCC) of the World Meteorological Organisation projected an increase of 0.1 to 0.3°C by 2010 and 0.4 to 2.0°C by 2020 in South Asia. It was estimated that the implication of climate change might result in a decrease in cereal production in the South Asian region (Houghton *et al.*, 1990).

The studies conducted on secular changes in rainfall and air temperatures of northwest India showed that there was a marginal increase in the rainfall by 141 mm in the past 100 years (Pant and Hingane, 1988) and more so in irrigated belts of Ganganagar region particularly during the past three decades (Rao, 1996). The studies on climatic changes over Jodhpur region showed that the rainfall and air temperature were favourable, but the increase in human population (400 %) and livestock (127 %) during the twentieth century, resulting a major shift of land use pattern and tremendous pressure on surface and groundwater resources were the main causative factors for drought and desertification conditions in the region (Rao and Miyazaki 1997).

Kind of Droughts

Drought means different things to different people and there are probably as many definitions as there are users of water. To the agriculturist it is the absence of soil moisture to support plant growth, to the meteorologist it is the absence of rain and to the hydrologist it is the absence of water in the storage reservoirs and canal systems for irrigation and power generation. The National Commission of Agriculture (1976) defined drought in three categories:

(i) *Agricultural drought.* It occurs when soil moisture and rainfall are inadequate during the growing season to support a healthy crop growth to maturity and cause crop stress and wilting. It may also cause decline in production from grazing lands, pastures and trees being used as top feed in arid regions.

(ii) *Meteorological drought.* It is a situation when there is a significant (more than 25 %) decrease in rainfall from the normal value over the area.

(iii) *Hydrological drought.* Meteorological drought, when prolonged, results in hydrological drought with a marked depletion of surface water and consequent drying up of reservoirs, lakes, streams and rivers, cessation of spring flows and also fall in groundwater levels.

Under this classification, if drought occurs in 20 % of the years in any area, it is classified as drought prone area and if the drought occurs in more than 40 % of the years, it is classified as chronically drought prone area. Indian arid zone falls in the category of chronically drought prone areas.

Droughts in India

Failure of the monsoon rainfall is the most important cause for droughts/famines in India while occasionally floods and failure of crops due to epidemics of insects and pests are also responsible for famine like situations. Also extensive deforestation over centuries has altered hydrologic cycle and tended to increase the incidence of droughts in pockets. A study of moderate and severe droughts that occurred in India indicates that, except for very small pockets in the Northeastern India and Kerala, there were no areas, which had not been affected by drought at one time or the other. While the entire country could thus be considered as drought prone, there are certain areas, which are chronically subject to such condition and merit the appellation 'drought prone'. Technical Committee on Drought Prone Areas Programme and Desert Development Programme identified about 120 million ha of the country's area, covering 185 districts (1173 development blocks) in 13 states (Figure 1), as drought prone (Anonymous, 1994).

Scarcity of food, fodder and water resulting from deficit rainfall has been a recurring feature in India. Based on the historical records, Jaiswal and Kolte (1981) reported 120 droughts/famines in one or other part of the country between 1291 and 1979. Das (1988) mentioned that from the 11th to the 17th century, there were at least 14 famines in different parts of India. Another 12 famines were recorded between 1769 and 1858, a ninety-year period. In the next 49 years between 1860 and 1908, there were 20 famine years. Of these the worst famines were in 1877, 1899 and 1908, when in each case 50 % of the country had received less than 75 % of normal rainfall ravaging more than 60 % of the country. A study

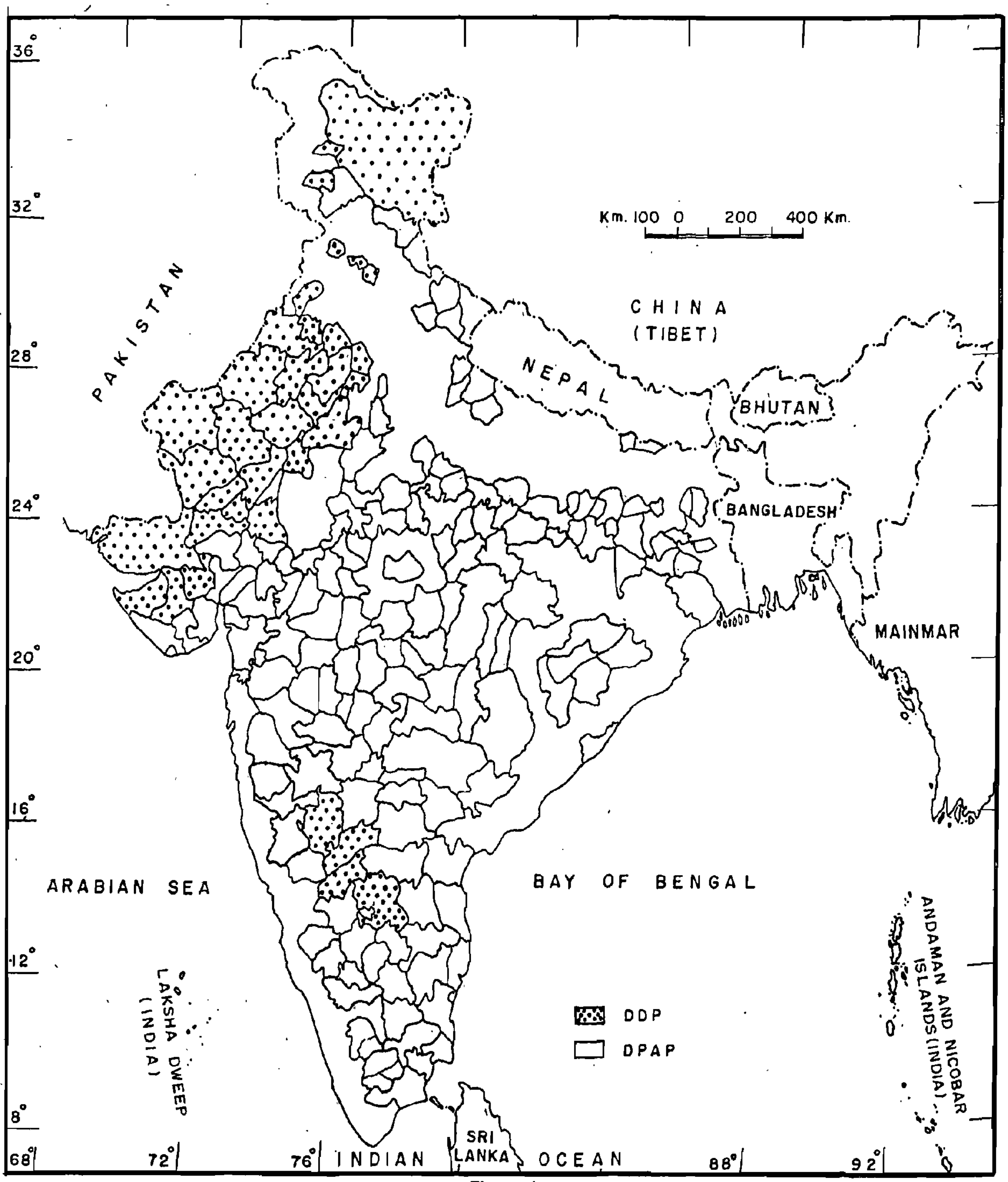


Figure 1, DDP and DPAP districts in India of slight, intense and severe famines that occurred in India during the 19th century showed that with the exception of very small pockets, there were no area which had not been affected by famine at one time or the other (Bhatia, 1967). He further reported that between 1800 and 1966 severe or wide spread droughts led to a sharp fall in food production in the country as a whole and gave rise to famine conditions. Such famines and near famine conditions resulting from drought recurred every quinquennium or so until 1923-24. However, the situation has changed during the last 75 years. Canal irrigation as well as other major and minor sources of irrigation reduced, to a large extent, the effects of droughts.

Droughts in the Indian Arid Zone

Nearly two-thirds of the Indian arid zone is made up of dunes and sandy plains. The region has disorganised drainage network over a major part, deep and often saline groundwater and high rates of evapotranspiration. Spatially, the rainfall is erratic and meagre, ranging from 500 mm in the Eastern margin of the region along the Aravallis to less than 100 mm in the West in Jaisalmer district. Added to this decreasing rainfall gradient the year-to-year variability increase from 40 % in the east to 70 % in the West. Therefore, droughts and disastrous famines are recurring features of the Indian arid zone. The main causes of droughts are: geographic location not favouring the abundant monsoon rainfall, poor quality and excessive depth of groundwater, absence of perennial rivers and forests, poor water holding capacity of soils and huge withdrawl from limited groundwater resources.

The region supports a high human and livestock population; the livestock outnumbering human by about 4 times in Jaisalmer, 3 times in Barmer, 2 times in Bikaner, and 1.5 times in Banaskantha, Jalor and Jodhpur districts as against only one-half in rest of the country. As a result, there is a perennial fodder shortage to the tune of 28.2 million tones/annum. Also, in about 75 % area, the water table is declining @ 0.20 to 0.40 m annually due to overexploitation as a result of increased demand. The agriculture is wholly dependent on rainfall. In other words, whenever drought or famine synchronized for the want of rainfall within the region, the people were bound to suffer severely. Popular saying in the Indian arid zone goes like this: In the course of a decade, one year would be a bumper crop (100 %), five years of average produce (60-75 %), three years of scanty harvest (40-60 %) and one year of famine (< 25 %). There is a defined and true impression that irregular and uncertain rainfall followed by drought and famine is an inevitable, every three years cycle, in the region.

HISTORICAL ASPECTS OF DROUGHT

Archives of Drought Before 1900 AD

Although well documented records are lacking on rainfall and its distribution due to lack of instrumentation in past yet revenue records, market prices of commodities, migration of people and casualties are the historical evidences of droughts and famines in the region. As many as fifteen droughts/famines of different intensities have been reported in the Indian arid zone between 1792 and 1899, out of which nine were serious triple droughts (Table 1).

Table 1. Historical droughts and famines in the Indian arid zone (1792-1899)

S. No.	Year	Intensity of drought
1.	1792	Agricultural, Hydrological and Meteorological
2.	1804	Agricultural and Meteorological
3.	1812-13	Agricultural, Hydrological and Meteorological
4.	1833-34	Agricultural, Hydrological and Meteorological
5.	1838-39	Agricultural and Meteorological
6.	1848-49	Agricultural, Hydrological and Meteorological
7.	1850-51	Agricultural and Meteorological
8.	1853-54	Agricultural and Meteorological
9.	1868	Agricultural, Hydrological and Meteorological
10.	1869	Agricultural and Meteorological
11.	1877	Agricultural, Hydrological and Meteorological
12.	1891-92	Agricultural, Hydrological and Meteorological
13.	1895-96	Agricultural and Meteorological
14.	1898-99	Agricultural, Hydrological and Meteorological
15.	1899-1900	Agricultural, Hydrological and Meteorological

There are reasons to believe that the history of Indian arid zone is full of drought stresses because:

- Nine times out of ten in the past whenever there was a severe drought in the State of Gujarat, the Western Rajasthan, being less favourably placed could not have escaped the calamity.
- The past records of Haryana State revealed that during drought years there was a considerable immigration from Rajasthan, a majority of people from the Western Rajasthan.
- Awakening about the drought actually begins on confirmation of happenings.
- Long-term planning to combat the drought calamity has been lacking at various levels.

In the historical archives, the chronicle of droughts in the region opened with the year 1792 (Anonymous, 1951). Twelve years later (1804) there were scarcity conditions in the Central India and in the entire Indian arid zone, while the Western Rajasthan was involved in severe distress. The year 1812-13 saw a triple devastating drought (agricultural, meteorological and hydrological drought) yet owing to a fair reserve of fodder the livestock could be saved then. A widespread scarcity of fodder was again experienced during the year 1833-34 in the region forcing people to migrate to the adjoining areas with better reserves. After a short-interval of only three years, the region was again stricken with a severe agricultural drought during 1837-38. During the year 1838-39 there was a severe drought in Rajasthan as well as in the neighbouring States of Gujarat, Madhya Pradesh, Delhi and Haryana.

In 1848-49, the region was again in the grip of a triple drought causing devastation of human and livestock population considerably. This triple drought was the second in the series after an interval of 32 years. Agricultural droughts occurred again during 1850 and 1853-54 in the region causing considerable hardship to the people.

A detailed account of first of its kind of a triple drought during 1868 (the third in the century) in the region is available in the historical archives. This drought affected the entire North India with failure of *kharif* as well as *rabi* crops. The estimated casualty figures were 373,000 humans and 200,000 cattle. The local administration abolished the import duty on food grains and did its best to relieve the distress.

The crops failed again during the year 1869 in succession. The severity of drought could be judged by 287 % rise in the price of wheat over that at the beginning of the 1868. The severity of distress in the region during 1868 and 1869 was further aggravated by the adverse conditions in the adjoining states.

The next famine in the region was during 1877-78. In these two years and the preceding one of 1876 parts of India, covering an area of about 640,000 km^2, were affected by droughts and famines. The annual rainfall within the region was only 113 mm against the normal annual rainfall of 591 mm resulting in only one-fifth crop production. The scarcity of water and poor harvest further added to the shortage of fodder. The losses to the human and cattle were estimated to be Rs. 1,000,000.

The year 1891-92 was one of a triple droughts in the basin and fourth of its kind in the century. This year, a sudden and copious burst of rainfall was followed by a long dry spell resulting in complete failure of crop and fodder. In all, an area of 33,843 km^2 was affected and price of food grains rose between 190 and 255 %. Nearly half the livestock population decimated.

The year 1895-96 and 1896-97 were drought and famine years in the history of Indian arid zone. In the year 1895 the rainfall was insufficient and untimely so the *kharif* crop was no better than in name only. Similar was the case during 1896. The food grain export to the famine stricken Provinces was three times than normal, raising local price beyond the purchasing capacity of people. Relief works were opened in all the affected districts costing Rs.160,000 by way of employment wages and Rs. 80,000 as gratuity to the infirm and sick people.

During 1898-99, the region experienced a disastrous record of rainfall, which was unprecedented. The rainfall was deficient in almost all the districts for half of the year, slight and scattered in May and June and fairly distributed in July. The total rainfall was about 200 mm. As a result, the fate of *kharif* crop was sealed and prospects of *rabi* crop were uncertain. The grain yield ranged between 50 and 60 % and the fodder crop failed. About three-fourth livestock population perished. The price of imported food grain rose steadily causing hardship to the people. The total cost of relief works by the end of August 1900 was Rs. 2,632,000 - a princely sum then.

Meteorological Drought Records After 1900 AD

The sensitivity of recognising a drought has increased by instrumentation after 1900 AD as moderate droughts remain unaccounted for in historical archives. The Indian arid zone experienced agricultural drought 33-46 years during 1901-1999 with varying frequency from location to location. These droughts were assessed not only from quantum of rainfall received but also its distribution during the crop-growing period. The frequency and years of occurrence of moderate and severe droughts are given in Tables 2 and 3.

Table 2. Frequency of agricultural droughts in the Western Rajasthan (1901-99)

District	Moderate droughts	Severe droughts	Total number of droughts
Barmer	18	29	47
Bikaner	23	22	45
Jaisalmer	25	42	67
Jodhpur	26	16	42

Jaisalmer district is the most prone to drought. During 1901 to 1999, agricultural drought in the region occurred in 67 years, out of which in 42 years it was severe and in 25 years it was moderate affecting considerably the crop and fodder production. Next to Jaisalmer district, the Barmer district experienced severe drought in 29 years and moderate drought in 18 years. Bikaner district experienced severe agricultural drought in 22 years and moderate drought in 23 years. While Jodhpur district experienced severe drought only in 16 years and moderate drought in 26 years. The decreasing order of drought intensity in Jaisalmer > Barmer > Bikaner > Jodhpur matches with the proverbial description of drought/famine as having legs in Bikaner, head in Barmer, stomach in Jodhpur and stays for ever in Jaisalmer.

Often drought persist continuously for 3 to 6 years with different intensities as has been experienced during the periods of 1903-05, 1957-60, 1966-71, 1984-87 and 1997-99 causing multiplier effects on crops and fodder production, groundwater and on availability of drinking water resources (Rao 1997). However, the Western Rajasthan sometimes gets normal to above normal rainfall in subsequent years like the one following 1987 drought from 1988 till 1996 (Rao *et al.*, 1997) leaving ample scope to utilise excess rainfall for artificially recharging the groundwater.

The droughts, famines and their consequences have taught many lessons to the people in the region. The people developed comparable courage and power of endurance in adversity. The distance, lack of communication and inhospitable terrain made relief works difficult and expensive in the region. It has been now realized that drought/famine is a regular feature in the area and all possible efforts should be made by the Government to mitigate effects of drought on a long-term basis.

Impact of Drought

Water resources

Irrigation through surface water storage had never been a significant component of crop production in the Indian arid zone. Although the ephemeral channels of the Luni and the Sukri basins dammed at a number of places viz. Jawai, Jaswant Sagar, Sardar Samand, etc., yet the water storage is dependent on the scanty and erratic rainfall and therefore, could not save crops during prolonged drought but contributed to groundwater recharging. The duration of availability of water in surface water sources reduced significantly (Table 4) and these were dried up quickly, before the onset of summer, in drought years. Other traditional water storage structures like *Nadis* and *Tankas,* meant primarily for drinking, and *Khadins,* check dams, etc., meant for crop production, met similar fate during drought years. Wells are thus

Table 3. Agricultural drought years with different intensities in four drought prone districts of the Western Rajasthan (1901-99)

District	Intensity of drought	
	Moderate	Severe
Barmer	1903,1920,1928,1935,1939, 1945,1954,1959-60,1963,1970-71,1973,1980-82,1985 and 1997 (14)	1901-02,1904-05, 1911, 1915, 1918,1923,1925,1930,1936, 1951,1957, 1958, 1962, 1966-69, 1972, 1974, 1977-78, 1986-88. 1991, 1998 and 1999 (19)
Bikaner	1904,1912-13,1915, 1925,1938, 1941,1946,1951-52,1960,1961-62, 1965, 1970-71, 1979, 1982,1986,1988, 1990,1993 and 1997 (19)	1901-02, 1905, 1911, 1918, 1939, 1948, 1957-58, 1963, 1968-69,1972,1974-75, 1980, 1984, 1985, 1987,1991.1998 and 1999 (18)
Jaisalmer	1902-03,1905,1927,1934,1936, 1938,1941-43,1952,1954,1956, 1958-59, 1960, 1962, 1975, 1980-82, 1988, 1991, 1993 and 1994 (19)	1901,1904,1911,1913,1915, 1918-19, 1921,1925,1928, 1930, 1939,1946,1948-51, 1957, 1961, 1963,1964-69, 1971, 1972-74, 1977,1979, 1983, 1985-87,1989-90,1992, 1994 and 1997-99 (27)
Jodhpur	1901, 1906, 1914, 1920, 1922, 1925, 1930, 1935, 1941, 1946, 1949, 1951, 1957, 1960-61, 1968, 1971, 1974, 1980-81, 1984, 1988, 1991, 1993 and 1997-98 (23)	1902, 1904-05, 1911, 1913, 1915, 1918, 1921, 1939, 1958, 1969, 1972, 1985-87 and 1999 (13)

major source of irrigation in arid region but the quality of water is often brackish and questionable for drinking due to presence of toxins. The groundwater table has declined to the extent that the shallow wells dried up, deep wells further deepened and the quality of water in deep wells deteriorated from slightly saline to saline. Sometimes, the concentration of undesirable elements such as fluoride and nitrate increased to harmful/toxic levels. The poor people suffer the most since the wells owned by them are shallow and they do not afford

Table 4. Duration of availability of water in *Nadis* in the Indian arid zone

Landform	Duration of availability of water (months)	
	Normal year	Drought year
Sandy plain	8-12	1-4
Dune complex	3-5	1-3
Younger alluvium	10-12	7-9
Older alluvium	8-10	4-7
Rocky/gravel pediment	7-12	2-6

to deepen them. Thus, the philosophy of public welfare confined to the augmentation of water supply for human and livestock drinking during the drought/famine periods.

Vegetation

More than 600 plant species have been recorded in the Indian arid zone and these are fairly well adapted to the harsh climatic conditions of this region. But the continuous drought for two or three years has adverse effect on desert plants. The annual species were most adversely affected due to consecutive drought years of 1984-87 (Saxena, 1993).

Desert flora constitutes 61 % of therophytes (short cycled annual species) whose lifecycle coincides with the recession of monsoon and completes all the phenological stages with in a span of 45-75 days: i.e. from seed germination to dispersal of seeds. Many a therophytic species fail to germinate with meager precipitation during drought years. In many cases the germinated material failed to cross the vegetative stage and succumbed to prolonged droughts. In some cases the flowering could take place, but the formation of viable and healthy seeds failed completely. However, a few species like *Gisekia pharnacoides*, *Tribulus terrestris* and *Indigofera cordifolia* were capable weeds to leave fresh seeds to continue further generation. Amongst the grasses, *Aristida funiculata* and *Cenchrus biflorus* were successful in producing small quantity of seeds, even under moderate to severe drought conditions.

Successive droughts had adverse effect on the palatable tussock grass species also. They were subjected to heavy grazing pressure. Continuous droughts rendered the clumps very weak due to the exhaustion of stored food in their rhizomatous parts. Majority of them could not withstand grazing and trampling and finally die. Low perennial grasses like *Eleusine compressa* and *Dactyloctenium sindicum* produced negligible above ground biomass. There are some grass species such as *Lasiurus sindicus*, *Panicum turgidum*, *Cymbopogon jwarancusa*, etc. which are capable to produce reasonably well in the drought years. Their management and controlled grazing are issues to be regulated during adverse situations.

The natural tree species like *Prosopis cineraria, Azadirachta indica, Acacia senegal, Acacia leucophloea, Balanites aegyptiaca, Maytenus emarginatus*, etc., were able to withstand the prolonged drought very well. These may be termed as highly drought tolerant. However, there were some minor variations in their phenological behaviour. Silvi-pasture systems of these species with grasses, and *Colophospermum mopane+Lasiurus sindicus* could withstand drought to some extent.

Livestock

The difficulties of conceptualization not withstanding, visitation's of drought culminates into several socio-economic observations related to livestock rearing. Some of these observations include distress role of cattle, increased mortality of cattle and sheep, strained feed and collection of non-conventional drought feed from forests. Sale of sheep and goat at very low prices for survival, letting loose the cattle at their own, sale of valuables, out standing loans for food and feed result in collapse of the purchasing power. Decrease in size of herd was reported due to frequent droughts and famine occurrences (52 %), sale of livestock (49 %), mortality due to diseases (18 %), natural death (12 %), succession (13 %) and others including gift in dowry, mortality due to saline water and theft. In a pastoral tract droughts/famines were reported to be the chief reasons of decrease in livestock (73 % household reported). During 1939-40 famine, scarcity of water and fodder led to large scale migration and mortality of livestock About 40 % livestock were lost between 1935 and 1940 in the region (Famine Report, 1940). In the recent past severe droughts during 1968 and 1985-87 in the Western Rajasthan (Table 5) and during 1985-1987 in the arid part of Gujarat (Table 6) led to large-scale mortality of livestock.

Table 5. Livestock trend in the arid districts of Rajasthan with reference to drought

Type of livestock	Before (1966) (in, 000)	After (1972) (in, 000)	Change (%)	Before (1983) (in, 000)	After (1988) (in, 000)	Change (%)
Cattle	4689	3482	-26	4570	3386	-26
Buffalo	1055	1109	5	1760	1759	-0.06
Sheep	5541	5160	-7	8773	6485	-26
Goat	4256	5814	37	7447	5562	-25
Horses and Ponies	16	10	-38	9	9	-
Donkeys and Mules	91	76	-16	125	100	-20
Camels	555	625	-13	639	568	-11
Pigs	6	10	7	27	34	260
Total	16209	16286	0.5	23349	18202	-22

Source: Department of Animal Husbandry, Jaipur, Rajasthan.

Table 6. Livestock trend in the arid districts of Gujarat with reference to the drought years 1985-87

District	Year	Cattle	% (+) or (-) in 1988 over 1982	Buffalo	% (+) or (-) in 1988 over 1982	Sheep	% (+) or (-) in 1988 over 1982	Goat	% (+) or (-) in 1988 over 1982	Other Live-stock	% (+) or (-) in 1988 over 1982	Total	% (+) or (-) in 1988 over 1982
Bansakantha	1982	550276		358293		288646		345802		32755		1575772	
	1988	393959	-28	345786	3	169091	-41	319036	-8	23145	-29	1251017	-21
Sabarkantha	1982	416623		373757		32702		221658		21683		1066423	
	1988	406034	-3	375583	1	39428	21	279490	26	13778	-36	1114313	4
Mehesana	1982	348618		573171		52517		153997		41163		11694666	
	1988	273689	-21	553721	-3	33491	-36	169718	10	27470	-33	1058089	-10
Ahmedabad	1982	272074		248916		26541		88378		34085		669994	
	1988	242846	-11	270747	9	32030	21	127334	44	19010	-44	691967	3
Gandhinagar	1982	24831		62180		3268		8322		3859		103060	
	1988	21973	-12	72487	17	4042	24	11905	43	2242	-42	112649	9
Kutch	1982	418330		117438		587431		492088		54166		1669453	
	1988	286531	-32	96177	-18	357671	-41	300693	39	31322	-42	1072394	-36
Total	1982	6254168											
	1988	5300429	-15										

Source: Department of Animal Husbandry, Gandhinagar, Gujarat.

As a case study, impact of drought on livestock in the Shergarh Tehsil, Jodhpur is given in Table 7. On an average, about 90 % of the total livestock @ 89 per km^2 and a household having 15 livestock units @ 2.7 per capita were affected during the drought period. Mean livestock decreased from 380,000 in 1961 to 305,000 in 1966 giving a net decrease of 19.7 %. Significant decrease occurred in case of Cattle 20 %, buffalo (17 %) and sheep (4 %) while there was an increase in case of goat (35 %) and camel (39 %) during 1961 to 1972. Thus, drought affected cattle adversely, decreasing its composition from 23.3 % to 11.7 %. The goat increased from 37.9 % to 57.2 % between 1961 and 1972.

Feed and Fodder Resources
Insufficiency of feed and fodder, both in quantity and quality, was the major problem during droughts/famines. *Prosopis cineraria* leaves had poor regeneration due to successive droughts in 1987. Also, the regeneration of *Zizyphus nummularia* was very poor with only 10 % survival rate. *Caparis decidua* was consumed by goats, which spoke their better survival during the 1987 drought. The regeneration and growth of *Calotropis procera* was least affected among all other vegetation in the region. Goats were seen regularly feeding green leaves and flowers of

Table 7. Impact of drought on livestock in the Shergarh Tehsil, Jodhpur

Year	Total (,000)	Number of Livestock affected per unit			
		Area (km^2)	Village	Household	Capita
1968-69	305	80	3318	13	2.7
1969-70	297	78	3223	13	2.6
1972-73	379	99	4123	17	2.8
1974-75	379	99	4123	17	2.8

Goat feeding on un–preferred *calotropis procera*

Calotropis procera. Even sheep were seen regularly feeding on un-preferred weeds such as *Cortalaria burhia* during the 1987 drought. During droughts, all the available quantity of *Citrullus colocynthis* served as animal feed.

Health, Reproduction and Production
No severe out break of diseases was recorded during droughts in sheep and goats due to large-scale migration. The most common and important condition was debility due to malnutrition. Few cases of small pox, enterotoxaemia, and foot and mouth diseases were also reported. The most common disease was the deficiency of vitamin A, revealed in the form of diarrhoea, skin eruptions followed by lacrimal discharge and corneal opacity (Mathur *et al*, 1991a).

***Salvadora oleoides* protects animals against scorching sun**

In general, the onset of puberty was late. The usual breeding season was delayed and 40-50 % of animals did not exhibit signs of oestrus (Mittal *et al.*, 1990). The breeding potential of males was also depressed. The conception rates were lower than normal years. Incidences of abortions and premature births were increased in many livestock. The newly born were under weight and the mortality rate was high.

The overall production was severely affected. Rate of weight loss was higher in ewes and cows than in their males. Sheep lost weight more rapidly than goat. There was drastic decrease in wool production from sheep (Mathur *et al.*, 1991 b) and milk yield from livestock. The rate of purchase of sheep and goats had gone down significantly in this area. Farmers had reservations for sale of female animals. Cows in general were let loose to maintain at their own.

Socio-economic issues

Since 1755 the Rajasthan State had at least 25 famines causing either Annakal (food grain famine) or Jalakal (scarcity of water) or Trinakal (fodder famine) or Trikal (Scarcity of food grain, water and fodder). The highest number of moderate to severe drought years was observed during 1981-87 (3 out of 7 years). The previous were 3.72 to 3.8 years during 1901-1910, 1911-1922 and 1961-1970. During 1987-88 drought occurred in four consecutive years in the 112 years of Rajasthan's climatic history.

Such frequent drought disasters affect socio-economics and cause severe distress to the human, livestock, crops and agricultural development and socio-economics of people. Rise in prices, contraction of charity, diminution of credit and consequently enhancement of the rate of interest of loans, a reduced activity in grain trade, increase in petty crimes, unusual migration of the people accompanied by their flocks and herds, eruption of land alienation, disinterest and irrigation development, etc. were the most common factors prevailing during droughts.

The estimate of effects of drought of 1985-86 (Bharara, 1999) on various parameters have shown that drought had affected 85 % of the total Tehsils of arid Rajasthan comprising more than 61 % of the villages of which 12 % were affected with 50-74 % drought severity and 49

% with 75-100 % severity. The drought affected more than two-thirds of the total human population. less than one third of the area and about half the livestock in the region.

A positive relationship between drought intensity and number of people affected, number of villages affected and crop loss was found. Recurring droughts and famines brought changes in the nature and extent of the socio-economic values and attitude of the people. During 1987-88 droughts, major shift (74 %) was observed in occupational distribution (Purohit, 1993). The agricultural sector was not in position to provide basic employment to working population, which resulted in the migration and underemployment. There was decline in net sown area by 84.3 % and all the crops failed. Expenditure on social ceremonies and socio-religious functions cut down drastically and women of the rural area were overburdened with additional work of employment on relief works. The infant mortality was high succumbing to host of diseases. Taking infant children to work or on migration also led to increased child mortality. The mother and child had high morbidity due to low intake of calories, which was not in proportion to the energy spent for hard labour at relief works. However, during drought, harmony existed among the people of the same caste as was among different castes. Behaviour of people was soft and helping particularly towards infirm and people below poverty line.

CURRENT DROUGHT SITUATION (1999-2000)

Climatic Aspects

The current drought spreads in 12 States affecting about 100 million human and 60 million livestock population in the country. The most affected States are Rajasthan, Gujarat, Andhra Pradesh and Madhya Pradesh. In Rajasthan drought influenced 23,400 villages in 26 out of 32 districts affecting 28 million human and 34 million livestock population. In Gujarat, drought influenced 25 million human and 7 million livestock population affecting 9,421 villages in 17 out of 25 districts. In Andhra Pradesh 17,431 villages in 18 out of 23 districts are affected by drought influencing 40 million human and in Madhya Pradesh 3,240 villages, in 7 out of 45 districts, are affected by drought influencing 3 million human and 3.4 million livestock population. There is 15 % loss in food grains production from normal production in the country as a whole. The drought impact is estimated to have caused 30 % reduction in food grain production in Gujarat, 25 % in Andhra Pradesh, 23 % in Rajasthan and 10 % in Madhya Pradesh.

Drought is usually referred to dryness or deficiency in water as a result of failure of rainfall, depletion of soil moisture and water resources. Absence of rainfall for longer periods results in shortage of drinking water, food grains and livestock fodder, leading to famines and mortality in human and livestock. Many a times, drought is aggravated by human intervention such as excessive pressure of human population, cultivation of high water requirement crops, maintenance of large number of productive and unproductive livestock. Incidents of droughts prevail in all geographical regions of the world, but its impact is felt more in arid and semi arid regions.

During 1999, the monsoon rainfall was deficient in many regions. The rainfall deficiency from normal in drought affected different States was -38 % in Gujarat, -36 % in Tamil Nadu, -25 % in Rajasthan, Andhra Pradesh, Haryana and Uttar Pradesh and -20 % in Madhya Pradesh.

A cyclone was developed over Arabian Sea on 18 May 1999, but it advanced in the Northerly direction towards Pakistan causing low activity over the Western Rajasthan. This depression brought some relief rainfall around 22 May 1999 to some of the Western districts of Rajasthan. The chief amounts of rainfall recorded were Ramsar - 145 mm, Chohtan - 115 mm, Jaisalmer - 94 mm, Barmer - 68 mm and Bikaner - 53 mm. The other arid districts of Rajasthan did not received significant rainfall since the depression moved away from the Rajasthan.

Onset of the Southwest monsoon over the Western Rajasthan was late by three weeks during 1999 from its normal dates. A depression centred over the Udaipur Division on 16 July 1999 caused widespread rainfall in that Division. This system slowly advanced to Kota, Jaipur and Ajmer Divisions on 19 July 1999 causing widespread rainfall in these areas. It further advanced towards the Western parts of the State and thereby scattered rainfall was received in Bikaner, Ganganagar, Hanumangarh and Jodhpur districts up to 28 July 1999. This depression caused 300 mm rainfall at Bilara and 260 mm at Jaswant Sagar (Jodhpur) on 31 July 1999.

At Jodhpur, first sowing rain of 17 mm occurred on 19 July 1999. This initial phase of monsoon remained active up to 23 July 1999 and a cumulative rainfall of 48 mm was received during the period enabling sowing of the *kharif* crops in the region. After a gap of one week, monsoon again became active from last day of July and a cumulative rainfall of 147.5 mm occurred in a 4-days long wet spell during the last week of July 1999. The *kharif* crops could be established with this rainfall. After this wet spell, there was a long break in monsoon rainfall for 35 days, which caused water stress during active vegetative stage. A weak monsoon revived from 1 September 1999 and caused scattered rainfall in Bikaner, Hanumangarh and Barmer districts. Thereafter the monsoon had practically withdrawn from the Western Rajasthan. Ultimately, the *kharif* crops experienced terminal drought during the reproductive phase and agricultural production was severely affected in the region. The annual rainfall during 1999 in twelve arid districts of the Western Rajasthan is given in Table 8.

Besides poor distribution of rainfall in the Western Rajasthan, quantity of seasonal rainfall was also below normal in Jalor (-60 %), Ganganagar (-53 %), Sikar (-43 %), Nagaur (-40 %), Churu (-37 %), Jhunjhunu (-32 %), Pali (-27 %), Hanumangarh (-25 %) and Jodhpur (-12%) districts (Figure 2). Remaining two districts viz. Jaisalmer (+17 %), Bikaner (+6 %) recorded normal amount of rainfall during the same period (Table 8). In arid parts of Haryana, monsoon onset was late by about three weeks, which has shortened the growing period for rainfed *kharif* crops in the region. The total seasonal (July-September) rainfall at Hisar was quite low (184 mm), which has adversely affected the agricultural production in the region. Similarly, in Tharad Taluka of Gujarat only 109 mm rainfall was recorded during 1999 against normal rainfall of about 400 mm/annum.

In arid parts of Anantpur (Andhra Pradesh) and Bellary (Karnataka) in the South India, monsoon arrived late and became active from the last week of May 1999. However, total seasonal rainfall received at Anantpur and Bellary was 300 and 274 mm, respectively, which was not adequate for good crop production.

Table 8. Annual rainfall (mm) in the Western Rajasthan during 1999

District	June	July	August	Sept.	Seasonal	Annual
Barmer	44	30	48	7	129	224
Bikaner	16	95	30	11	152	215
Churu	29	83	63	5	182	224
Ganganagar	32	49	6	1	88	148
Hanumangarh	63	98	15	10	186	256
Jaisalmer	17	21	134	0	172	273
Jalor	20	56	59	11	146	252
Jhunjhunu	53	126	41	31	251	302
Jodhpur	33	112	98	7	250	303
Nagaur	23	117	36	35	211	243
Pali	73	185	93	18	369	451
Sikar	51	100	68	13	232	279

Impact of Drought

A sample survey was conducted within the severely drought affected districts in Rajasthan and Gujarat (Figure 3). The number of affected villages were 704 (99 %), 1889 (100 %), 199 (93 %), 1058 (99 %) and 135 (100 %) out of 708, 1889, 215,1072 and 135 villages in the Jalor, Barmer, Jaisalmer (Pokaran sub-division), Jodhpur and Banaskantha (Tharad Taluka) districts, respectively. The impact of current drought on water resources, vegetation, crops, livestock and socio-economic aspects is discussed in the following sections.

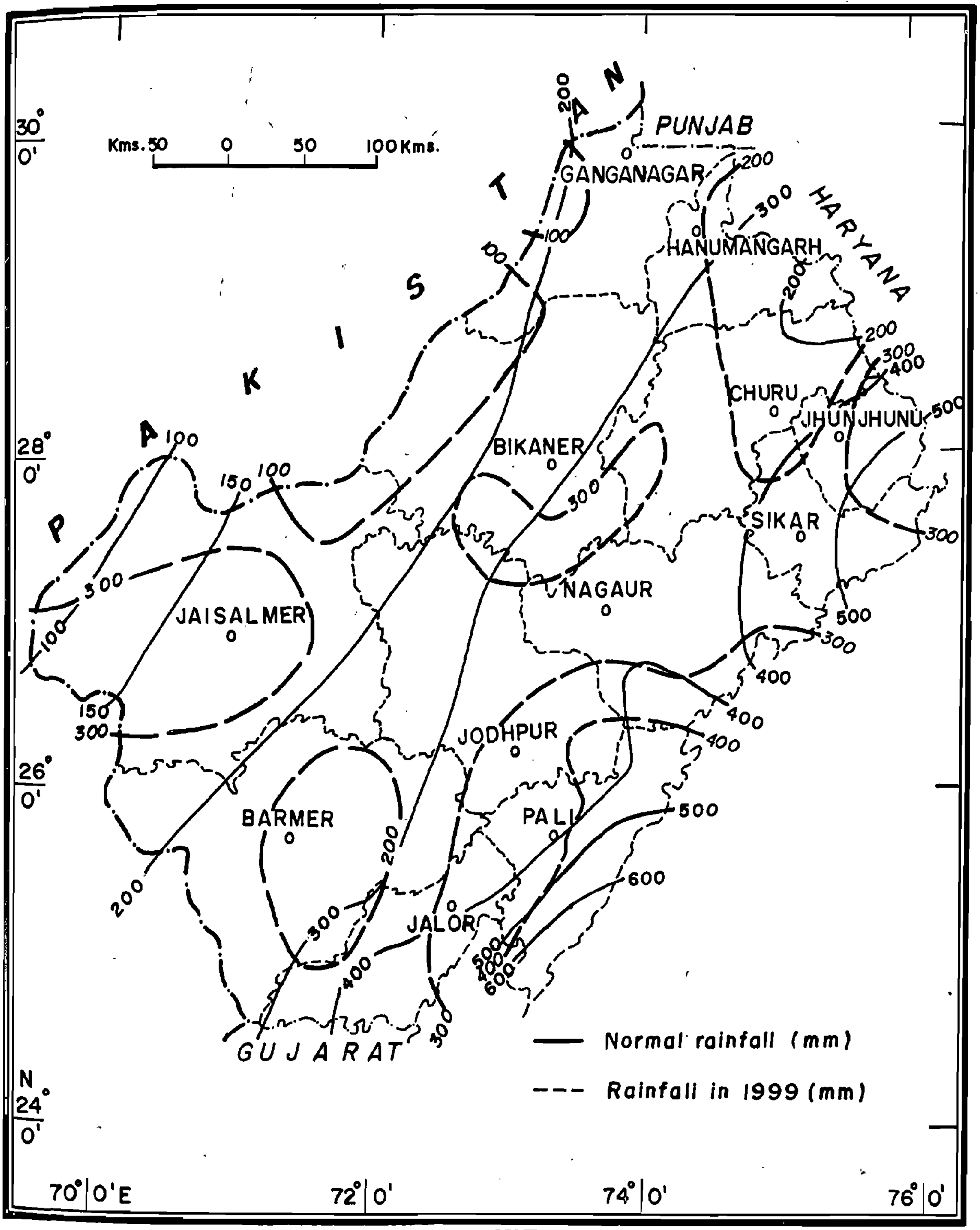


Figure 2. A comparison of annual rainfall during 1999 with normal rainfall in the western Rajasthan

Figure 3. The Rajasthan and Gujarat States

Water resources

All the surface water sources have dried up by February/March 2000 as they received/stored less runoff during the monsoon season of 1999 due to low and erratic rainfall compared to the normal. Since March/April 2000 none of the surface water bodies viz. *Nadis*, *Talaos*, anicuts, check dams, dams, earthen bunds, etc. contained water, when the demand for drinking water was the maximum due to peak summer. All the shallow wells have dried up and the water

Animal and human quenching thrust from the same source at Araba (Barmer)

People have no choice but to use highly saline water from *beri* (shallow well) at Parashar (Jaisalmer)

table dropped by 12 to 15 m in deep wells in the affected area. The quality of groundwater also deteriorated from moderately saline to saline and the concentration of undesirable elements increased to toxic/harmful levels. For example, the concentration of fluoride and nitrate in groundwater samples found to be 15-20 and 800-1400 ppm as against the permissible limits of 2-3 and 20-100 ppm, respectively in the arid regions. In some of the areas viz. Balotra, Jodhpur, Pali, etc., industrial effluents contaminated limited water in streams and adjoining hand pumps affecting livestock and human health alarmingly.

Vegetation

The annual species of desert vegetation are most adversely affected by the current drought, particularly the species, which are grazed by animals. The annual species like *Brachiara ramosa, Indigofera cordifolia, Indigofera linifolia* and *Convolvulus microphyllus* are adversely affected by overgrazing. The perennial grasses like *Cenchrus ciliaris, Lasiurus sindicus, Cenchrus setigerus, Eleusine compressa, Dactyloctenium sindicum* and *Panicum antidotale* are also the victim of drought, mainly due to overgrazing. *Crotalaria burhia* and *Aerva persica,* which are not preferred by sheep and goat, were able to attain relatively better growth. However, as the drought progressed sheep, goat and cattle started grazing the leaves of these weeds also. Because of the scarcity of fodder, the dry leaves of *Crotalaria burhia* and *Aerva persica* are being collected by the farmers for mixing with other available fodder.

Overexploitation of scarce grazing resources

Among the shrubs, *Zizyphus nummularia* was the worst affected species. Its growth was poor due to drought and whatever leaves were produced by the plants became the target of grazing animals, particularly goat. *Capparis decidua* and *Calotropis procera* are frequently browsed compared to the normal season. The drought has worsened the effect of frost on fruit plants, especially the grafted *ber* varieties viz. *Seb, Gola, Mundia,* etc. during the preceding winter season.

The impact of drought is not so pronounced on the trees, because the trees have very deep root system and are well adapted to the arid zone conditions. However, the growth of some tree species like *Prosopis cineraria, Azadirachta indica* and *Tecomella undulata* is adversely affected. *Prosopis juliflora* having a limited utility as fodder appeared to be the least affected by drought. *Prosopis cineraria* proved to be the most useful tree species during the drought, and as a consequence it is overexploited. Its leaves (*loong*) are harvested twice a year (around October-November and April-May) as top feed but the production of *loong* is reported to be only about 75% of that in normal season during winter and about 60 % during summer. The *loong* collected during winter season is of better quality and is preferred by animals compared to the *loong* collected in summer season. The pods of this tree are also collected at large-scale as substitute of green vegetables. In normal years, though the green pods are used as human food, but not at this scale, which are then consumed by animals, both in green and dry form. The production of pods per tree however, is not adversely affected by drought. The drought has impact on flowering and fruiting of *Acacia tortilis*. This tree is reported to shed its pods within a fortnight this year, which otherwise continues for over a month in normal season. This year, the farmers are collecting its pods to feed sheep and goat. The leaves of *Salvadora oleoides* and *Azadirachta indica* were also used as top feed at a relatively larger scale. Some people from the villages near the cities have also resorted to cutting and selling the shrubs and trees to earn money. However, this is done only at small scale and mostly dry trees are cut. Only *Prosopis juliflora* is cut green for this purpose at limited scale.

Crop Production

The *Kharif* crops were adversely affected by drought during the last three years (1997-99) in general, and during last two years in particular. During all the three years, though the rainy season crops were sown in large area, the crops failed in most of the sown area during 1998 and 1999.

The year 1997 was however, better from crop production point of view except in The Jaisalmer district. During this year productivity of rainfed pearl millet crop ranged from 0.21 tonnes/ha in Barmer district to 0.53 tonnes/ha in Jodhpur district. Production of *kharif* pulses, clusterbean and sesame was also satisfactory in the three districts during 1997. Rainfed *kharif* crops failed completely during 1998 and 1999 in Jalor district, Pokaran sub-division of Jaisalmer district in Rajasthan, and Tharad Taluka of Banaskantha district in Gujarat. Situation was also not better in Jodhpur and Barmer districts where the crops failed in large area and the total production of rainfed *kharif* crops was even less than 10% of that obtained in 1997. Hence, 1998 and 1999 may be considered as severe drought years in the region.

The effect of drought was more pronounced on fodder availability as compared to the availability of food grains, which can easily be transported to the drought affected areas from buffer stocks. Similarly, the increase in price of fodder was more pronounced (2-3 fold). This scarcity of fodder reflected in the choice of irrigated crops. The area under irrigated pearl millet crop increased by 212 % in Jodhpur district, 559 % in Jalor district and 1015 % in Barmer district during *kharif* 1999 compared to *kharif* 1997. The area under irrigated clusterbean also increased markedly during *kharif* 1999 (Tables 9-12) obviously at the cost of overexploitation of groundwater.

In normal years, most farmers in the region prefer to take rainfed crops during *kharif* season and irrigated crops during *rabi* season. This practice is followed because of the fact that the groundwater is mostly saline (and/or sodic). Taking rainfed crops during rainy season helps in reducing salt load in soil profile due to leaching with good quality rainwater. But acute shortage of fodder, and to some extent food also, forced them to take irrigated *kharif* crops, particularly the pearl millet. The practice will not only cause declining water table but shall result in lowering of ensuing crop yields due to positive salt balance of preceding crop.

Similarly, the increase in area under irrigated wheat was more pronounced in Barmer and Jodhpur districts (district level data for Jalor not available for 1999) compared to other crops, because wheat straw is also a preferred fodder. This is not a healthy trend for groundwater resources. The farmers of Jalor district also increased the area under wheat during *rabi* 1999, but the yields were very poor (25 to 50 % of 1997) because their tubewells are recharged by ephemeral rivers, and due to scarcity of rainfall during 1998 and 1999, the recharging of groundwater declined substantially. The scarcity of fodder was so severe in Barmer and Jalor districts that farmers had to feed mustard and isabgol straw to their cattle, which is otherwise never fed under normal conditions. Because of the scarcity of fodder, a large number of farmers were taking summer pearl millet crop in as much area as they can irrigate. In normal years, a land race of pearl millet (locally known as *rijka bajri*) is grown in small area to meet green fodder requirements. Increase in area under irrigated wheat and pearl millet for fodder causes tremendous pressure on groundwater, which is fast depleting.

Scarcity of fodder compelled cattle to sustain on unpalatable mustard stover

Cultivation of *rijka bajri* on dune slopes in summer using scarce groundwater at Dhorimanna (Barmer)

Table 9. Area sown, crop failure and production of important *kharif* and *rabi* season crops in Jalor district

Crop		Sown area (ha)			Crop failure (ha)			Production (t)		
		1997-98	1998-99	1999-2000	1997-98	1998-99	1999-2000	1997-98	1998-99	1999-2000
***Kharif* season**										
Pearl millet	Irrig	1818	8654	11976	-	-	718	1301	4878	7881
	R fed	272861	173739	217028	4616	173739	217028	133938	-	-
Clusterbean	Irrig	15	264	523	-	-	-	10	185	366
	R fed	85703	16987	56121	6588	16987	56121	39557	-	-
Mungbean	Irrig	6	155	75	-	-	-	4	96	53
	R fed	45431	28182	38104	4611	28182	38104	24492	-	-
Mothbean	Irrig	-	11	-	-	-	-	-	7	-
	R fed	1121	260	315	7	260	315	445	-	-
Sesamum	Irrig	32	149	109	-	-	-	19	73	55
	R fed	31423	17149	25270	14364	17003	25270	8529	5	-
***Rabi* season**										
Mustard	Irrig	134602	131848	NA	-	1	NA	134602	171401	
	R fed	44341	38404	NA	73	2918	NA	30576	28389	
Wheat	Irrig	43132	44576	NA	8	4	NA	38929	80230	
	R fed	2746	1330	NA	7	710	NA	2186	620	
Cumin	Irrig	47498	42167	NA	-	9357	NA	23749	16405	
	R fed	-	6	NA	-	3	NA	-	1	
Gram	Irrig	1361	7	NA	-	-	NA	1089	6	
	R fed	7753	11955	NA	205	4443	NA	4529	7512	
Isabgol	Irrig	55522	43800	NA	-	-	NA	44417	39420	
	R fed	-	4	NA	-	-	NA	-	2	

Table 10. Area sown, crop failure and production of important *kharif* and *rabi* season crops in Barmer district

Crop		Sown area (ha)			Crop failure (ha)			Production (t)		
		1997-98	1998-99	1999-2000	1997-98	1998-99	1999-2000	1997-98	1998-99	1999-2000
***Kharif* season**										
Pearl millet	Irrig	1144	5511	12753	-	-	1918	333	3216	5897
	R fed	561850	512808	484200	75296	480090	471675	121384	7016	5995
Clusterbean	Irrig	80	879	2593	-	-	316	17	432	636
	R fed	328218	184750	344840	35492	161716	342412	73681	4937	1792
Mungbean	Irrig	23	118	155	-	-	-	5	162	149
	R fed	42762	40524	38157	191	34483	35028	10213	2051	3129
Mothbean	Irrig	4	94	50	-	-	-	1	56	25
	R fed	7379	7812	10367	-	7207	9844	1641	249	70
Sesamum	Irrig	84	83	53	-	-	3	19	58	41
	R fed	13355	5370	4758	308	4816	4644	736	189	112
***Rabi* season**										
Mustard	Irrig	14962	22806	18737	-	-	-	18069	26826	22721
	R fed	368	12241	21	-	-	-	258	5209	21
Wheat	Irrig	12307	16322	19321	-	-	-	10234	14028	18857
	R fed	178	279	9	-	-	-	1010	104	4
Cumin	Irrig	53911	57406	63845	-	-	-	18061	18131	19783
	R fed	-	-	-	-	-	-	-	-	-
Gram	Irrig	-	-	-	-	-	-	-	-	-
	R fed	470	2280	144	-	-	86	283	669	29
Isabgol	Irrig	38611	37165	33075	-	-	-	19978	22998	19354
	R fed	-	-	-	-	-	-	-	-	-

Table 11. Area sown, crop failure and production of important *kharif* and *rabi* season crops in Jodhpur district

Crop		Sown area (ha)			Crop failure (ha)			Production (t)		
		1997-98	1998-99	1999-2000	1997-98	1998-99	1999-2000	1997-98	1998-99	1999-2000
***Kharif* season**										
Pearl millet	Irrig	4062	6323	12676	-	322	25	4874	6001	11464
	R fed	612115	504965	467729	288160	478867	459905	323955	26078	5477
Clusterbean	Irrig	233	1911	6009	-	471	16	210	101	4195
	R fed	153402	101300	190817	100598	97075	187581	36263	2957	1342
Mungbean	Irrig	189	202	139	-	10	2	151	96	82
	R fed	68929	69890	53983	8315	66146	52845	36368	1872	569
Mothbean	Irrig	12	69	123	-	5	1	6	32	73
	R fed	178822	133266	134361	79344	125150	131418	47739	4058	1437
Sesamum	Irrig	149	180	106	18	23	1	105	109	73
	R fed	41842	40589	19120	15325	29683	18700	15910	6543	84
***Rabi* season**										
Mustard	Irrig	73385	75929	75802	1285	7	6	54890	77155	68979
	R fed	10028	4094	280	310	80	-	5359	2846	133
Wheat	Irrig	31870	38746	44480	-	-	-	50236	66245	79898
	R fed	2982	46	20	-	-	-	3942	43	20
Cumin	Irrig	17738	15867	12339	5072	8739	2	10133	4277	7402
	R fed	805	15	-	490	15	-	126	-	-
Gram	Irrig	4	5	15	-	-	-	4	6	18
	R fed	14935	4835	688	-	148	-	8961	4687	688
Isabgol	Irrig	35	18	19	-	-	-	14	9	.9
	R fed	2	-	-	-	-	-	0.4	-	-

Table 12. Area sown, crop failure and production of important *kharif* and *rabi* season crops in Pokaran sub-division (Jaisalmer district)

Crop		Sown area (ha)			Crop failure (ha)			Production (t)		
		1997-98	1998-99	1999-2000	1997-98	1998-99	1999-2000	1997-98	1998-99	1999-2000
***Kharif* season**										
Pearl millet	Irrig	121	145	154	-	-	-	56	57	2
	R fed	97835	72517	44149	97800	72517	44149	1	-	-
Clusterbean	Irrig	1940	5019	19349	-	-	-	34	1416	7744
	R fed	78032	49638	113177	74415	49638	113177	57	-	-
Mungbean	Irrig	145	95	17	-	-	-	21	13	2
	R fed	240	29	46	234	29	46	1	-	-
Mothbean	Irrig	5	1	-	-	-	-	1	0.1	-
	R fed	7	5	-	7	5	-	-	-	-
Sesamum	Irrig	36	18	93	-	-	-	6	2	1
	R fed	866	359	92	864	359	92	0.2	-	-
***Rabi* season**										
Mustard	Irrig	924	1310	2390	-	-	6	542	751	956
	R fed	820	5333	121	-	-	-	439	1754	73
Wheat	Irrig	4130	5735	7711	-	-	-	3257	4519	3856
	R fed	9	52	181	-	-	-	7	36	109
Cumin	Irrig	468	412	347	-	-	-	159	41	37
	R fed	-	-	6	-	-	-	-	-	1
Gram	Irrig	1401	2743	3704	-	-	-	561	1097	1111
	R fed	1	8	-	-	-	-	0.2	.5	-
Isabgol	Irrig	-	-	63	-	-	-	-	-	13
	R fed	-	-	-	-	-	-	-	-	-

Livestock

The current drought has affected livestock the most due to drastic scarcity of water, fodder and feed. Roughage stock of farmers was almost exhausted during 1998. Provision of subsidized wheat straw at different places was observed, but quantity was not sufficient. The goats proved to be hardy and comparatively less affected. However, alopacia and increased incidences of ectoparasitic infestation is prevalent among goats. The present selling price of sheep and goat is Rs. 200/- to 250/-, compared to Rs. 500/- to 1000/- in a normal year.

Most of the cattle are let loose on their own leading to their mortality in some cases. The mortality rate is high in cattle and sheep. The possible causes for livestock mortality during drought are:

- Malnutrition and debilitated weak conditions
- Negative protein balance caused by wheat straw
- Intake of highly saline/contaminated water
- Intake of polythene bags and choking of intestines
- Incidences of various diseases

Large-scale starvation of cattle during drought

Livestock Migration

Livestock migration is a predominant characteristic of arid and semi arid areas of Rajasthan. It is considered to be an ameliorative measure of drought and practiced by livestock raisers since generations. Various groups like Raika, Jat, Seervi, Bisnoi and Gujar of the Hindu community and Sindhi of the Muslim community are the predominant pastoral nomads of the area. According to various studies, the fodder deficit in the Western Rajasthan amounts to 30-50 % in normal years but in drought years becomes alarmingly low. So livestock migration in lean period is a common feature of the area. It has been found that 78 % of the livestock migrated from the Barmer district followed by 70 % from the Jaisalmer and 20% from the Jodhpur districts.

Socio-economic (Rajasthan)

Data on traditions, values, attitude, beliefs, gender differential work participation, occupational diversification, water resources, diseases and relief works were collected on well structured schedules by personal interviews as well as PRA. The primary data collected from selected farm families and secondary data on land use, etc. compiled, analyzed and the following results emerged out:

Impact of drought on land use pattern: It has been found that drought lead to an increase in culturable waste and fallow lands in the four districts of Rajasthan inferring thereby less area under cultivation by the farmers (Table 13). Degenerated lands including forest, hills, pasture and barren lands have not shown any relationship with drought condition, as these lands remained almost same in normal and drought year for all the districts. Net sown area has shown significant decline ranging from 7.89 % in Jalor to 11.1 % in Barmer, conformed by decline in per household net sown area. It shows that farmers were able to anticipate about the drought that is why they have sown less area to minimize the crop losses.

Occupational Diversification: Major shift has been observed in occupational distribution in all the selected districts. Due to drought, agricultural sector is not in a position to provide employment to working population and raw material to agro-based industries. Drought caused under employment to the rural people in this region. Relief works and labour (outside the villages) have been given temporary employment. Further, about 77 % of farmers, with

Table 13. Land use pattern in study districts (Area in ,000 ha)

Land use	Barmer		Jodhpur		Jalor	
	Normal	Drought	Normal	Drought	Normal	Drought
Culturable + fallow land	677	951	761	962	240	314
	(24.03)	(33.76)	(33.73)	(42.69)	(22.73)	(29.73)
Net sown area	1535	1241	1242	1043	626	543
	(54.45)	(44.05)	(55.05)	(46.23)	(59.28)	(51.42)
Rainfed	1497	1185	1243	1042	524	262
	(53.14)	(42.06)	(55.10)	(46.18)	(49.62)	(24.81)
Degenerated land	530	548	178	174	153	153
	(18.80)	(19.45)	(7.89)	(7.71)	(14.48)	(14.48)
Per capita cultivated land (ha)	1.16	0.92	0.89	0.75	0.49	0.24
Per house hold net sown area (ha)	6.42	4.95	5.78	4.85	3.52	3.05
Per capita culturable fallow land (ha)	0.52	0.74	0.55	0.69	0.22	0.30

employment to working population and raw material to agro-based industries. Drought caused under employment to the rural people in this region. Relief works and labour (outside the villages) have been given temporary employment. Further, about 77 % of farmers, with the maximum (88 %) in Barmer and minimum (70%) in Jalor districts, are getting temporary employment through these relief measures. Crop farming and livestock farming, which are the traditional occupation of this area, are replaced by the labour for subsistence.

Consumption pattern and level of self-sufficiency in food grains, fodder and fuel: Consumption of pearl millet has reduced significantly while consumption of wheat has shown an increase over the normal year. It is due to the fact that their limited stock of food grains, primarily pearl millet, has already finished and now they are purchasing wheat from market, there is not much difference in prices of both the grains so the farmers prefer wheat. Secondly wheat is being sold at subsidized rates and gratuity as relief measures. Regarding self-sufficiency in the major consumable articles it has been observed that in all the selected districts there was a deficit in food grains and fodder at farmers level while in case of fuel and milk they are able to manage at their own. The drought hit much harder the population below poverty line as is observed in distribution of relief by the State departments and NGO's.

Income: Amount and sources of income have shown a significant change over the normal period. A drastic reduction in income over the normal years has been observed due to failure of crops. It has been observed that in normal years, in all the study districts (barring Jaisalmer), crop farming was the major source of income providing 42 %, 69 % and 45 % in Barmer, Jodhpur and Jalor districts, respectively while in Jaisalmer district other sources such as labour provided the maximum income (47%). The other major source of income was animal husbandry in all the districts. But in drought year the scenario has changed completely because now the major source of income has became labour, providing income ranging from the maximum 85% (in Jaisalmer) to minimum 70% (in Jodhpur).

Livelihood: As in all the arid regions, crop farming is uncertain due to erratic and low rainfall since it could not provide adequate employment to the people in this region. In that case even in the normal years, some of the people migrate in search of livelihood in neighbouring States. But during drought, situation gets worse, although relief measures provide temporary employment to the people but it is not sufficient, so women get employed and men go out in search of employment. It has been observed that in our study maximum number of people

Human migration seen near Balotra (Barmer)

(10 % of the total population) in Jalor district followed by Jaisalmer (8 %), Barmer (6 %), and Jodhpur (2 %) districts have migrated for livelihood. The migrants are generally of lower caste comprising of Meghwals, Bheel, Harijans, etc. Besides, artisans just like 'Suthar (Carpenter) Kumhar(potmaker) Lohar (iron beaters) Darji (Tailor) have also gone out in search of employment.

Impact of drought on gender work participation: Although in normal years women also play a vital role in arid zone family system yet their contribution in family income increase in drought period as the women, who were mainly confined to households, were forced to work as labourers in relief works. Secondly, their work burden, which indicates fetching water from distant places in scarcity period and collection of fuel wood, increases significantly. Thirdly, as most of the male members of the households go out in search of livelihood, all the domestic works including animal husbandry are to be taken care of by women, so time spent by women in domestic as well as in economic activities increased. The survey reveals that in relief works, in all the districts (barring Jalor), 80 % to 90 % were women as their male counterparts have migrated. Secondly, it is also found that drought has increased the extent and magnitude of tuff jobs for rural women, as in normal year hardly 5 to 15 % of their time is devoted in water fetching, but in drought year it gets increased from 25 % (in Jaisalmer district) to 35 % (in Barmer district). Time allocation in crop and livestock activities is reduced by 30 to 50 % but on the other hand it has increased in water and fuel wood collection. So it can be inferred that drought has increased the work burden as well as drudgery of women.

Changes in social values: It has been observed that cooperation and harmony have increased among the same caste as well as among different caste people to mitigate the effects of drought. Expenditure on socio-religious liabilities, social ceremonies like marriages has declined drastically as opined by more than 80 % respondents. In extreme cases, consideration for selection of bridegroom is available water source nearby rather than cattle heads in a family. No effect on theft was observed in all the districts. About tree cutting, only 20-30 % increase was reported in some of the districts (Barmer and Jaisalmer) to meet out the fuel requirement of the households.

Incidence of diseases: Due to non-availability of adequate food to the rural people, malnourishment is common, which causes outbreak of the diseases in human as well as in cattle. Consumption of polluted/saline water and low protein fodder, are added causes of diseases outbreak in cattle. In our study few cases of heatstroke, diarrhea and vertigo have been observed. The severity is not very high but if adequate measures are not taken up in time it may increase. Shortage of proper medical facilities have also been reported, although most of the villages are having Primary Health Centers but still it is not sufficient so the people have to go to cities in case of severity.

Socio-economic (Gujarat)

All the 135 villages in the Tharad Taluka are affected by drought and scarcity. The information regarding the sample villages shows that the area is mainly rainfed as 68.9 % land is unirrigated and only 17.7 % is irrigated. Literacy rate of male is 44 % and of female is 14.7 %. Rajputs, Patels and Muslims dominate the caste structure. Sources of drinking water are tube well, *Tanka* and open well and the villages are connected by dirt roads.

Occupational diversification: Due to drought there is shortage of basic employment in agriculture so the people, who were workers in normal years, have come in the category of non-workers from 30 % to 25 %. Further, work force engaged in agriculture (40 %) reduced (12 %) and they all are working as labourers in relief works.

Consumption pattern and level of self-sufficiency: In the study area pearl millet is the major food grain crop and its consumption has reduced at a significant level due to shortage at farmers level. In normal year, the farmers are self-sufficient (100 %) in case of food grains but now only 25 % of the total requirement is fulfilled by their own stock. Rest is to be purchased from the market. The same is the situation in case of fodder. Only in case of fuel they are able to fulfill their requirements up to 75 % at their own level.

Income: Significant changes in the amount of income and sources of income have been observed. In normal year, on an average, annual income is about Rs 38,000/- per family while in drought it remains only at Rs 20,000/- per family i.e., about 49 % of their income has reduced. Besides, primarily crop farming was the major source of income but in drought labour has become major source of income.

Migration (livestock and livelihood): In the study area of Gujarat livestock migration is comparatively less, only small ruminants have migrated while the cows of Rajasthan State are immigrating in this area. Migration of people for livelihood is a common phenomenon for these people and in drought about 20 % of the total population has gone to the neighboring States or to other industrial cities in search of livelihood.

Impact of drought on gender work participation: Although women of this area are also playing a vital role in their household economy still their position is better than in the Rajasthan State. They are not as much burdened. The women of weaker sections of society are working at relief works and other works yet their percentage is low (about 50 %) as compared to the Rajasthan State.

Changes in social values: Not much significant difference in the change of social values of Rajasthan and Gujarat States has been observed. The only difference is cutting of trees, which is more in Gujarat compared to Rajasthan. Besides, expenditure on social functions like marriage is also somewhat more in Gujarat compared to Rajasthan.

Relief Measures Undertaken

The periodic droughts and scarcity in the Indian arid zone have been the topic of attention of administrators and policy makers for the past 150 years. The problems caused by drought/famine were faced with fair amount of competence and dedication. However, the approach was essentially that of starting *ad hoc* relief works, as per famine code, to provide employment to the distressed population rather than having the long-term perspective for improving the conditions in the region and to reduce the impact of drought. This approach did not prove effective in mitigating the drought conditions. It was only since 5th five-year plan that a long-term view was taken for evolving technological and organizational innovations, which were accepted as the strategy for integrated development of drought prone areas. At present, the main objectives of relief works undertaken during a drought period are:

- Distribution of essential commodities such as water, fodder and food at subsidized rates, sometimes under 'food for work' Programmes.
- Optimum utilization of resources in the affected areas with emphasis on primary resources viz. land, water, vegetation, livestock, manpower, etc.

- Improvement in terms of living conditions of the rural poor below poverty line who suffer most due to scarcity and drought in particular, and the community in general by creating direct and indirect wage employment and taking up short gestation programmes of development.

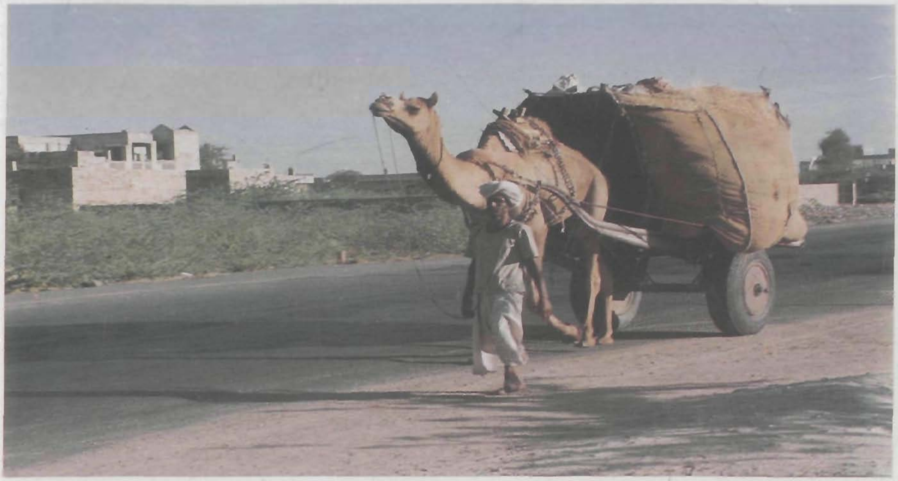
Renovation of *Nadi* as a relief measure at Mandoli (Jalor)

To relieve the suffering of human and livestock, relief measures are being undertaken by the State Governments of Gujarat and Rajasthan, and NGO on a large-scale. Based on the sample survey, Tables 14 and 15 depict the type and extent of relief measures undertaken in the region to relieve the adversity caused by the current drought. These measures could have further multiplied with conscious efforts of press and media and policy makers at State and Central level.

Fodder depot under operation at Kavas (Barmer)

Table 14. Type of relief measures undertaken in the sampled districts (as on 01 May 2000).

Relief measures	Remarks
A. Wage employment	
1. Development of water resources	a. Renovation of *Nadi*, well, *Baori*, *Talao, etc.* b. Repair of anicut, check dam, *Khadin*, dam, earthen bund, flood protection bund, etc. c. Canal desilting
2. Construction of road	Earthen/murrum/gravel roads: only incomplete roads/works left since 1998-99
3. Infrastructure development	Construction of shops, schools, *Piaos*, Panchyat and community buildings under various Centrally/State sponsored schemes (only labour component)
B. Provision of drinking water	
1. New groundwater sources	Sinking tube wells, hand pumps, etc.
2. Repairing of existing groundwater sources	Repairing hand pumps, pump sets, electric connections to wells/tube wells
3. Drinking water supply through water tankers	The water is supplied through road and railway tankers @ 5 l per person per day. This supply is restricted to villages having no water source in 1.6 km radius. 100 % subsidy on diesel and lubricating oil.
C. Livestock management	
1. Supply of feed and fodder	Wheat/rice/gram straw, sorghum, grass, etc. is supplied through fodder depots at subsidized rate; subsidy on fodder @ Rs. 600 per tonne
2. Livestock camps	Special livestock camps have been opened supporting about 50,000 animals, subsidy @ Rs. 10 per cattle and Rs. 5 per sheep/goat
3. Subsidy to approved Gosala	@ Rs. 10 per cattle and Rs. 5 per sheep/goat
4. Health care	Control of diseases, vaccination, treatment of diseases
D. Public Distribution System	
1. Distribution of sugar	@ 400 g per head per month; Rs. 13 per kg
2. Distribution of wheat	For BPL @ 40 kg per family per month and for APL @ 20 kg per family per month; Rs. 5 per kg
3. Distribution of Kerosene oil	@ 8 l per family per month in urban and @ 4 l per family in rural area; variable rates as per distance
E. Human health care	
1. Preventive measures	Preparedness at health centers, establishment of control/monitoring cells, water purification, quality control of food items, general cleanliness and hygiene
2. Treatment of diseases	Gastroenteritis, jaundice, cholera, sunstroke, hepatitis B, malaria, measles, etc.



As a relief measure about 200 kg wheat straw is given at subsidized rate to each family

Table 15. Extent of relief measures undertaken in the surveyed area (as on 01 May 2000).

District	No. of approved works	Sanctioned man days*	Amount (Rs. In lakhs)	No. of road tankers employed	No. of fodder depot sanctioned	Fodder supplied/ sold (t)	No. of cattle camp sanctioned
Jalor	1033	NA	300	3	27	505	NA
Barmer	1358	99382	3427.42	28	321	12197	50
Jaisalmer (Pokran sub-division)	185	7980	178.43	8	32	3522	12
Jodhpur	1077	69055	2148.65	16	233	9601	61
Banaskantha (Tharad Taluka)	31	11191	58.30	2	4	1800	Nil

* Employment is given to at least one member in a family. Minimum wage in Rajasthan is Rs. 25/- /head/day.

STRATEGY FOR COMBATING DROUGHT

Early Warning and Drought Monitoring

Drought in the Indian arid zone can be monitored from the progress of onset and withdrawal of the Southwest monsoon. Quantum and rainfall distribution are two key factors, which determine the crop production. Weather forecasts broadly can be classified into three categories viz. (1) short range forecast (validity for less than 3 days), (2) medium range forecasts (validity from 3-10 days), and (3) long range forecasts (validity from 10-30 days). These forecasts are issued by the India Meteorological Department and National Centre for Medium Range Weather Forecast (NCMRWF) and broadcasted through All India Radio, Doordarshan and various Newspapers.

Central Arid Zone Research Institute, Jodhpur has started issuing agro-meteorological advisory service to farmers of Jodhpur and surrounding area with effect from July 1998. This agro-meteorological bulletin is issued every Tuesday and Friday based on the medium range weather forecast received from NCMRWF, New Delhi. This bulletin is also released to all local daily newspapers on the same day. It includes different agricultural operations to be performed under the anticipated weather conditions. This medium range weather forecast is given for eight meteorological parameters viz. cloud cover, precipitation, wind speed, wind direction, maximum and minimum temperatures, and maximum and minimum relative humidity. Validation of forecast is also done for weather of next 24 to 72 hours from the time of issue. These forecasts are given for the benefit of farmers for planning their agricultural operations and for planners for advance planning in case of an anticipated flood or drought.

Long-range Forecast

It is in purview of IMD and accurate oceanographic pre-monsoon conditions. Besides, date of onset and withdrawal of monsoon, accurate forecast about amount and distribution of rainfall in ensuing *kharif* season would be of great value for planners as well as farmers to develop contingent plans, rather a all season weather coat, for drought as well as floods. IRS P-4 satellite with *Oceansat* OCM, MSMR sensor may prove of great value in studying ocean situation. Great emphasis is to be laid in future on long-range forecasts to combat drought.

Contingency Crop Planning for Drought Proofing

Several technologies were developed and tested by Central Arid Zone Research Institute, Jodhpur to increase crop production under aberrant weather conditions in the Indian arid region. Often variability in the Indian monsoon influences the risk in crop production and therefore the cropping strategies should be based on the availability of monsoon rainfall from year to year.

When a severe drought is preceded by a consecutive drought for 3 to 4 years followed by unfavourable monsoon conditions, it is difficult to support any cropping system due to fast depletion in groundwater levels. Southwest monsoon is the main water source for crop production in the Indian arid region. Varying behaviour of monsoon might result in following four general climatic settings:

1. Normal onset of monsoon followed by normal rainfall
2. Normal onset of monsoon followed by inadequate rainfall
3. Late onset of monsoon followed by normal rainfall
4. Late onset of monsoon followed by inadequate rainfall

The cropping strategies for each of the rainfall situations are given below:

Normal onset of monsoon followed by normal rainfall
Arable farming is favourable under normal monsoon conditions. The crop growing period in such conditions varies from 90 to 120 days. Cereals like sorghum, pearl millet, maize, pulses like cowpea, mungbean, blackgram, and oilseeds like sesame, castor and groundnut with high density planting followed by leguminous/fodder crop can be grown with reasonably good returns.

Normal onset of monsoon followed by inadequate rainfall
In case, rainfall is not adequate after sowing crops like pearl millet, pulses, etc, mid-season corrections like reducing plant population (thinning), spraying anti-transpirants like kaolin, weeding and creating soil mulch are some of the strategies which can be adopted to reduce drought effects.

Late onset of monsoon followed by normal rainfall
Selection of short-duration varieties is an important strategy to over come this kind of drought situation under late onset of monsoon. The crop growing period in such situations varies from 40 to 60 days only. Pearl millet (variety CZP-9401, ICMV-155, CZH-859), mungbean (variety S-8, K-851, P-9075), clusterbean (variety Maru) etc. are some of the drought tolerant crops and are performing well even in moderate rainfall conditions.

Late onset of monsoon followed by inadequate rainfall
Under late and low monsoon conditions crops like clusterbean, moongbean, cowpea, mothbean (variety CAZRI Maru-1), sesame and other leguminous crops perform well. These mature in short duration and give good yields.

To avoid risk from such aberrant weather conditions, mixed/intercropping is advisable, so that if the rainfall pattern is not suitable to one crop, it may be suitable to the other crop and hence farmers can get a crop insurance against the weather adversaries. Recommended mixtures are: pearl millet-clusterbean, pearl millet-mungbean and pearl millet-cowpea.

Integrated Watershed Management
So far development programmes were planned and implemented by taking the revenue district as a unit. However, this unit was often found to be unwieldy and also, to a large extent, heterogeneous in its resource endowments. The strategy under the DPAP, therefore, envisaged to a significant departure from this practice by adopting watershed as the unit for integrated planning and implementation. To utilize the rainfall wherever it falls and flows, a watershed is the key element of integrated watershed management. The watershed is claimed to be the most scientific unit for efficient management of land and water resources as it is basically an agro-climatic unit with relatiyely more homogeneity of land and other resources as compared to the revenue district. A suitable size of watershed can be selected for making concentrated efforts and for easy management. A land capability survey is undertaken to prepare a soil use map. Other basic information should also be collected through hydrological, vegetation, socio-economic and site specific surveys to fully ascertain the status of land and water resources of a watershed and the human and livestock pressures on them. According to the survey findings, measures like afforestation, pasture development, livestock management, field crops, water storage, etc. are undertaken in the areas identified as suitable for such measures. Suitable soil and moisture conservation measures like contour vegetative barriers, tillage, mulching, and shelterbelts and wind strip cropping along with cropping strategies will minimize the risk due to drought. Rainwater harvesting techniques are also to be

employed for successful crop production, runoff storage and recharging groundwater by adopting the latest technologies.

An approach of 'index catchment' recommended by Central Arid Zone Research Institute, Jodhpur and Integrated watershed management plays a key role in fighting drought conditions. This approach ensures planning on the basis of the total available water resources, conjunctive use of surface and groundwater, allocating priority for rational use of water and also the preparation of a coordinated plan. Thus, watershed management holds the promise of conservation of land and water resources and their optimal utilization in reality.

Rainwater Harvesting for Drinking

With the present rate of increasing demand for water, the Western Rajasthan is likely to face a deficit of about 2500 million m^3 by the year 2010. Adopting the proven rainwater harvesting methods and evolving new and innovative water resources development techniques for utilizing the excess rainfall/runoff during the surplus years is a key to meet a greater portion of this deficit.

Rainwater harvesting is traditional way of life in arid regions. In the Western Rajasthan it is an age-old practice in the form of harnessing meager runoff in different forms like rooftop rainwater harvesting, *Nadis* (village pond) and *Tankas* (underground cistern). These systems of rainwater harvesting have helped in mitigating the drinking water problem in the region where low and erratic rainfall and saline groundwater are the realities, while complementing the groundwater recharge.

Rooftop Rainwater Harvesting

Rooftop rainwater harvesting comprised of the rooftop as the catchment's area, connected by gutters and pipes to a storage tank. Rooftop rainwater harvesting is used traditionally in most part of the Indian arid zone (Sharma, 2000). This system provides an on-site source of water supply next to homes or public buildings. In the Western Rajasthan, all the old buildings, forts and palaces have rooftop rainwater harvesting systems. However, with the advent of piped water supply, the rooftop rainwater harvesting technique has been neglected. It should be made mandatory by the town planners to harvest rainwater for drinking and household uses of a family.

Rainwater yield from rooftop surfaces depends upon the type of roof and material used in its construction. The most suitable rooftop surfaces are corrugated iron sheets, tiles, asbestos sheets, stone slabs and lime concretion. Thatched roofs pose problems as the runoff is less and generally of low quality.

The rooftop should be smooth, made of nontoxic substances, and sufficiently large to fill the storage tank with the available rainfall conditions. Existing rooftops of houses and public buildings can be used for a rooftop catchment's system. In some cases, enlarged or additional roofed structures may be built. The function of guttering is to protect the building by collecting water running off the roof and direct it via a down pipe to the storage tank. A range of material is used for water tanks including polythene, galvanized iron, brick, stone, masonry, reinforced concrete and ferrocement. First 20 to 30 l of rainwater of the season, which contains large quantities of leaves and bird droppings, should be discarded to keep the water potable. Rooftop rainwater harvesting system requires good periodic management and maintenance to ensure that the quality and reliability of the water supply is high. The system could also be utilized for groundwater recharging through abandoned wells and injecting in abandoned hand pumps. Required technology is available with Ground Water Boards for such purpose. The rooftop rainwater harvesting in urban areas should be made mandatory for approving a house plan by development authorities for utilizing runoff for household purposes and groundwater recharging.

Nadis

These are small excavated/embanked rainwater harnessing structures to mitigate the scarcity of drinking water. Water from *Nadis* is available from two months to a year after rainfall, depending on the catchment's characteristics. the amount of rainfall received and its distribution. The traditional *Nadis* suffer with heavy sedimentation, high evaporative and seepage losses, and water pollution thereby limiting proper utilization of stored water. Traditional way of maintaining *Nadis* by community efforts as common property resource might solve drinking water problems to a great extent. On the average, sediment deposition in *Nadis* varies from 2.7.to 18.4 m^3/ha/year. The loss of water through evaporation varies from 1500 to 2473 mm/year, whereas the same through seepage varies from 666 to 1493 mm/year under different physiographic conditions. *Nadis* have been very powerful systems for groundwater recharging.

The recommendations of Central Arid Zone Research Institute, Jodhpur for development of *Nadis* and optimum utilization of stored water are as follows (Figure 4):

(i) Sediment input to *Nadis* can be reduced appreciably by constructing silt traps at the inlet.
(ii) Optimizing the depth in relation to impermeable soil layer and surface area could minimize the evaporative and seepage losses.
(iii) To minimize the pollution of water, the entry of animals and human beings into the *Nadis* must be restricted. Use of catchment's areas for the purpose of defecation by the villagers and movement of livestock must also be checked.
(iv) To prevent the seepage losses, lining in beds of *Nadis* may be done, if expenditure permits. Many a times sides of *Nadis* are made as *pucca* wall, which is a wasteful expenditure.

Tankas

The underground *Tankas* are traditional water sources in the Indian desert up to 300 mm rainfall zone and the water from these is used for human drinking. These *Tankas* are constructed on individual household basis or on community basis since ancient time (Vangani *et al.*, 1988). The traditional *Tankas* are temporary structures and are subjected to leakage from bed and sides. Moreover, their catchments are not commensurable and thus, low volume of runoff is being harvested even during the average rainfall year. Further, stored water is subjected to seepage and evaporative losses, and water pollution. These problems could be minimized through the adoption of improved designs prepared by the Central Arid Zone Research Institute, Jodhpur (Figure 5).

A dependable annual rainfall of 130 to 250 mm (at 60% probability), and a catchment's area of 420 to 780 m^2 can meet the drinking water demand for a family of 6 persons throughout the year. The catchment needs to be impermeable and smooth for harvesting reliable volume of runoff. However, perfect sealing of the soil surface is expensive and some infiltration losses must be accepted. In several situations ground sealing increases the runoff yield by improving the hydraulic efficiency of the catchment. Several experiments on use and efficiency of different sealing materials have been carried out in different countries. The experiment conducted at Central Arid Zone Research Institute, Jodhpur on use and efficiency

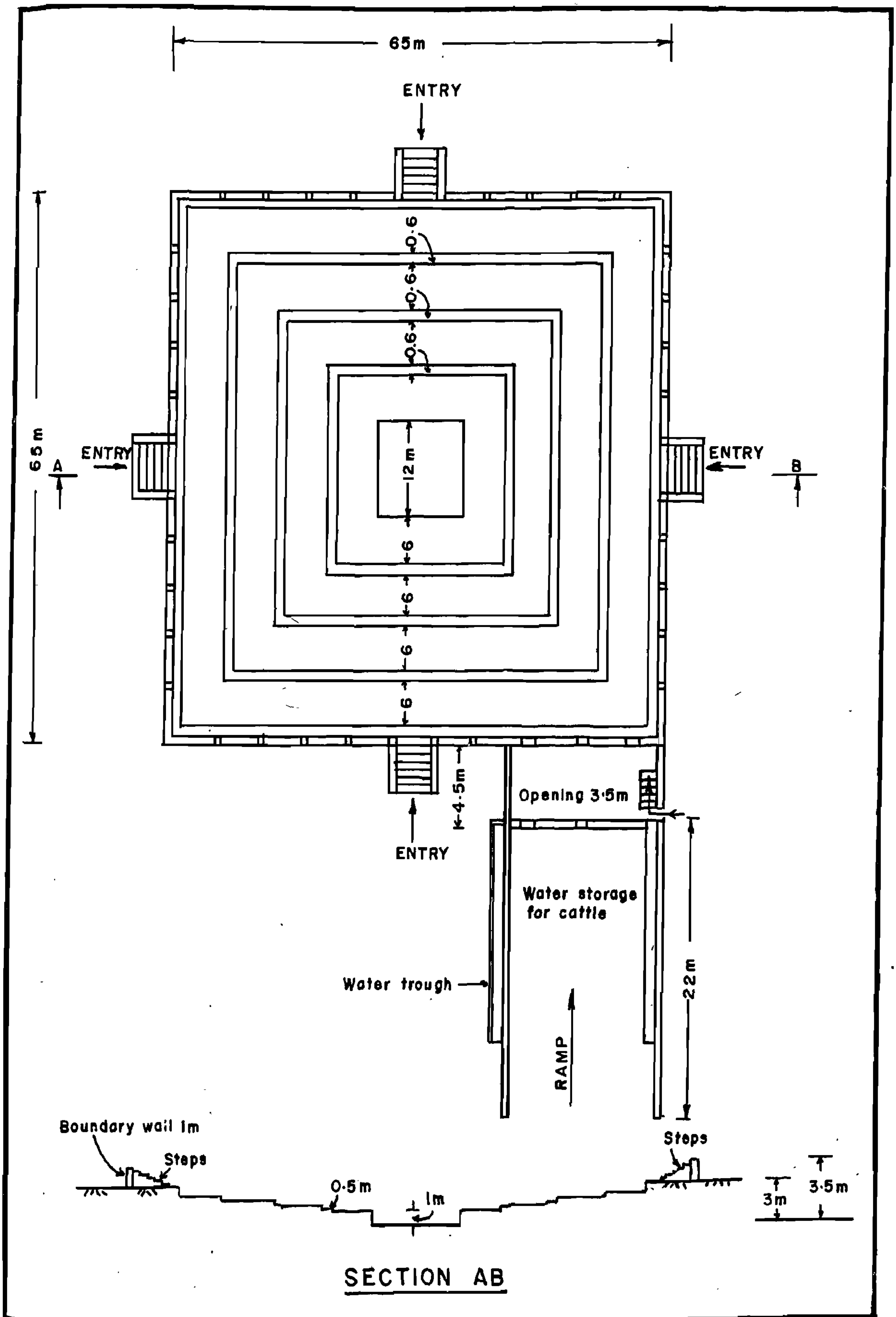


Figure 4, Design of an improved *Nadi*: capacity 4000 m^3

Design of an improved *Tanka* for a single family: capacity 21 m^3

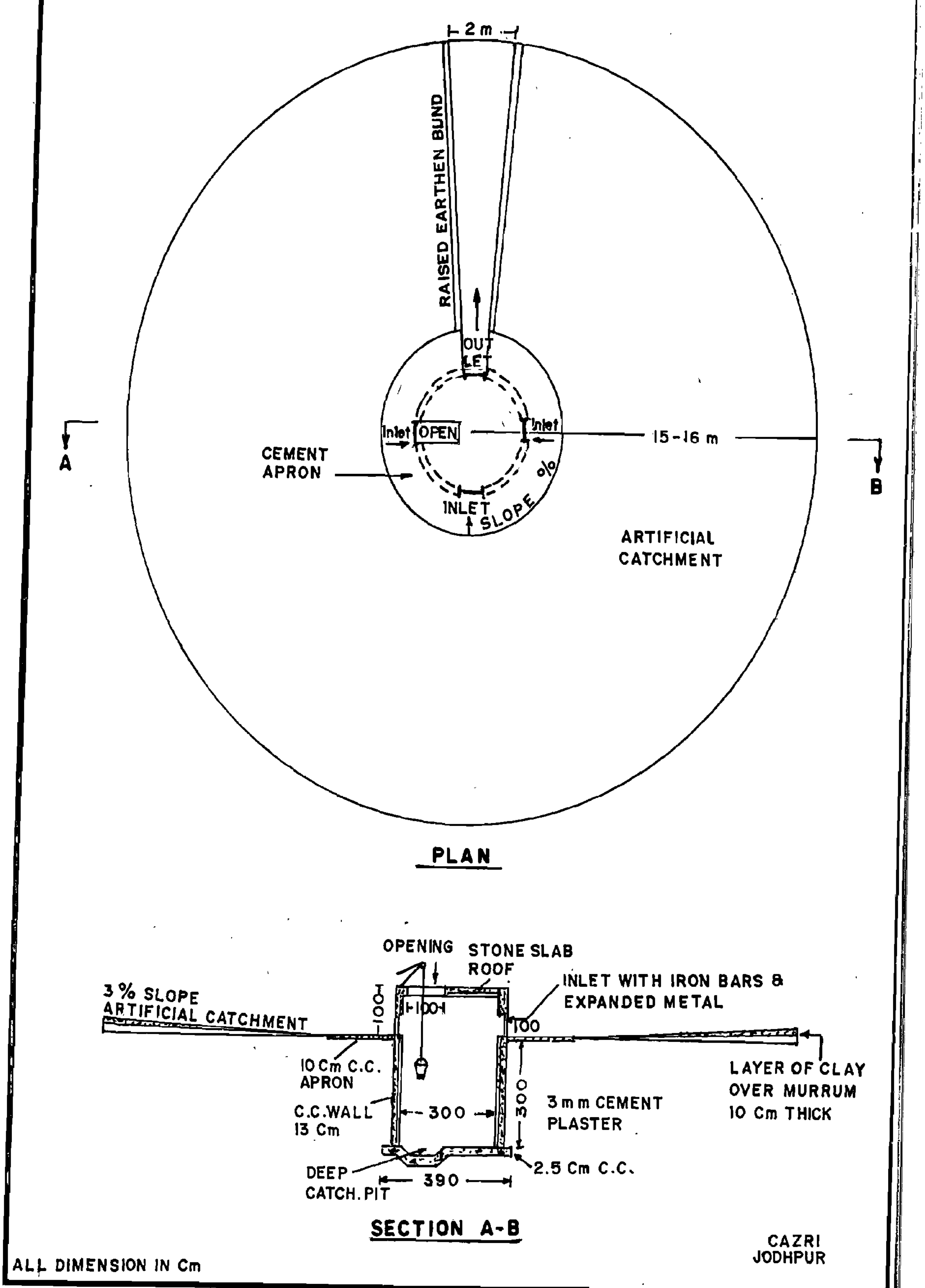


Figure 5,

of different sealing materials indicated the efficacy of spray of sodium carbonate @ 1 kg/10 m^2 as efficient and cheap. It generated 66 % of rainfall as runoff up to a period of four years (Murthy *et al.*, 1978).

The important constructional features are as follows: (i) circular in shape, (ii) diameter equal to depth, (iii) construction with stone masonry in cement mortar, (iv) stone slab roofing, (v) cemented apron around the tank with 3 % inward slope, (vi) silt collecting gutter, (vii) three inlets and one outlet, and (viii) inside surface fully plastered.

In-situ Utilization of Rainwater

In-situ moisture conservation and inter-plot rainwater harvesting for crop production have been in vogue for arid regions. Studies on *in-situ* rainwater harvesting at Central Arid Zone Research Institute, Jodhpur revealed that ridge-furrow system (60:40 cm) and micro-catchments of 4 % slope resulted in 210 and 120 % higher yield of pearl millet, respectively than the regular flat planting (Singh, 1973). The Inter Row Water Harvesting System (IRWH) maintained higher soil moisture storage throughout the growing season as compared to planting on beds and flat planting (Anonymous, 1979). The surface runoff varied from 7-15 %, being highest in flat planting system followed by bed planting and IRWH. Singh (1978) reiterated the importance of tree crops in utilizing the moisture stored in sub-stratum and suggested the trees to be grown under runoff farming. The results of studies on runoff farming (Sharma *et al.*, 1982, 1986) for Jujube (*Ziziphus mauritiana)* are summarized below:

- The runoff concentration results in the storage of bulk of rainwater within the deeper soil profile.
- Catchments area of 31.5 m^2 with 5 % slope is adequate for optimum rainwater harvesting in jujube orchards.
- In normal and high rainfall years receiving 300 to 500 mm monsoon rainfall, 2 m deep soil and sub-stratum profile with runoff catchments contained twice the soil moisture compared to control. In low rainfall year receiving 200 to 250 mm monsoon rainfall, 1 m soil profile maintained 40 to 60 % higher moisture storage than control. Effectiveness of the micro-catchments water harvesting technique in all types of rainfall regime is thus revealed.
- Length of run on catchment's slope should be kept as minimum as possible. This will give less opportunity time for rainwater infiltration within the catchments; the contribution of runoff to the planting zone would be greater.

Further, it was suggested that conversion of only the canopy area into runoff catchments might serve the objective of obtaining the required soil profile recharge. Sharma (1986) observed that due to crust forming nature of the sandy soils, the natural catchments get sufficiently crusted and stabilized during 2 to 3 seasons. Thus, the use of artificial sealants for augmenting runoff from the natural catchments may not be required. Similar, results were obtained by Singh (1988) also for the pond silt treated catchments.

Looking to the high cost of construction of bigger catchments, Gupta and Muthana (1985) developed circular catchments of 1.5 m radius and 2 % slope as runoff areas. The technique proved efficient for improving the moisture regime in the plant root zone. Growth and establishment of tree saplings was significantly higher in the treated plots.

For imparting yield stability to crops. Singh and Gupta (1989) suggested the following runoff farming techniques: (a) *in-situ* water harvesting from artificial micro-catchments having a catchment's to cropped area ratio of 0.5, (b) IRWH by ridge and furrow configuration, and (c) micro-catchments water harvesting from 50 cm wide catchments into cropped area of the same width. Singh (1988) found the catchments to cropped area ratio of 0.5 as optimum for the type of soil, climate and surface sealing with pond silt.

Khadin

Nearly 8 % area in the Western Rajasthan is rocky/gravelly, generating runoff in response to intense rainfall. This *in-situ* rainwater harvesting practice is known as *khadin* cultivation in local parlance. It is somewhat similar to 'Haveli' cultivation in the Bihar State. This practice dates back to several centuries and is being followed in 100-200 mm rainfall zone in the Indian arid zone. Entire runoff and sediment is conserved *in-situ*. The runoff is harvested in contiguous farm lands by constructing earthen bunds across the gentle slope of the land in the valley bottom to facilitate spreading and standing of harvested water on the farm soil. Water is thus made to accumulate to a depth of 60 to 90 cm. This water seeps into the ground and recharges the adjoining wells as well as groundwater. Besides, on conserved moisture cropping is done during the *kharif/rabi* season, depending upon the depth/amount of accumulated runoff. Cropping is started from upper reaches to lower reaches on receding water situation. The *khadins* can be replicated on a vast scale at appropriate places preferably in heavier soil areas – sandy loam onwards. So much so that with this technique the present cropping intensity /single *kharif* crop can be doubled in many situations.

At present in most of the *Khadins* local varieties of crop is grown and the fertilizer use is negligible. There is thus considerable scope to improve upon the system to increase production by agro-horticulture and agro-forestry systems. This technique requires a cropland in proximity to a rocky catchment, and is therefore site specific (Kolarkar *et al.*, 1980). The catchment to command area ratio varies from 11.27, 8.22 to 2.22 in 217, 240 and 310 mm rainfall zones, respectively.

Utilizing Flash Floods for Artificial Recharge of Groundwater

On an average in a five years period, there is an excess rainfall year when at localized places the annual rainfall exceeds 200 % of the normal long-term average rainfall. Since 1917 there have been 15 flash floods of moderate to severe intensity in various parts of the region, each generating about 3500 million m^3 of runoff in a short span of 5-7 days. This colossal amount of water, out flowing as flood water to the ephemeral river system and finally to the Rann of Kachchh, if harvested, is adequate to meet the water demand of entire human population (19.81 million) in this region for about 13 years.

By all possible means, it is advisable to harvest nearly one-third, i.e., about 1200 million m^3 of flash flood for the human consumption. This water could be used as follows:

1. Ground water recharge : 12 million m^3
2. Human/livestock drinking : 509 million m^3
3. Evaporative losses : 153 million m^3
4. Irrigation (@ 0.3 m per ha) : 90,000 ha

Greater emphasis should be placed on multiplying the recharge structures such as anicuts, check dams, diaphragm across the stream flow, percolation tanks, injection wells, ponds and surface storage structures to enhance the artificial recharge of groundwater.

Development of Localized Water Resources

The rocky/gravelly areas in isolated patches constitute about 15,600 ha in the region. In an average rainfall year, this area generates about 22.5 million m^3 runoff with following disposition:

1. Recharge to groundwater : 3 million m^3
2. Storage in *nadis*, *tankas*, etc. : 4.9 million m^3
3. Evaporation losses : 1.5 million m^3

The rest 13.1 million m^3 disappears in the adjoining blown sand and deep alluvium as a soil moisture storage. These areas are utilized for cropping on conserved moisture during the *rabi* season in localized patches. In this way at least one crop is assured. It is proposed to identify more such locations for better utilization of conserved moisture and increasing cropped area.

The above water resources development programme should form the focal projects under DDP/DPAP in the region. Utilizing the excess rainfall during surplus years will not only mitigate the flash floods but also provide the scarce water in the normal/drought years. The surplus water is going waste at present, which is the most valuable resource in the arid lands.

Water Conservation Measures

Contour Bunding

By far the conservation and utilization of surface water should continue to be the chief method of development in the Indian arid zone. In order to secure uniform soaking of the rainwater and to prevent the loss of rainwater by surface runoff, Kanitkar (1944) proposed universal contour bunding to be constructed by means of cattle drawn implements. Bunds of 0.3 to 0.6 m height were found to be sufficient for sandy soils. The bunds must be placed in a series from ridge to the bottom of a valley, one below the other, to form terraced slopes. However, the natural surface drainage should be maintained and used for occasional overflow of water along bunds. It was observed that 25 mm of rainwater could penetrate 13-15 cm depth for future use by the growing crops. Tamhane (1952) observed that at certain places in the desert region, i.e., in the Southeastern portion of Rajasthan, desert streams, rivulets and rivers carry a good deal of water in the rainy season, often to waste. He suggested that the beds of such streams and rivers should be bunded with small earthen bunds, check dams, etc. and existing tanks should be deepened so that water might percolate through the sandy soils along the banks and supply waters to wells nearby. Wasi Ullah *et al.* (1972) conducted an exhaustive study on the performance of contour furrows and contour bunds in grasslands in the Western Rajasthan. They observed that the contour furrows alone, on an average, stored 39 % more soil moisture than the contour bunds alone (27 %) and combinations of the contour furrows and contour bunds (26-32 %). The higher soil moisture resulted in 14 to 181 % increase in the fodder yield.

Contour Furrowing

Contour furrows have been extensively used in the Indian arid zone as a measure of moisture conservation as well as economical and quick alternative for soil preparation for better establishment and growth of grasses. Verma *et al.* (1977) recorded the highest soil moisture at the centre of the furrow throughout the season. The mean soil moisture storage at the middle of the ridge, top of the mound and at centre line of the horizontal spacing followed a similar pattern of moisture accretion and depletion, and were non-significantly different among themselves. Sharma et *al.* (1980) recorded the significantly higher soil moisture at the centre of furrow and at the middle of ridge than at top of mound and centre line of horizontal spacing and observed the highest depletion and low peak retention at the centre of furrow and top of mound, respectively. The middle of ridge recorded the highest plant population, dry matter production and precipitation use efficiency over a period of two years in the arid regions (Sharma *et al.*, 1983).

Contour Vegetative Barriers

Biological measures such as contour vegetative barriers of suitable grasses, shrubs and trees offer cheap productive cum protective measures in place of earthen structures (Narain *et al.*, 1998) for conservation of runoff and sediment *in-situ*. Sharma *et al.* (1997) designed contour vegetative barriers (CVB) to replace the traditional soil and water conservation measures such as contour bunds in arid regions. In general locally adapted, native, fast growing perennial grasses with extensive root system such as *Cymbopogon jwarancusa, Cenchrus ciliaris* and *Cenchrus setigerus* transplanted 0.30 m apart on contours at 0.6-1.0 m vertical interval form a dense hedge in a two year period against soil erosion and conserve soil moisture. In a four year study the runoff volume was reduced by 28 to 97 %. Also the CVB fields stored about 2.5 times more soil moisture than control. In CVB fields the grain yield of clusterbean and pearl millet increased by 37 to 51 % and by 19 to 40 % over control, respectively.

Reducing Deep Percolation Losses

To minimize loss of rainwater or irrigation water through deep percolation in sandy soils an array of technologies have been developed. Some of these are: (a) use of sub-surface barriers of asphalt (22 mm layer), bentonite (5 mm layer) and pond silt/clay (5 mm layer) at 60 cm depth in the profile (Gupta and Aggarwal, 1980; Gupta and Muthana, 1985), (b) use of amendments such as pond silt, vermiculite, etc. for increasing soil moisture storage (Gupta *et al.*, 1979), and (c) use of organic or inorganic mulches (Singh and Gupta, 1989). These techniques increased the moisture storage capacity of sandy soils by 50 to 60 % for pond silt, 60 to 70 % for bentonite and up to 100 % for asphalt. The mixing of pond silt up to 30-40 cm soil depth @ 76 tonnes/ha increased the available water storage capacity from 6.5 to 6.9 %, reduced the infiltration rate from 15 to 13.2 cm/ h and increased the yield of pearl millet by 40 to 50 % over control. Use of vermiculite @ 20 tonnes/ha increased the 0.1 bar moisture retention from 10.3 to 12.4 %, reduced the saturated hydraulic conductivity from 8.6 to 6.5 cm/h and bulk density from 1.62 to 1.57 g/cm^3. In some cases appropriate combination of these technologies yield good results and some of these have also been adopted for horticultural crops and forest trees also.

Management of Groundwater Resources (Anonymous, 1999)

The selection of site and the design of wells/tubewells should take into account the geological formations, the fluctuation of groundwater levels, water quality at different depths, aquifer characteristics, well parameters, etc.

Construction of Recharge Facilities

The recharge to groundwater around the well and in the area as a whole shall need to be augmented by constructing suitable types of recharge structures like a jacket well around the drinking water supply well. Construction of infiltration tanks, check dams, injection wells, etc. must be undertaken at all technically feasible sites in rural and urban areas.

Revival of the Village Pond Concept

The traditional village ponds, which have been filled up in most of the villages, used to act as storage tanks for the cattle drinking water and were the natural means for augmenting recharge to groundwater. These ponds must be rehabilitated and made usable for storage and recharge of groundwater.

Protection from Pollution
The main cause of pollution in the villages and the cities is the faecal disposal. The haphazard disposal of the wastes has led to an increase in the nitrate content in groundwater in the rural areas. This is a cause of concern. The location of laterines *vis-a-vis* hand pumps must be suitably decided keeping in view the groundwater gradient in the area.

Ground Water Recharge in Urban areas
The urbanization process carries with it the hazards consequent to concreting and paving. As a result, there is a lot of shrinkage in the land area, which was earlier acting as place for the recharge of groundwater. Further, the requirements of water increased due to migration of the population from the rural to the urban areas and the increase in the per capita use of water. It has been observed that consequent to urbanization, the area earlier available for groundwater recharge has reduced to less than 40 %. In addition, because of the unsystematic disposal of the urban and industrial wastes, the groundwater gets polluted and thus rendered unfit for drinking and domestic use. It is therefore, essential that construction of groundwater recharge structures for trapping and recharging the rooftop runoff should be made mandatory by amending the urban by-laws:

- It should be the responsibility of the urban municipal bodies to recharge the storm runoff from the city drainage system
- The urban liquid wastes, after the required treatment, must be recharged underground for re-circulation through the aquifers. During the passage of the wastewater through the aquifers, the pathogens are automatically killed. Such a practice therefore, does away with the normal procedures of water treatment and purification and thus results in cost saving.

Supply of Water of Lower Specifications
In many areas, particularly in the Western Rajasthan, the waters of higher salinity are available in some areas. However, since these do not meet the prescribed standards, these are not tapped for use. The villagers are however, using waters of even lower specifications, which have even other deficiencies. In other cases, the marginally high fluoride waters are used for drinking purposes in the absence of other sources. Such waters may be used after blending with better quality waters.

Creation of Ground Water Sanctuaries/Protection Zones
In many areas in the State, though the present sources are adequate to meet the requirement of drinking and domestic uses; they may not sustain the pressure of population after ten or fifteen years. In such cases it will be desirable to locate alternate aquifers either in the space or depth range and declare these as reserves for drinking and domestic uses. These could be termed as Ground Water Sanctuaries. Similar zones may have to be set apart near urban agglomerates. Growth of any polluting industry near such areas in a manner that it may cause degradation of groundwater quality should be prohibited. Such zones may be declared as 'Protection Zones' and set apart for future drinking and domestic water uses.

Funding of Ground Water Development Programmes
Work on construction and electrification of drinking water source should be financed initially from the public exchequer since besides being a welfare measure it shall also lead to

substantial reduction in water borne diseases. The users may however, be required to make some contribution either in the form of cash or in kind.

Setting up Village Hand Pump/Water Source Maintenance
Even though the initial investment for the creation of the resource may be made from public sources, the responsibility for the maintenance, repair and future replacement should vest with the users. The users should therefore, be encouraged, rather it should be a pre-requisite that the villagers constitute a Users Group and set up a maintenance fund in a local financial institute. The state public health agency, during the course of construction of the structure, also train a couple of village youth who could act as Hand Pump mechanics. The users should also maintain these resources as common property resources.

Adoption of Water Saving Devices
Large-scale adoption of water saving devices like sprinkler and drip irrigation systems may be propagated. Liberal subsidies to the users may be provided in suitable situations. Losses on account of subsidy shall be compensated by the gains from the additional production from water saved by adopting these devices.

Community Irrigation Wells - Setting up of Water Cooperatives
The small-sized and fragmented land holdings do not qualify for assistance from the institute resources because of the lack of economic feasibility. The alternative therefore, is to persuade farmers to form cooperatives and share the water from the well. The approach shall lead to economy in water use and over-capitalization.

Availability of Quality Power
Availability of quality power at the right time is utmost essential for avoiding breakdown and for enhancing the life of the pumps. It is therefore essential to assure uninterrupted availability of power for at least six hours in a day during the irrigation season. If need be, roster of power should be adopted to achieve the objective.

Strategy for Assuring Drinking Water Supplies
1. A detailed inventory of the habitations, villages and *dhanis*, must be made and their locations plotted
2. The existing groundwater sources should be plotted on maps and their capacities and state of health examined
3. Detailed field hydrogeological surveys for the location and design of additional groundwater structures be undertaken
4. The groundwater recharge structure should be planned, designed and constructed for each well/tubewell as a part of the rural water supply scheme
5. It is seen that in certain areas the quality of groundwater is such that it does not meet strictly the National Drinking Water Standards. In the absence of better water quality sources, the people are using waters of available quality. In such cases where the recommended quality water is not available, the water of lower specifications, if this does not carry any health hazard, may be supplied
6. Storm water drainage recharge and liquid waste recycling through the aquifer systems should be the responsibility of the municipal bodies
7. Suitable aquifers and areas must be set apart and declared as groundwater sanctuaries for meeting the village water requirements

8. For the water supply to urban agglomerates. groundwater protection zones should be identified and precisely located and notified. Setting up of any industry or other likely sources of pollution should be prohibited by law in such areas
9. The government may initially finance all drinking water schemes. The users should however, share part of the expenditure. This shall also give a sense of ownership and belonging to the user.
10. Repair, maintenance and future replacement of the water source should be the responsibility of the users. The users must be asked to set up a 'Village Hand Pump Maintenance Fund' to which every user must contribute either in cash or in kind. The management of such schemes should be participatory and by the users as a common property.
11. Where groundwater of potable quality is not available locally, the villages may be served through a regional water supply scheme. In such cases availability of power for three to four hours has to be ensured.
12. The main quality hazards in Rajasthan are from fluoride and salinity. Since the installation of community treatment plants, have not been successful, because of the various constraints such as availability of power. the emphasis should be to implement house-hold based treatment methods

Improved Agronomic Practices

The crop yields in arid regions are low compared to the humid and sub-humid regions. The major cause of low yields is the deficiency of water. Availability of surface and groundwater for irrigation is meagre, and crop production is mainly dependent on low and erratic rainfall. Hence, the most obvious priority is to achieve maximum production of an economic yield per unit of available water.

Crop yields may be adversely affected by drought stress during a sensitive growth period, or stress caused by lack of nutrients, diseases, insects or other factors without having much effect on seasonal evapotranspiration. The genetic potential of landraces is low, and their response to improved management practices is also poor. Most farmers in the arid regions are poor and their risk bearing capacity is low. Their poor economic condition coupled with unreliable precipitation tends to keep the use of inputs such as improved seed, chemical fertilizer, pesticides and hired labour to a minimum. Without adequate input supply, crop growth and consequently rainfall use efficiency remains poor.

Maximizing Production per Unit Rainfall

Because of the limited water resources in the region, there is no escape from increasing the efficiency of rainwater use. Kanwar (1994) suggested five steps to improve rainwater use efficiency: i) to retain precipitation *in-situ* and minimize the runoff, ii) to reduce evaporation in relation to transpiration, iii) to use drought tolerant crops that fit in the rainfall pattern, iv) to recycle the runoff water after rainwater harvesting and drainage, and v) to use integrated watershed approach for maximizing rainwater use.

Efficient water conservation and harvesting can carry crops over an otherwise disastrous dry period and can stabilize and increase production. Deep ploughing is more effective in conserving rainwater and increasing rooting of crops even in light textured soils without any hard pans. The water holding capacity of coarse textured soils can be improved by adding organic matter. Choosing optimum plant population and row spacing is one of the important considerations. Generally wider spacing of the plants are recommended for drylands, because conserved soil water can be used in later part of the season, thereby increasing the harvest index and total grain yield. However, too low plant densities may not fully exploit the available soil water for the complete season, whereas high densities on the other hand, may use too much of available soil water early in the season.

Several technologies have been developed over the years to increase the productivity of dryland farming/cropping systems. Lal and Miller (1990) suggested that controlling erosion, conserving water, alleviating soil compaction, enhancing soil fertility, increasing biological activity of soil fauna and managing soil temperature are some of the soil related endeavours that can transform subsistence into sustainable farming. Some of the components suggested by them to increase crop productivity are improved cultivars and cropping systems, conservation tillage and residue management, application of fertilizers and organic amendments, and water management

Choice of Crops and Their Varieties

The existing cropping systems of a region are not necessarily the most suitable ones. Farmers grow certain crops for convenience or by conviction. This is because first priority of a farmer continues to be the production of food for his family and feed for his livestock. On the other hand, selection of crops suitable to the environment leads to increased and stabilized production and efficient utilization of natural resources. The recommended varieties of important *kharif* season crops for arid region are:

Pearl millet	: CZIC 923, HHB 67, HHB 68, GHB 183, GHB 1399
Clusterbean	: Maru guar, FS 277, HG 75, HG 182, HGS 365, RGC 936, PLG 119, PLG 85, Suvidha, Naveen
Mungbean	: Asha, K 851, RMG 131
Mothbean	: RMO 40, Maru moth, Jadia, Jawala, IPCMO 880, T 88, CAZRI moth-1

Onset of Rainfall and Length of Growing Season

Analysis of rainfall data of the Indian arid zone has shown that the length of growing season is positively correlated with onset of rainfall, i.e., the growing season is longer if the onset of rainfall is early. Hence, long duration crops/cultivars should be selected to fully utilize the benefits of long growing season if onset of rainfall is early. If onset of rainfall is late, the choice will obviously be short duration crops/cultivars. The relationship between onset of rainfall and growing season length can be used to guide farmers for selecting crops taking into consideration the i) length of growing season of crop/cultivar, ii) soil depth and water holding capacity, iii) crop coefficient for estimation of water requirements, and iv) evaporative rate throughout the season. Therefore, the crop/cultivars that will reach maturity within the rainy period, or within a time period following the final rainfall, but before the extractable soil water is depleted, should be selected. The choice will also depend on soil type. Thus, a shallow sandy soil should be put under short-term crops/cultivars even at an earlier onset date, while a deeper soil with loamy or clayey texture should be put under longer duration crops.

Tillage

Tillage operations, if done properly and at appropriate time, create a favourable root proliferation zone, thereby increasing WUE and fertilizer recovery. Tillage also incorporates organic matter, controls weeds and improves soil moisture conservation. Coarse textured and structure-less soils of arid region become compact (due to increased bulk density) after heavy rainfall and crusting after light rainfall, reducing the infiltration rates substantially. As infiltration rates decrease, runoff and soil erosion increases. Tillage can be very effective on these soils for breaking crusts/loosening the soil, increasing aeration and increasing the water stored in the soil profile, and creating favourable conditions for crop growth. Under Jodhpur conditions, preliminary tillage was found to result in higher pearl millet yields and lower weed population compared to the zero tillage (Table 16). One post sowing cultivation after 20-25 days of emergence in loamy sand was also effective in controlling weeds and increasing the growth, yield and WUE of pearl millet (Table 17). Post sowing cultivation in light textured soils improves soil aeration and breaks the continuities of micro-pores, creating dust mulch on soil surface and thus reduces evaporative losses.

Table 16. Effect of tillage on weeds and pearl millet yield

Tillage	Yield (kg ha^{-1})	Weed count (m^{-2})
No-tillage	506	208
One tillage	888	56

Table 17. Effect of post emergence cultivation on the weed dry weight and pearl millet yield

Treatment	Weed dry wt. (kg ha^{-1})	Grain yield (kg ha^{-1})	Water use (mm)	WUE (kg ha^{-1} mm^{-1})
No cultivation	1720	50	310	0.16
One post sowing cultivation	60	1140	292	3.90

Management of Soil Crust

In sandy and loamy soils in arid environments, seedling of crops such as pearl millet, cowpea, mungbean, etc. sometimes fail to emerge because of soil surface crusting. Soil sealing and crusting result from unstable soil structure where original macro-pores become micro-pores upon wetting because of either physical (slaking) or chemical (dispersion due to imbalance of cations in soil solution) processes. The resultant micro-pores restrict the movement of water and air into the soil profile. When dry, the crust becomes a hard, thin layer of soil on the surface, causing mechanical impedance to the emerging seedlings and often results in very poor plant stands or crop failures.

Joshi (1987) found that application of FYM over seed furrows reduced the crust strength to 49 KPa on 3rd day and 69-74 KPa on 7th day after sowing as compared to 108-128 KPa on 3rd and 162-172 KPa on 7th day under drill sowing. The lower crust strength with FYM application allowed greater ultimate emergence. The FYM over seed furrows reduced rain drop impact resulting in lesser breaking of aggregates. Secondly, FYM absorbed more rainwater and thus kept 2.26 % higher moisture content of the surface layer. Organic amendments like straw, FYM, etc. have been suggested to reduce the problems of crusting and hard setting on structurally unstable soils of Indian semi arid tropics.

Weed Management

Crop-weed competition is one of the most important constraints to crop production in drylands. Weeds compete with crops for soil moisture and nutrients, which are the most limiting factors for crop growth. Weed management, therefore, is an important factor that determines the production efficiency on a farm. When improved management practices are adopted, efficient weed control becomes even more important, otherwise weeds benefit from the costly input rather than the crops.

Most crops are sensitive to weed competition in the early stages of growth. Lack of effective weed control during first 4-5 weeks causes maximum yield loss in crops. The late maturing crop however, may require a longer weed free period. Therefore, timely weed control is essential to realize high production potential of crops.

Soil Fertility Management

Crops in the arid and semi arid areas suffer not only from moisture stress but also from 'nutrient stress'. Poor fertility of soils in these regions is a major limitation to increasing crop yields. Experiments conducted under the All India Coordinated Research Project for Dryland Agriculture have indicated the high pay-off for applied nutrients in drylands in different agro-climatic conditions. The response of rainy season crops to applied nitrogen and phosphorus fertilizers is summarized in Table 18. The response to applied fertilizer, however, was found to vary with soil type, available water storage at seeding and seasonal rainfall during the growing season.

Table 18. Response of rainy season crops to nitrogen and phosphorus

Crop	**Range of response**	
	Kg grain kg^{-1} N	**Kg grain kg^{-1} P_2O_5**
Sorghum	3.4 – 43.4	2.4 - 59.0
Pearl millet	2.1 – 24.8	1.7 - 14.3
Finger millet	5.0 – 42.4	6.4 - 38.9
Maize	4.1 – 67.4	6.8 - 80.0
Sunflower	1.5 – 22.6	1.2 - 7.0
Linseed	1.2 – 11.5	1.2 - 7.0
Sesame	1.3 - 5.0	1.1 - 3.1
Clusterbean	-	6.7 - 10.7
Green gram	-	1.5 - 11.6
Black gram	-	1.8 - 6.7
Pigeonpea	-	3.1 - 8.3

In future, higher targeted yields and intensive cropping systems will remove more nutrients and deplete the resource base for the following crops unless the nutrients are replaced. Hence, moderate fertilizer doses may be essential to boost up the crop production in these regions. Moreover, the yield superiority of improved cultivars generally occurs in the presence of adequate soil nutrients. In dryland soils, the surface layers often remain dry for a major part of the growing season. Therefore, fertilizer placement in deeper layers of active root zone is more desirable. Since, the major demand for phosphorus is early in the life cycle of crops, basal application of P is more useful. For nitrogen, a better approach is to split the applications. Apply only minimal starter amounts at the beginning of the season and adjust subsequent applications to the crop performance and environmental conditions. Because of frequent dry periods, placement of soluble fertilizers with the seed is extremely hazardous in dryland soils. Not more than 15 kg N/ha may be applied with seed. Higher rates might result in high osmotic potential near the germinating seed. Application of fertilizer in nutrient deficient soils increases the crop growth and yield, and also WUE (Table 19). Initial fertilizer application increases crop vigour and crops develop deeper root system thereby extracting water from lower layers during later period of growth. Secondly, more rapid and larger growth of the canopy due to fertilizer use shades the soil surface thus reducing the evaporative losses.

Table 19. Effect of nitrogen application on pearl millet yield and water use efficiency

Rainfall (mm)	**N ($kg\ ha^{-1}$)**	**Yield ($kg\ ha^{-1}$)**	**WUE ($kg\ ha^{-1}\ mm^{-1}$)**
266	0	500	1.9
	40	870	3.3
331	0	790	2.4
	40	1360	4.1

Mitigating Aberrant Weather Conditions

To meet the weather aberrations the following strategies have been found useful in low rainfall zones of India. The crops suitable for timely onset of rainfall may not perform well under delayed conditions. Hence, alternate crops for such situations have been identified. For example, sowing of pearl millet beyond 3rd week of July gives poor yields whereas, legumes like clusterbean, mothbean and mungbean give good yields under delayed sown conditions. Where possible, transplanting of 18-20 days old seedlings of pearl millet may also give good yields. Due to long dry spells, crops may face water stress at various growth stages. To reduce the effects of early stage droughts, sowing of crops immediately after rainfall is found helpful as it helps in better crop establishment. However, if the crop stand is poor due to early drought, gap filling of pearl millet by transplanting is found to be effective. In crops where transplanting is not possible, it is better to re-sow the crops with subsequent rainfall rather than having inadequate plant stand in the fields.

Complete removal of weeds, use of residue mulch and creating dust mulch are effective measures to combat mid season moisture stresses. Thinning of plant population by removing every third row was found to be advantageous to mitigate drought stress in sorghum and pearl millet. Protective irrigation from harvested rainwater, if available, may be useful in case of mid season or late drought conditions. Some transpiration control measures as a means of decreasing soil moisture use were found to increase the grain yields of pearl millet (Kaushik and Gautam, 1984). Foliar application of chemicals such as borax, kaoline or atrazine, or pre-sowing seed treatment with 0.2 % solutions of KNO_3 or NaCl were as good as straw mulch applied at the rate of 5 tonnes/ha to the pearl millet crop.

Judicious Use of Limited Irrigation Water

Availability of water for irrigation is much below the desired level in this region. Irrigation is using 90 % of the groundwater abstracted, compounding the problems of fragile arid ecosystem (Mohile, 2000). Water table is falling at an alarming rate as a result of overexploitation of groundwater in several parts of this region, while the excessive use of canal water (IGNP command area) has created the problems of waterlogging and salinity. Considering the fragile nature of arid agro-ecosystem and meagre irrigation resources, judicious use of irrigation water is essential. In intensively irrigated areas, where the land is the most limiting factor, the objective is to get maximum production per unit of land. But in arid regions, where water is the most limiting factor, the objective should be to obtain maximum yield per unit of water rather than per unit of land.

Extensive Irrigation Approach

This approach aims at obtaining maximum production per unit of irrigation water. The limited amount of water is used to give irrigation in relatively large area so that maximum water use efficiency is achieved. The work done at Central Arid Zone Research Institute, Jodhpur has shown (Tables 20 and 21) the advantage of this approach in the Indian arid zone. Though the production from a unit area declines as the same amount of water is used to give irrigation in relatively larger area, the over all production and WUE are increased.

Table 20. Effect of increased area under supplemental irrigation (same amount of irrigation water) on pearl millet production

Good rainfall (331 mm)			**Medium rainfall (266 mm)**			**Low rainfall (173 mm)**		
Irrigation (mm ha^{-1})	Area (ha)	Yield (kg)	Irrigation (mm ha^{-1})	Area (ha)	Yield (kg)	Irrigation (mm ha^{-1})	Area (ha)	Yield (kg)
190	1.0	3660	292	1.0	3620	341	1.0	3540
76	2.5	7225	145	2.0	5380	209	1.6	4528
38	5.0	12950	73	4.0	7560	117	2.9	5829
0	1.0	2280	0	1.0	1400	0	1.0	1080

Table 21. Effect of extensive irrigation (for a given water supply) on production and WUE of crops

Crop	**Water use (mm)**	**Area (ha)**	**Yield (kg)**	**WUE (kg ha^{-1} mm^{-1})**
Wheat	840	1	5500	6.5
		3	9100	10.8
Mustard	250	1	1100	4.4
		1.5	2000	8.0

Improved Irrigation Methods

As the soils in the Indian arid zone are mostly light textured and undulating, the conventional methods of irrigation are inefficient. Sprinkler and drip irrigation methods are most suitable for our conditions, though these methods need relatively high initial investment.

Sprinkler system is most suitable for narrow-spacing crops (wheat, mustard, etc.) grown on undulating light textured soils. This technique has gained popularity among the farmers of the region. The conveyance losses of water are practically negligible, and risk of soil erosion is low as the application rate is low. This system helps in saving sufficient amount of water (at least 20 %). At Central Arid Zone Research Institute, Jodhpur sprinkler system on irrigation gave 33 and 37 % higher wheat yield compared to check basin and border strip methods of irrigation, respectively (CAZRI, 1979). However, high wind velocity and use of saline water may restrict its wider application in the region.

The drip irrigation system is not affected by high wind velocity as it applies water directly in the root zone. Though the initial cost of drip irrigation is high, it is quite pertinent to our region where availability of irrigation water is scarce, soils are light textured and undulating, wind velocity is high and evaporation demand is high. This method of irrigation is more suitable for wider spacing crops and orchards. Drip system of irrigation provides water through a network of pipes at slow rates to maintain the optimum soil moisture level. As the irrigation is given directly near the root zone in drip system and whole soil surface is not wetted, wasteful loss of water is minimized (Table 22). The crop does not face any water deficit as the irrigation may be given frequently to meet the crop water requirements. It has been found that maize and most vegetable crops respond well to this system, giving perceptibly higher yields (Table 23) compared to surface irrigation (Shankarnarayan and Singh, 1985). Water-soluble fertilizers can also be applied through drip irrigation. The drip system has a special utility in the region where groundwater is generally saline. Daily irrigation by drip forces the salts to the sides and below the root zone, thereby allowing gainful utilization of water having a relatively high salt content (Table 24).

Table 22. Water use in potato under drip and furrow irrigation methods

	Water use (mm)	Yield (t ha^{-1})
Furrow	366	20.2
Drip	183	20.5

Table 23. Yields from drip and conventional methods of irrigation (t ha^{-1})

	Tomato	Cabbage	Cauliflower	Potato	Maize	Watermelon	Musk melon	Long gourd	Round gourd
Drip	78	36	26	33	12	128	23	56	12
Conventional	23	30	20	25	4	18	9	18	10

Table 24. Use of saline water for irrigation in potato

	Water quality	Yield (t ha^{-1})
Drip	3000 μ S m^{-1}	26
Furrow	Sweet	20

To reduce the cost, the crops may be planted in paired row system where one lateral controls both the rows of a pair. In this way, it is possible to reduce the cost of laterals by half, making the system an economically viable proposition.

Alternate Land Use

With the increased pressure on land, marginal lands are now brought under cultivation. Small and marginal farmers mostly cultivate these lands. Another dimension to the problem is overgrazing or deforestation of the community lands (CPR). Further, good lands are sometimes going under tree farming either due to labour problems or absentee land tenurial system.

Taking an overview of the problem and the need for fuel, fodder, fruit and timber at the village level, a concerted effort has to be made to adopt suitable land use systems keeping in consideration the rainfall, soil type and needs of the people in the region. The selection of land use components should primarily be determined by the length of crop growing season. which in turn depends mainly on the duration and other characteristics of the rainy period. The assured crop growth period in arid and semi arid areas of Rajasthan, calculated from weekly water balance studies varies from 3 to 12 weeks under shallow soils and from 5 to 14 weeks under deep soils (Rao *et al.*, 1994). The crop growth duration of selected crop/grass species should match the growing season of the area to avoid drought effects and maximize/stabilize the yields. Venkateswarlu (1997) suggested ideal farming systems for arid zone of India using the criteria of crop growing season (Table 25).

Bhati (1993) evaluated the alternate land use systems viz. agro-horticulture, agro-forestry, silvi-pasture and agri-pastoral system over arable farming. All these systems showed high

Table 25. Existing and ideal farming systems for the Indian arid zone

	Growing season (weeks)		Cropping pattern	
	Shallow soils	Deep soils	Ideal	Existing
Bikaner	5	7	Grasses, trees and shrubs	Pearl millet, Clusterbean
Barmer	5	6		
Jaisalmer	3	5		
Jalor	9	11	Short legumes with Pastures in shallow soils; pearl millet in deep soils	Pearl millet, Clusterbean, moth bean
Jodhpur	7	11		
Nagaur	9	10		
Churu	8	10		
Jhunjhunu	10	12		
Sikar	9	10		
Pali	10	12		

benefit-cost ratio over the dryland crop production (Table 26).

Table 26. Economic evaluation of arid land farming systems (Estimated over 18 years)

S. No.	Farming System	Benefit- Ratio at 20 % discount rate
1.	Agro-forestry	1.69
2.	Silvi-pastoral	1.66
3.	Agri-pastoral	1.87
4.	Agro-horticulture	1.46
5.	Crop production	1.24

Agro-forestry System

Agro-forestry including livestock component is way of life in the Indian arid zone. Agro-forestry is a collective name for land use systems and technologies in which woody perennials (trees, shrubs, etc.) are deliberately combined on the same land unit with herbaceous crops and/or animals, in some form of spatial or temporal sequence. In such systems there are both ecological and economic interactions amongst the different components of the system. In arid regions of India, most dwellers raise livestock as a subsidiary occupation and allow trees and shrubs to grow along with cultivated crops mainly to cover the risks and uncertainty of crop production. The agro-forestry system is suitable for rainfall zone of 250-400 mm. which is supported by the highest benefit-cost ratio.

In traditional agro-forestry system farmers harvest the foliage of *Prosopis cineraria* and *Zizyphus nummularia* to get the fodder. This practice not only provides the fodder for animals. but also enables the crops to produce higher yields. Experiments have shown that *Prosopis cineraria, Hardwickia binnata* and *Holoptelia integrifolia* are suitable for agro-forestry system in this region. As high tree density adversely affects the crop growth, the tree density of about 100 trees/ha is found to be optimum.

Silvi-pastoral System
Arable farming, in low rainfall zones with sandy soils, results in frequent crop failures and accelerated wind erosion. In these areas, especially below 250 mm rainfall zone, the most ideal system is silvi-pasture. It may not be practical to adopt pure silvi-pastoral system in these areas and, therefore, agro-forestry system may be adopted in relatively heavy textured soils preferably with a source of supplemental irrigation to save the crops from vagaries of weather. The experiments conducted at Central Arid Zone Research Institute, Jodhpur (*Prosopis cineraria, Acacia tortilis* and *Albizzia lebbeck* with five grasses viz. *Chrysopogon fulvus, Cenchrus ciliaris, Sehima nervosum* and *Cenchrus setigerus*) and Pali (*Acacia tortilis, Albizzia lebbeck, Azadirachta indica* and *Holoptelia integrifolia* with four grasses – *Dichanthium annulatum, Panicum antidotale, Cenchrus setigerus* and *Cenchrus ciliaris*) revealed that trees do not have adverse effect on grass production. *Zizyphus nummularia* is one of the most important shrub components of the traditional silvi-pastoral systems. It is an excellent browsing material, especially for goat. *Tecomella undulata* and *Colophospermum mopane* are some of the other important tree species, which are compatible with the grass (*Lasiurus sindicus*) to form a good silvi-pastoral system in low rainfall regions of Jaisalmer.

Agri-pastoral System
In low rainfall areas with light textured soils, agri-pastoral system is more sustainable than crop production. Crops can be grown in between the strips of permanently planted grass strips. This system also checks the soil erosion. Intercropping of mungbean, moth bean and clusterbean with *Cenchrus ciliaris, Cenchrus setigerus* and *Lasiurus sindicus* increased the grass yields compared to pure stand of grass, in addition to the legume yields. In shallow loamy soils of Pali, *Dichanthium annulatum* is more suitable for intercropping with legumes than *Cenchrus setigerus.*

Farming Systems Involving Horticultural Components
In relatively high rainfall areas of the arid zone, there is high potential for agri-horti or agri-horti-silviculture systems depending upon the soil, climate and other economic factors. *Ber* (*Zizyphus mauritiana*) is the most suitable fruit crop of this region. Efforts made by Central Arid Zone Research Institute, Jodhpur in selecting and popularizing *Seb, Gola* and *Mundia* varieties of *ber* made this fruit crop the most popular in the region. Five-year old trees may yield 50-70 kg *ber*/tree under rainfed conditions. However, instead of pure horticulture, combination of horti, agri, silva and pasture components would be more suitable for this region to provide climatic stability.

Agri-horti system: In this system the inter spaces between two rows of horticultural crop is utilized for the cultivation of a suitable rainy season crop. The crop can be legume or non-legume but the thumb rule for selecting an intercrop is that the height of the intercrop should not be more than the height of the fruit plants. The advantage of selecting a legume crop (clusterbean, mung bean, etc.) is that there is less competition between the intercrop components for resources than the cereals (pearl millet). Clusterbean and mungbean have been found to give additional crop yields without adversely affecting the production of *ber*.

Horti-pastoral system: This system provides fodder for animals and fruits for additional income. *Ber* with grass can form an ideal combination because it provides fodder from grass as well as leaves of *ber*. In an experiment at Central Arid Zone Research Institute, Jodhpur (Vashishtha and Prasad, 1997), *Cenchrus ciliaris* was introduced in 18-year old *ber* orchard, There was no adverse effect on *ber* yield, and an additional dry fodder (2.5 tonnes/ha) and grass seed (25-30 kg/ha) could be obtained from the introduced grass. At other site (Barmer), after five years of establishment, growth of *ber* was more than two times and production of dry leaves of *ber* was six times when grown with *Cenchrus ciliaris*, as compared to the *ber* grown as mono crop. In such system however, it is desirable that budding in *ber* should be done at 1 m height to avoid damage by animals.

Horti-silva system: In this system both fruit and forest trees are planted together to act as complementary to each other. For this region drought hardy species of both the components are selected. The forest tree species like *Acacia tortilis*, *Cassia siamea*, *Albizzia lebbeck*, *Zizyphus nummularia*, etc. can be successfully planted as windbreak all around the orchard of *ber*, pomegranate or any other orchard. In another system, rows of forest trees may be planted in the orchard also, to act as windbreak. Such system is more beneficial where wind velocity is high. The tree species may provide fuel wood or marginal timber wood and fodder and at the same time may protect the orchard from hazards of cold and hot winds. The tree species can be selected as per local demands e.g. fodder trees should be selected in predominantly animal husbandry areas. The component of grass can also be included to form a horti-silvi-pastoral system that is another suitable alternate land use system for subsistence. In case of failure of one component, the farmer can get income from the other components.

In land use systems where tree/horticultural crops are grown with grass and/or crops, trees (both forest and horticultural) face maximum competition during the first year. Therefore, the tree component should be well established in the first year, preferably with the irrigation facilities. Crops/grass could be taken in between the rows of trees/horticultural crops from the second year onwards.

Considering the poor organic matter and nutrient content of the desert soils, selection of the component species for alternate land use systems should be such that they should improve the soil fertility and should be self-fertilizing as far as possible. Addition of leaves of fast growing leguminous trees like *Leucaena leucocephala*, *Acacia*; *Prosopis* etc. will be useful for this purpose. Similarly, leguminous crops like clusterbean, mung bean and moth bean should be preferred in such systems.

Pasture Development

The flora of the Indian desert consists of a large number of grass and legume species. Of these, the perennial grass species like *Cenchrus ciliaris*, *Cenchrus setigerus*, *Dichanthium annulatum*, *Lasiurus sindicus* and *Panicum antidotale* are highly productive and suitable for pasture development in this region. The soil and climate of the arid region are well adapted to grassland husbandry. The measures to be adopted for improvement of animal husbandry largely depend on the improvement of native pastures, which are over-exploited. In order to sustain livestock industry, the carrying capacity of the native pasture should be increased and its quality improved. Reseeding degraded grasslands and controlled grazing can increase the carrying capacity of grasslands several fold (Yadav, 1993) as is evident from Table 27.

The Central Arid Zone Research Institute has developed four improved varieties of pasture grasses and one of pasture legume, which can be used to increase the productivity of farming systems involving grass component. These varieties are:

Marwar Anjan (CAZRI-75) of *Cenchrus ciliaris*
Marwar Dhaman (CAZRI-76) of *Cenchrus setigerus*
CAZRI-30-5 of *Lasiurus sindicus*
Bundel Anjan of *Cenchrus ciliaris*
CAZRI-1461 of *Lablab purpureus*.

Table 27. Carrying capacity of sheep in different pastures

Pastures	Carrying capacity of sheep ha^{-1} $year^{-1}$
Sown pasture of *Lasiurus sindicus* and *Cenchrus ciliaris* in sandy soil at Jodhpur (Rainfall 300 mm)	5.0
Sown pasture of *Cenchrus ciliaris* and *Dichanthium annulatum* in sandy loam soil at Pali (Rainfall 500 mm)	7.3
Natural pasture under protection for 3 years in sandy soil at Pali	2.5
Natural pasture under protection for five years in sandy soil at Bikaner (rainfall 250 mm)	2.0
Natural pasture under protection for five years in semi-rocky areas at Beriganga near Jodhpur (rainfall 300 mm)	1.1
Natural pasture unprotected, near Jodhpur	0.5

Feed and Fodder Resources

During droughts, severe shortage of animal feed, especially of roughages is encountered. The major feed and fodder resources for livestock are natural vegetation on common grazing lands, rangelands, forest area, industrial by products and crop residues. Decrease in biomass production in drought years and shifting of priorities result in scarcity of feed and fodder.

Cereal Straw

Wheat and paddy straws, the by-products left after harvesting of the grains, form the main bulk of roughages and are stable feed for cattle. Though they are poor in nutritive value, containing about 3 % protein and 40 % carbohydrates, the straw along with small quantities of protein supplements can maintain adult non-producing cattle. However, certain factors like high lignin content reduced palatability, dustiness and high oxalic acid content in paddy straw, affect calcium absorption and limit their extensive use as cattle feed.

Alkali Treatment of Straw

Paddy straw should be treated with a solution of 1.25 % NaOH in water at the rate of 1 l solutions to 1 kg of straw and thin dried. This would reduce the oxalic acid content of the straw to the minimum and improves the absorption of calcium.

Soaking Wheat Straw in Water

Soaking 1 kg of wheat straw in 1 l of water improves the palatability, dry matter consumption and nutrient utilization. Soaking also reduces the dustiness and improves the intake.

Impregnation of Straw with Urea Molasses
The poor protein content of cereal straw limits the intake by the livestock. Impregnation of chaffed straw with molasses and urea improves intake by making them more palatable to the livestock. Impregnation of straw with 10 % molasses and 1 % urea on dry matter basis will improve its nutritive value.

Urea Treated Straw
Wheat/paddy straw treated with 2.5 to 4 % urea in water to create 50 to 60 % moisture and stored under cover for 15-21 days will improve nutritive value of straw in terms of nitrogen and TDN.

Steam Treated Sugar Cane Begasse
Sugarcane begasse from the states of U.P. and Maharashtra, where major part of it is burnt as energy source, could be utilized after steaming. Since stream is available as by-product in the sugar mills, only stream treatment and bailing may be required.

These fodders along with 0.5 to 1 kg of concentrate and equal parts like Tumba (*Citrullus colocynthis*) seed cake (a cheaper, non-conventional feed resource of desert and available readily) and wheat bran, 1% common salt and 1% mineral mixture will be able to meet the maintenance requirement of low to medium level production/growing/working livestock under drought conditions.

Use of Urea Molasses Mineral Blocks
These blocks are compact, occupy less space and are easy to transport. Blocks contain urea, molasses, and bulky ingredient like wheat bran or rice bran and a binder like magnesium oxide and used as a lick. The blocks are fortified with minerals and synthetic vitamins.

Feeding Tumba Seed Cake (TSC)
It is a cheaper, locally available, non-conventional feed resource of arid region having 16 to 22 % crude protein and available in plenty in oil extraction mills. TSC is particularly used as fuel for furnaces and thus wasted. Feeding of TSC along with some energy sources like cherished pearl millet grains/wheat bran will meet the maintenance requirement of protein to some extend.

Use of Urea Molasses Mineral Blocks
These blocks are compact, occupy less space and are easy to transport. Blocks contain urea, molasses, and bulky ingredient like wheat bran or rice bran and a binder like magnesium oxide and used as a lick. The blocks are fortified with minerals and synthetic vitamins.

Fodder Banks – Standby Source of Livestock Feed
Fodder banks should be created as a source of livestock feed during droughts. Their establishment should be encouraged at a central place, well connected by road and having good source of water supply. Fodder banks should also be created as a buffer stock in the normal years as a part of long-term contingency plan.

Animal Health
Health camps should be organized to treat the sick animals and preventive measures like vaccination, ectoparasite treatments and dewarming to avoid spread of any infections or contagion diseases in livestock.

Socio-economic Aspects

Droughts occur due to complex imbalance in agro-meteorological parameters and biotic environment in the region. The frequent occurrence of droughts for a longer period lead to famines, scarcity of food and feed in the region and price rise. The most important socio-economic aspects of drought and its management can be dealt with prediction, monitoring and early warning, impact assessment, planning, measures taken by government and role of community (Sinha, 1988). Drought code includes programme and information on how early in the season can scarcity conditions be anticipated, maximizing production and alternating cropping patterns when necessary in irrigated areas and building up of appropriate seed and fertilizers buffers to implement the drought coping strategy. A two-pronged strategy i.e. curative and preventive can be adopted to cope up with droughts.

Immediate Curative Measures

To avert drought effects some of the curative measures should be undertaken by State and Central Governments on priority basis. These can be:

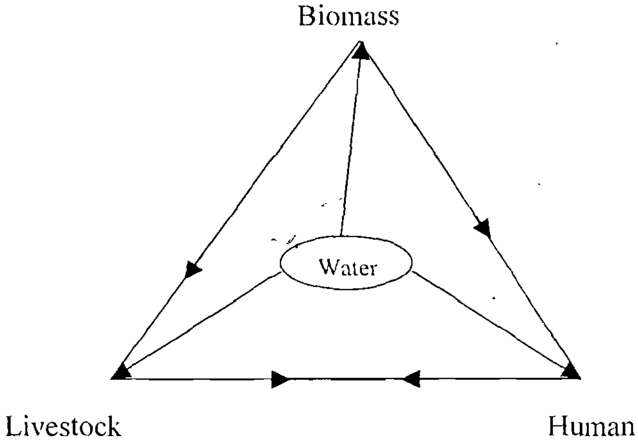
- Assuring the availability of drinking water and food grains.
- Fodder depots.
- Food for work.
- Contingency plan.
- Cattle camps
- Relief Works

Long-term Preventive Measures

Despite above preventive measures to tackle the drought problem on long-term basis and to minimize the adverse effects of drought, some preventive measures are also needed. These measures can be:

- Early long-term forecast of monsoon to enable planners and farmers to plan accordingly
- Timely availability of resources such as credit, fertilizers, pesticides and power should be ensured for increasing crop production
- Improvement in communication and transport system
- Introduction of cottage industries and other alternatives for employment generation
- Crop and livestock Insurance
- Remunerative prices of produce in good years
- Reasonable buffer stock of food grains and fodder
- Rational utilization of common property resources such as water and grazing lands.
- Afforestation/pasture development on wastelands
- Disposal of unproductive livestock
- Motivation for the adoption of proper technologies at the required time by Governmental agencies
- Education and training to combat drought situation

Low and erratic rainfall, and fragile land resources govern intricate cycle of water–biomass production-livestock and human sustenance in arid region. Severe scarcity of surface and ground water, failure of crops, and decreased production from grasses and tree fodder are hitting the cattle and people below poverty line the most. Many socio-economic issues such as drudgery of women for water, work and family care due to shift in occupation crop up during drought years.



Rainwater harvesting both the *in-situ* and through traditional water harvesting systems, water conservation, groundwater recharging and alternate grass and tree based land use systems discouraging water intensive crops would be long-term answers for sustainable development of the arid region.

EPILOGUE

A study on long-term rainfall records of the Indian arid region showed that the region experiences agricultural drought every third to alternate year in one or the other location. To overcome the current drought situation many strategies are being adopted by the State agencies through Central and other relief. The measures include provision of drinking water. fodder and food for human and livestock, employment generation schemes, subsidy to cattle camps and *Gosalas*, etc. Drought relief funds are scarce and these must be utilized more efficiently to meet the emergent demands of the affected people as well as to evolve a long-term strategy to combat drought.

The drought situation like the present are/will continue to occur in this region and it needs a proper planning to combat drought/famine. Drought impacts are generally more severe on livestock than on human beings. Some of the measures that can be taken up for combating drought could be as follows:

Short-term measures

1. Early warning and drought monitoring should be carried out on the basis of long, medium and short-term forecasts.
2. Constitution of task forces in each district to initiate relief measures immediately after the drought strikes.
3. Supply of good quality drinking water to human and livestock in severely affected areas.
4. Fodder banks should be established in the region. Low quality fodder/alternate fodder resources should be enriched to meet the protein demand.
5. Cattle camps should be opened and fodder should be provided at a subsidized rate.
6. Contingency crop plans should be prepared in advance to meet out the aberrant weather conditions such as early/late setting of monsoon and or early/late withdrawal of monsoon.
7. Implementation of crop and livestock insurance schemes.
8. Timely availability of credit, postponement of revenue collection and repayment of short-term agricultural loans.
9. Training of personal involved in drought relief measures on short/long-term basis.

Long-term measures

1. Greater coordination among line departments should be ensured.
2. Constitution of a drought monitoring committee to advise on drought situation.
3. Rainwater harvesting for both the drinking and *in-situ* cropping, improvement and popularization of traditional rainwater harvesting systems and rainwater conservation/efficient utilization.
4. Rejuvenation of traditional rainwater harvesting systems viz. *Nadis*, *Tankas*, *Khadins*, etc.
5. Systematic study on the use, artificial recharge and augmentation of groundwater aquifers.
6. Completion of IGNP lift canals to divert water to drought prone areas.
7. Human and livestock population should be managed to reduce the pressure on fragile arid ecosystem.
8. Popularizing the improved agronomic practices to maximize the crop yield per raindrop.
9. Integrated watershed management for efficient management of land and water resources should be given top priority. Appropriate land use planning, discouraging water intensive crops, encouraging sprinkler and drip irrigation systems, and practicing alternate land use such as agro-forestry, agro-horticulture and silvi-pasture would provide long-term drought proofing in the Indian arid zone.

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