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**Review/Overview Article**

# Drought in India: Its impact and mitigation strategies – A review

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## ABSTRACT

Drought is temporary reduction in water or moisture availability significantly below the normal amount for a specific period. It is a climatic anomaly characterized by deficient supply of moisture resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need or a combination of all the 3 factors. Droughts, in general, are extreme hydrologic events causing acute water shortages which persist long enough to trigger detrimental effects on human, vegetation, animals and ecosystem over a considerable area. To a meteorologist, drought is the absence of rain, while to the agriculturist it is the deficiency of soil moisture in the crop root zone to support crop growth and productivity. Based on the criteria, concept of its utilization and different schools of thought, drought is broadly categorized into meteorological drought, hydrological drought, agricultural drought and socio-economic drought. In rainfed areas, drylands are more prone to 'drought'. Since last one decade of 21st Century, it has been observed that monsoon rains are deviating much from its predictions and the states/regions which never experience such a natural calamity comes under mild to acute drought–prone regions. In cases of field crops and other vegetation, it creates moisture-stress conditions when the amount of water needed for evapotranspiration exceeds the total amount of moisture available in soil. To define, drought is taken to have occurred over an area where the annual average rainfall is less than 50–75% of the normal south–west (S–W) monsoon rains. Delayed onset of S–W monsoon rains or early receding of monsoon rains towards half–way of the season or long gaps between 2 heavy and effective rains during rainy season are the general phenomenon of agricultural drought in India. The India Meteorological Department (IMD) generally predicts the monsoon status (weak or normal) 3–4 months before for each state/region. In this article, the nature, impacts of recent agricultural droughts in India and mitigation strategies are reviewed.

***Key words***: Drought, Impacts of drought, Drought mitigation strategies



In India, only 4.2% of the world fresh water resources are available. Agriculture sector in India has been and is likely to remain the major user of water (NCA, 1976). It is estimated that the share of water allocated for irrigation is likely to decrease by 10–15% in near future. Rainfall is the ultimate source of water, affecting crop production and other biomass by directly influencing soil–moisture status as well as supporting surface and ground water irrigation. However, possibilities of occurrence of drought in India vary from once in two years in Western part of Rajasthan to once in 15 years in north-east Indian states (NRAA, 2009). The frequency and intensity of extreme weather events like droughts, floods, heat/cold waves, cyclones, delayed or early onset, long dry spells, early withdrawal, floods in drought frequented areas and droughts in flood afflicted areas have increased during the last 2 decades due to global warming (Roy and Hirway, 2007; NRAA, 2009). Rainfall pattern is an index of water resources. The strong dependence of Indian agriculture and the country's economy on monsoon is well established. It is well known that the Indian agriculture contributes around 14% of the national Gross Domestic Product (Economic Survey, 2013). India's current production (mainly from irrigated agriculture) and reserves make the country food secure. The Ministry of Agriculture, Government of India, projects that the domestic demand of foodgrain by 2020 will be around 285 million tonnes. This will require a paradigm shift based on harnessing all the available natural resources for sustainable development of agriculture in drought–prone rainfed areas too, which was bypassed during the Green Revolution era (Saxena, 2012).

The Indian sub–continent is influenced by South–West (S–W) monsoon during June–September and North–East (N–E) monsoon during October–December. Nearly 70% of the annual rainfall in India is received during the S–W monsoon (Saxena, 2012). During the rainy season, gener-

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ally extreme variations occur in rainfall. Floods and drought can strike the country simultaneously at different places (Singh, 2002). Nearly 60% of the net cultivated land is rainfed and the rest is irrigated. According to National Commission on Agriculture, the country has an ultimate irrigation potential of about 113 million ha (NCA, 1976). At present, irrigated area in India is around 63 million ha (DAC, GOI, 2012–13). All rainfed areas are not alike. There are great regional variations because of rainwater availability. About 28% of agricultural land is drought prone and as such suffers from critical water shortages (Samra, 2004). As uncertainties swing in the onset, continuity, and withdrawal pattern of monsoon make crop production a risky preposition. In rainfed areas, drylands are more prone to drought which is found from north to south and in western part of the country. In the last one decade, it has been observed that monsoon rains are deviating very much from its predictions and the region which never experiences acute drought comes under this natural calamity of drought (Roy and Hirway, 2007). The drought prone areas are low in agricultural productivity and also low in overall economic growth. Poor people in these regions are highly vulnerable to a number of risks due to their low and fluctuating income, high indebtedness and poor human development (NAAS, 2011). Helping the poor to come out of vulnerability and poverty and integrating the drought–prone areas into the mainstream of development is a serious challenge faced by policy makers at present.

Hence, an attempt was made in this article to discuss the real meaning of agricultural drought of 21st century, its impact and mitigation strategies for Indian sub-continent.



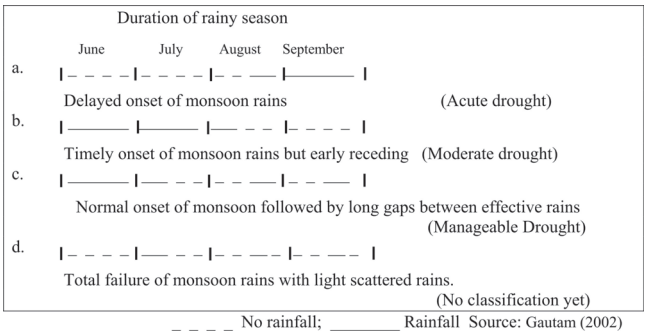
## Drought and its significance

Drought can be defined in many ways, such as, 'a period of dry weather' (Nagarajan, 2003); 'a condition of abnormal dry weather resulting in a serious hydrological imbalance, with consequences such as losses of standing crop and shortage of water needed by people and livestock' (Alexander, 1993); and 'a creeping situation of scarcity without recharging of resources'(Swami, 2001). Droughts are categorized in a number of ways as we have various measures to identify drought conditions in a particular space and time (Roy and Hirway, 2007). The meteorological drought**,** which is most widely accepted, is based on the degree of dryness and the duration of dry period. It defines drought conditions when precipitation deficit is more than 25% to its normal in a particular region. If the precipitation deficit is more than 50% of long–term average, it is called severe drought. The meteorological definition of drought does not take hydrological, ecological and manmade factors into consideration (Roy and Hirway, 2007; Reddy, 2008). Hydrological drought conditions occur when there is significant depletion of surface water causing very low stream flow and acute drying of lakes, ponds, reservoirs and rivers (Reddy, 2008). When inadequate soil moisture produces severe crop stress and affects crop productivity adversely is called agricultural drought (Reddy, 2008). Ecological drought occurs when primary productivity of natural or managed ecosystem declines drastically due to reduced precipitation in a long run. Socio–economic droughts are the aggregate of all the above droughts when precipitation is not adequate to meet the needs of human activities (Roy and Hirway, 2007).

## Agricultural drought

Agricultural drought is a period of dryness affecting the soil-moisture status and preventing the growth of plants. Drought creates a condition when the amount of water needed for transpiration and evaporation exceeds the total amount of moisture available in soil. It is the result of the moisture stress in soils and plants during crop growth (Reddy, 2008). In India, crops grown under arid and semi–arid conditions are often prone to the situations of agricultural drought (Gupta, 1992). The water–stress conditions created by drought are always linear and gradual. The intensity of drought may be moderate or severe depending on the deviations of seasonal rainfall. In other words, it commences with the inability of plant roots to obtain soil moisture rapid enough to maintain the internal water balance of the crop (Gupta, 1992). Distribution of rainfall also counts in determining the drought (Reddy, 2008). Delayed onset of S–W monsoon rains or early receding of monsoon rains towards half way of the season or long gaps between two heavy and effective rains during rainy season are the general phenomenon of agricultural drought in India (Box below).

Probable abnormal monsoon conditions in India




Rainfed agriculture generally refers to agriculture which is totally rain dependent. (Gautam, 2004). About 60% of the cultivated area (94 million ha) are rainfed in India and about 300 million people live in these areas

(Gupta *et al.*, 2011; NRAA, 2013); more than 50% of the region is affected by drought once every 4 years (UN, 1990). Rainfed dryland areas refer to areas where rainfall is low, erratic and for a short duration. Specifically, drylands are defined as the areas where the minimum annual average rainfall for producing a crop is estimated to be as low on 500 mm. This range of rainfall is not sufficient for the crop plants to grow as the evapo–transpiration exceeds moisture absorption (Gautam, 2004). These areas are more prone to droughts as compared to medium and high–rainfall areas. Paucity of rainfall is the most potent single factor which determines drought–prone areas (Gautam, 2002).

The first Scarcity Manual was prepared by the British Government in 1883, which was followed by other manuals by some provincial governments (Hirway, 2001). In 1928 the Royal Commission on Agriculture recommended promotion of dryland farming to promote agriculture in drought affected regions. However, the efforts were scanty and there was an alarming increase in the frequency of drought during the British period (Bhatia, 1985). In the recent past, India has experienced 22 large scale droughts in 1891, 1896, 1899, 1905, 1911, 1915, 1918, 1920, 1941, 1951, 1965, 1966, 1972, 1974, 1979, 1982, 1986, 1987, 1988, 1999, 2000 and 2002 with increasing frequencies during the periods 1891–1920, 1965–1990 and 1999–2012 (NRAA, 2009, 2013). After Independence droughts have received much more attention of Government and policy–makers than before. One observes an evolution in the drought policy over the past few decades. Famines have been eradicated and deaths due to starvation are rare. The government has adopted a 3–pronged strategy to face droughts: (i) providing relief to drought hit population under scarcity relief programmes, (ii) designing special area development programme for drought–prone areas and desert areas (DPAP–drought prone area programme and DDP–desert development programme) and (iii) promoting dry farming agriculture as a part of agricultural policy (Roy and Hirway, 2007).



**South–West monsoon in India and drought occurrence**

India gets abundant rainfall through S–W monsoon and it is 70–75% with largest number of rainy days between June and September every year (*indiastat.com*, 2013). The rainfall distribution varies widely as some areas are ever arid and some receive excess rains. The Indian sub-continent experiences an average annual rainfall of around 1,200 mm and its water resources are enormous. The regions that receive largest quantity of annual rainfall are the slopes of Western Ghats (8,500 mm) and N–E states (10,000 mm) of India. During this season, the lowest quantity (200–350 mm) of rainfall is received in Rajasthan and adjacent parts of other states (NAAS, 2011; *indiastat.com*, 2013). The variation from year to year also exists as the rainfall causes floods in one year and drought during next year. This requires proper management and conservation of water (NAAS, 2011). Normal monsoon rains distribution (Mean annual rainfall) in different regions of India is given in Table 1 (Khanna and Khanna, 2011).

**Table 1.** Normal monsoon rains distribution in different regions of India

| | Region | Mean Annual Rainfall distribution |
|---|---|---|
| (i) | 33% – Low rainfall region | 750 mm and less |
| (ii) | 35% – Medium rainfall region | 751–1125 mm |
| (iii) | 24% – High rainfall region | 1126–2000 mm |
| (iv) | 8% – Very high rainfall region | >2000 mm |

Failure of S–W monsoon rainfall or its receipt in lesser quantities is a frequent phenomenon in India, which results in drought and distress very often. Experts believe that there seems to be a clear association between "*El Nino*" and "*La Nina*" events and weak monsoon (Gupta *et al.,* 2011; Gautam, 2012). *El Nino* (meaning 'little boy' in Spanish) is marked by an abnormal warming of the 'Eastern Pacific Ocean' and creates havoc in weather patterns and linked with abnormal rains in 'Asia Pacific Region' including India. Abnormal rains could appear in any year due to *El Nino* effect, but its precise impact on Indian monsoon is still hard to gauge. An *El Nino* weather pattern had triggered India's 2002 and 2009 droughts shrinking farm output to a greater extent. *La Nina* (meaning 'little girl' in Spanish) on the other hand cools ocean water and helps rainfall in Asia Pacific Region including India. During the 90 years period between 1898 and 1988, drought occurred due to *El Nino* effect in 11 of the 21 drought years (NRAA, 2009; Gautam, 2012). It is well established that the *El Nino* phase of the south oscillation (ENSO) have direct impact on drought (Agarwal, 2003). The country receives an average of around 1,200 mm rainfall in a year and its fluctuation is wider. About 185 districts (1,173 developmental blocks) in the country spread over 13 states have been identified as drought-prone or water-stress areas, where rainfall is low, for a short spell (NAAS, 2011). There is often negative balance between annual rainfall and ET rate. These districts are more prone to drought as compared to other moderate to high rainfall states (Gautam, 2012). The drought, as a disaster in its severe form can cover any part of the country including or excluding the drought–prone areas, as it has been observed in the past (Table 2). Drought is a perennial feature in

some parts of India as about 28% of the sown area is at one or the other places susceptible to drought (Samra, 2004). Drought– prone areas are identified based on moisture index and shown in Table 2. Moisture index is computed using the data of annual precipitation (P) and the annual water need (PET) as per the following formula given by Thornthwaite and Mather (1955).

Moisture Index= (P–PET)/PET × 100

**Table 2.** Identification of drought prone areas

| Moisture index | Climatic zone | Per cent area of India |
|---|---|---|
| <–66.7 | Arid | 19.6 |
| –66.7 to –33.3 | Semi-arid | 34.0 |
| –33.2 to 0 | Dry sub-humid | 21.1 |
| 0 to + 20 | Moist sub-humid | 10.2 |
| +20.1 to + 99.9 | Humid | 7.8 |
| > + 100 | Per-humid | 8.3 |

Source: Khanna and Khanna (2011)



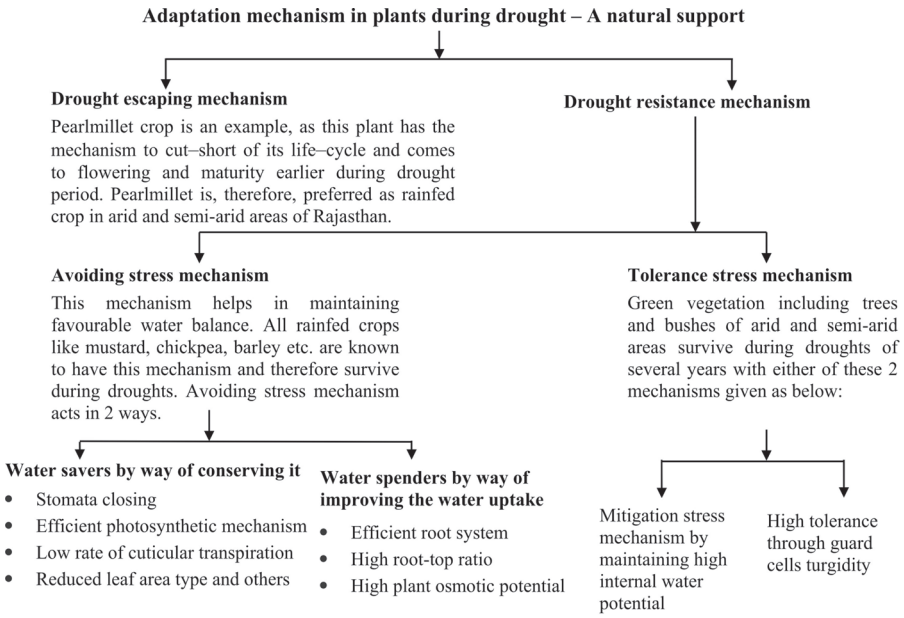
## Impact of drought

Mostly, the nature of impact attributable to drought is extensive/comprehensive, sometimes even difficult to identify. The problem is further compounded by the fact that drought invariably is handled as a 'crisis situation' and a short-term problem. At the household level, individuals perceive drought as a natural hazard, beyond human control. The impact of a drought on the overall economy of the country is evident both at the macro and micro levels. It is either direct or indirect and varies in nature and intensity. The extent and intensity of drought impact is determined by prevailing economic conditions, the structure of the agricultural sector, management of water resources, cereal reserves, internal and external conflicts etc. Micro–level impact is largely on the capability to produce and procure food, depending on the social structure, class, village and household resource endowments. The relative and absolute magnitudes of each impact will however, depend on specific regional characteristics. Droughts cause a loss of assets in crops, livestock and productive capital, as these are immediate consequences of water shortage. The lingering impact is felt on the shortage of quality seeds in the subsequent season (NDMG, 2010). Famines like conditions are created in acute drought conditions of the affected region/state. (Samra and Singh, 2002; Samra *et al*, 2006; Reddy, 2008; DAC, GOI, 2009)

## Impact of drought on agricultural field crops

- Delay or prevention of field preparation and other cultural operation, sowing/planting of field crops and crop establishment.
- Weakening or destruction of established crop. The effects are more pronounced in case of early season drought.
- Pre-disposition and vulnerability of crops to various insects-pests and diseases.
- Alteration of physiological and bio-chemical metabolism in plants.
- Alteration of quality of grain, forage, Fiber and oil etc.
- Drought is responsible for reduction in grain and fodder yield of field crops.

Plants develop various adaptation mechanisms to survive and reproduce during the drought condition as a natural support system and thus many plant species are capable to withstand against drought (Reddy and Reddy, 2005; Gautam 2002). These mechanisms are as given below:



The crops and other vegetation, bearing either of the above mentioned mechanisms, very successfully survive in drought prone areas of India (Gautam, 2002; Reddy and Reddy, 2005). In addition to natural support, farmers also try to adopt the agronomic practices for collecting, conserving and utilizing soil-moisture to improve water–use efficiency (WUE) as well as to harvest satisfactory crop yield even during drought seasons (Gautam, 2002; Reddy, 2008).

## Environmental, social and economic impacts of droughts

The usual impact of agricultural drought is in terms of loss of crops, malnutrition of human being and livestock, land degradation, loss of other economic activities, spread of diseases, and migration of people and livestock (NAAS, 2011). The droughts not only adversely affect the food security at the farm level but the national economy and overall food security as well. Predicted losses to agriculture in India were 50% during the drought of 1957–58. The drought of 2002, registering the steepest fall of 38.7 million tonnes in foodgrains production and affected 300 million human and 150 million cattle due to lack of food, fodder and water. Similarly, as a result of drought in the year 2009 the food grain production was estimated to be less by 7% compared to 2008–09 (Samra, 2004; Economic Survey, 2010; NAAS, 2011).

Excessive withdrawal of groundwater to save crops under drought condition has depleted groundwater in the North–western India and other parts of the country. It is irreversible loss in many cases due to lack of recharging possibilities. Farmers excessively consume electricity and fossil fuels for pumping groundwater in order to offset rainfall deficiency (NRAA, 2013). Cost of cultivation also increases especially for rice and other rainy season (*kharif*) crops due to greater use of energy and diesel for lifting groundwater and re-sowing (Gautam, 2012; NRAA, 2013).

The availability of water in surface water–bodies reduces significantly during the drought year. The groundwater table declines and the wells, especially shallower ones, dry up. Sometimes, the concentrations of salts and toxic elements such as arsenic, fluoride and nitrate also increase in the groundwater (NAAS, 2011; Gautam, 2012). Rise in prices, contraction of charity and diminution of credit and consequently enhancement in the rate of interest on loans, reduced grain trade, increase in petty crimes, unusual migration of the people along with their herds, etc. could be some of the most common outcomes of drought and thus affects social life of mankind (NAAS, 2011). Droughts also affect the livestock. Reduced productivity and mortality of the bovines are the direct effects. Depletion of forage resources, overgrazing and indiscriminate cutting of vegetation take place which consequently leads to land degradation. Under extreme drought situations, large–scale human and bovine migration and livestock mortality take place (Sagari, 2006; NAAS, 2011; Gautam, 2012).

## Impact of drought in different years in India

The S–W monsoon accounts for around 70% of the annual rainfall over major parts of India. Its timely occurrence in normal intensity and uniform distribution determine the prospects of agricultural production (Reddy, 2008). The drought of 2002 is considered to be the worst in last one hundred years and was termed as the most acute drought due to total failure of monsoon rains (64 mm only) till August 2002. During *kharif* 1987, the rainfall received was 102 mm as compared to 650 mm average rainfall of N–W part of India. Its impact, particularly in the year 2002, on human being, livestock and natural resources in states like Haryana, Rajasthan, Punjab, Uttar Pradesh, Odisha, Madhya Pradesh, Gujarat, Tamil Nadu, Karnataka and Kerala are on record (Samra, 2004; Sagari, 2006). Due to deficient rainfall, there were signs of drying of reservoir, rivers, depletion of surface water and soil moisture. Under such situations, groundwater could not meet the water demands of crop, animal and human beings for a longer period (Sinha, 2002; Gautam, 2012). Therefore, the area under cultivation was reduced (Sinha, 2002). The Government of India realized that area under rice (*Oryza sativa* L.), Pearlmillet [*Pennisetum glaucum* (L.) R. Br. emend Stuntz], sorghum [*Sorghum bicolor* (L.) Moench], maize (*Zea mays* L.), groundnut (*Arachis hypogaea* L.) and soybean [*Glycine max* (L.) Merr.] was reduced by 5 to 20% and the production of these *kharif* crops, thereby was recorded 5 to 7% less. Data on range of decline due to drought may be seen in Table 3.

Ghosh and Jana (1993) reported that in India during the last 120 years (1870–1990), drought occurred maximum during 1901–1925 across 29 out of 35 meteorological subdivisions. Gautam (2002) also reported that in the beginning of 21$^{st}$ century, i.e. the year 2002 will be remembered as the year of severe drought covering nearly 30 meteorological sub-divisions of India. This drought had close similarity with 1899, 1918, 1972 and 1987 droughts. Samra (2002) revealed that about one–fifth of the total geographical area is usually affected by drought once in 5 years and thrice in 10 years.

The main reasons for this type of natural calamity include the following:

- Prolonged low precipitation in terms of initiation, duration, intensity, persistence and termination was the major cause of severity of 2002 drought.

**Table 3.** Decline in foodgrain production in drought years during 1964–65 to 2003–04

| Range of decline (million tonnes) | Years |
|---|---|
| >20 | 1979–80, 2002–03* |
| 15–20 | 1965–66, 1966–67 |
| 10–15 | 1972–73, 1987–88, 1995–96 and 2000–01 |
| 5–10 | 1976–77, 1984–85, 1986–87, 1991–92, 1997–98, 2009–10 |
| <5 | 1971–72, 1974–75, 1982–83 |

*The most steep decline in food production of 38.66 million tonnes occurred in 2002–03, followed by 22.20 m tons in 1979–80. The time series data on total foodgrain production in India indicate that the values have declined in 16 individual years during 1964–65 to 2003–04. This has hampered the growth rate of production over the years apart from sufferings of the people during drought years.

Source: ICAR, New Delhi (2006); NAAS, (2011)



- Delay in land preparation and crop establishment was noted in all the drought affected areas.
- Weakening and distribution of established crop due to occurrence of drought in a linear direction.
- Predisposition of crops to insects, pests and diseases on a longer scale as compared to normal seasons.
- Alteration in physiological and bio-chemical metabolism in foodgrain plants is quite obvious during drought season.
- Degraded quality of farm produce like foodgrains, fodder, fibre and oilseed crops.
- Marked reduction in yield of crops both in rainfed as well as in irrigated areas.
- These droughts not only reduce the total crop production during the affected year but also pull-down the GDP and economic growth of the country.

Due to these acute water-stress conditions, there is a need for efficient drought management strategies for the survival of all living being and valuable vegetation including crops and trees.

**Agricultural drought–mitigation strategy**

In India, the IMD generally predicts in the month of January or February every year, normal or less rainfall or drought-like situation in a particular state or region of the country. On the basis of this information, the Government at the centre and state level becomes active and draw guideline to face the forthcoming drought, if any, and a disastrous situation is averted so that minimum losses occur particularly for food, fodder and fibre production in the affected areas (Gautam, 2012). The severity of the drought depends on its duration, degree of water deficiencies and the size of the affected area. Drought has significant consequences in terms of reduction of agricultural production, energy generation, livestock and human population migration and thus resources are required for mitigation the resulting hazards (NAAS, 2011).

On the basis of observation of Jakhar (2002), Samra and Singh (2002), Samra (2004), Samra *et al.* (2006), NRAA (2009), DAC, GOI (2009), NAAS (2011), Gautam (2012), NRAA (2013), Bana *et al.* (2013) and Bana (2014) an integrated approach to mitigating the drought effects in India has been summarized and presented below:

- During drought, to provide water for drinking purposes and life–saving irrigation to major field crops the water availability in the major reservoirs in the country is to be checked well in advance. For each irrigation reservoir, prepare a separate water budget. Monitoring of the expected damage to groundwater regime is also equally important. During drought period and in drought–prone areas, it is necessary to regulate the water supply to water–intensive industries.
- During drought, drinking water availability also attracts the attention of the Government. With the implementation of Rajiv Gandhi National Drinking Water Mission and Accelerated Water Supply Programme, vast network of water supply schemes have been setup in the entire country. Provision of hand–pumps, carrying water in water tankers and trains, digging of more bores for increasing the number of tube–wells and flowing water from major reservoirs into canals for making the water available for drinking on priority and agriculture purposes, if possible.
- Relief measures are also required for providing livelihood environment to upkeep the cattle wealth during and after drought as natural calamity. It includes, fodder availability and transport to the affected areas and monitoring of fodder. Fodder cultivation is to be encouraged in all possible regions/states of the country.
- In drought–prone areas, it becomes necessary to generate additional employment through labour–intensive works for water harvesting etc. at the village level.
- Public health and cattle health care should also be on priority and to monitor for the supply of disinfect drinking water to prevent spread of water–borne diseases and plans to cope–up with likely epidemic. Immunization and surveillance of public and livestock health measures be taken.
- Molasses–treated cattle feed and fodder in the form of pressurized bricks has been developed at IARI, New Delhi, which is now recommended.
- General public should come forward to learn more about various natural calamities including droughts.

Side by side, they are to be advised to know about available natural resources of a particular region and planning to minimize the risk by diversifying production technology to sustain better livelihood.

- There is a need to give more emphasis on better extension programmes to disseminate the modern technology for crop husbandry in drought–prone areas.
- Due to Global Warming, there are chances of unpredictable weather conditions and drought occurrence frequency even in high rainfall areas of Indian sub–continent. Therefore, there is a need to give serious thought on household strategies and farming system approach to manage drought and to provide alternate income sources to the farmers. For example, horticulture, tree plantation, poultry farming, bee–keeping, mushroom farming etc. are recommended for certain households. Investments in the processing of farm products generate income and diminish the risk of high dependence on water.
- Diversification of cropping system is needed in selected regions to save water and its efficient management. The low water–requiring crops and varieties and perennial component of vegetation including agro–forestry, agri–horticulture, medicinal and aromatic plants may be expanded and promoted in drought prone areas as income and employment–generating options.
- Adoption of resource–conservation technologies (RCTs) and conservation agriculture (CA) practices may be helpful in enhancing resource use efficiency, crop productivity and farm profitability. These technologies also assist in mitigating the stress of drought and climate change.
- Estimate indicates that by 10% increase in WUE, country can gain about 50 millon tonnes of additional foodgrains from the existing irrigated areas. Therefore, strategy should also be towards development of technology to improve the WUE for future. Minor irrigation projects, their planning and execution are the probable examples in this direction.
- To mitigate drought like situation, it is ideal to have integrated watershed approach for maximizing rain water use. Judicious use of limited irrigation water, rainwater harvesting and its recycling, retaining precipitation *in–situ* and minimize run–off is necessary for combating drought.
- Alternative cropping strategy/contingent crop planning is to be planned and implemented as per the nature of the drought. This is to be supplemented by providing extra electrical power, seeds of recommended crops, varieties and fertilizers etc. at subsidized rates.
- Life–saving practices/mid-way corrections should come in practice including adoption of agronomic practices, viz. thinning, mulching and use of anti-transpirants mainly to reduce the transpiration and evaporation losses during the water-stress periods. For saving the field crops from drought the agronomic measures suggested are as follows:

  - Reduction in plant population (up to the extent of 15%) so as to minimize the transpiration losses.
  - Need based intercultural operations in the form of dust mulching to check the evaporation losses and for efficient soil moisture utilization.
  - Spray of anti-transpirants like Kaolin (6%), Cycocel (0.03%) on the standing crops is recommended to check transpiration losses and to give green look to the crop for a longer period.
  - Application of agricultural polymers like Pusa hydrogel @ 2.5 kg/ha to reduce the moisture stress in the plants.
  - Doses of fertilizer may be reduced or its application may be delayed depending on the soil–moisture status for good crop growth.
  - Adoption of mechanical weed control with energy efficient farm implements and thereby intercultural operations mainly to minimize the evapotranspiration losses in the standing *kharif* crops.
  - To control/minimize the insect and pest incidence and impact on drought affected crops, crop specific and appropriate integrated pest management (IPM) practices may be adopted.
  - Experiments conducted at IARI, New Delhi on pearlmillet crop during *kharif* 1987 and 2002 seasons showed that the agronomic practices, viz. thinning, mulching, use of anti-transpirants, efficient nutrient, weed and moisture management and timely plant protection saved the late sown crops like pearlmillet, yielded about 1.6 t/ha of grain yield and 4.0 t/ha of stover.
  - During the same drought like situations of *kharif* 1987, experimental findings of another experiment revealed that fodder crop mixture of pearlmillet + clusterbean [*Cyamopsis tetragonaloba* (L.) Taub.] showed best performance in terms of producing maximum fodder yield in a short time.
  - The standing irrigated crops like rice, maize, pigeonpea [*Cajanus cajan* (L.) Millisp.], cotton (*Gossypium hirsutum* L.) and sugarcane (*Saccharum officinarum* L.) may be saved by applying life–saving irrigation at saturation point depth. This is just to follow economy in water use, so that larger area may be covered with life–saving irrigation.
  - Arrangements are to be made for supplying quality

seeds of non-traditional crops recommended for cultivation during drought–affected *kharif* season.

- Mulching with dry leaves, grasses and other organic farm waste also helps in lowering the subsurface temperature and checking evaporation losses.
- Green fodder sorghum crop should not be harvested before 45 days to avoid toxicity to cattle. Rather, it was advised for briquetting of fodder for bulk transportation from surplus to deficit areas.
- Conserve water either *in–situ* or *ex–situ*. *In–situ* practices like field leveling, bunding, trenching, terracing and fallow ploughing are necessary to arrest run-off losses of water and top soil. *Ex–situ* water–harvesting practices like farm ponds, community tanks, watersheds and pools are the water banks which can prove a life saver.
- Formulation of crop-weather-watch-group comprising farmers, media, bankers, government officials and scientists to monitor and to act as advisor to the farmer to use the crop-life saving techniques and alternative cropping programmes.

- The drought of 2002 has shocked many by its severity. It was the worst of the century and affected many states. Therefore, it was suggested to frame an action plan wherein the State Agricultural Universities must work in close cooperation with their state departments of agriculture and other relevant line departments for achieving the projected demand of foodgrains, pulses and oilseeds for *rabi* 2002–03. The ICAR organized a National Meet to discuss and suggest how best to compensate the losses of *kharif* 2002 season. The following were the contingency plans recommended to ensure enhanced production (ICAR, 2002).
  - The advance declaration of support procurement price for winter (*rabi*) crops in the month of October 2002 will lead to greater confidence among farming community and assist in maximizing the production.
  - The states of Asom, West Bengal, Jharkhand and Odisha using shallow tube-wells can take–up more area under high yielding winter season Boro rice. Likewise, the states of Andhra Pradesh, Tamil Nadu and Karnataka need to bring larger area under *rabi* rice for the purpose of more rice production just to compensate the loss occurred during *kharif* rice production.
  - The cultivation of *rabi* maize in eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal and Karnataka can increase total *rabi* production.
  - Wheat production is to be maximized in these areas by using high–yielding varieties (HYVs) and improved agronomic technology.
  - Subsidy may be considered for pressurized irrigation systems like sprinkler and drips to help in bringing more areas under cultivation in states like Rajasthan, Madhya Pradesh and Maharashtra.
  - To avoid the delay in wheat sowing, zero-tillage drills may be used by the farmers of irrigated areas. In addition to that, joint efforts of all concerned agencies need to be made to promote available technology across the drought– affected areas.
  - More rainfed areas in northern and central India should be covered under oilseeds and pulses such as taramira (*Eruca sativa* L.), rapeseed-mustard, lentil (*Lens esculenta* Medik.), and chickpea (*Cicer arietinum* L.). These crops can survive in a better way due to conservation of moisture by late monsoon rains.
  - In the region of Tamil Nadu, Karnataka, Odisha, Jharkhand and Chhattisgarh, alternative crops like horse gram (*Macrotyloma uniflorum* Lam.), *rabi* millets, sweet potato [*Ipomoea batatas* (L.) Lam.], and tapioca (*Manihot esculanta* Crantz) may be recommended.
  - There is a likelihood of an overall shortage of fodder production and therefore steps to setup fodder banks should be taken and arrangement may be made for unhindered fodder transport from fodder abundant areas to deficient areas.
  - For rainfed *rabi* crops, timely sowing of crop by using recommended methods and band placement of full doses of fertilizers in the moist zone needs to be done. The organic manures may be applied well in advance during land preparations. Aqua–fertilizer drill sowing and fertilizer application at wider row spacing are also preferred.
  - Intercropping in definite ratios may be followed in rainfed areas to have minimum risk against total crop failure and also for better moisture utilization.
  - In irrigated areas, proper leveling of fields, selection of HYVs of *rabi* season seeds, adoption of seed–cum–fertilizer drill for proper placement of fertilizer and seeds are necessary practices. Frequent but light irrigations are given either through sprinkler or by surface to cover more area with limited irrigation water. Preference is needed for conjunctive use of surface and groundwater in canal command areas. Raised bed method of planting is always superior to reduce water needs.
  - Development of dynamic and upgraded market infrastructure and market information system, so that the price watch group can keep the producer

(farmer), processing industry and consumer in a balance of mutual benefit.

- Under Emergency Relief Programme, there is a recommendation of giving loans to farmers on concessional rates.
- A mechanism should be developed to export more wheat (*Triticum aetivum* L. emend. Fiori & Paol.) so that the foreign exchange earned can be of use for the strategic import of edible oil and pulses, if necessary.
- In North–western India, the farmers may take–up potato (*Solanum tuberosum* L.) cultivation in September or go in for short–duration pea (*Pisum sativum* L.), radish (*Raphanus sativus* L.), cabbage (*Brassica oleracea var. capitata*) and then for wheat. The vegetable biomass can also be used as animal feed and this will give an economic relief as they fetch a better price.
- Area planning of different *rabi* crops needs to be developed region–wise, along with recommendations related to suitable varieties and agronomic package of practices with the cooperation of State Agricultural Universities and State Departments of Agriculture.
- In case of pulses, treatment with rhizobium culture should be made mandatory; seed–producing agencies should be allowed to sell the seeds only if the packaging encloses the inoculums of rhizobium culture.
- Pre–sowing seed treatment (hydration + fungicide) should be made mandatory and farmers must be educated to follow the simple technology to ensure lower disease infection and spread as well as higher levels of germination.
- Timely sowing is critical for higher yields in the moisture stress seasons. Better crop-stand establishment, early seedling vigour and better use of available moisture during the crop growth period are the various merits of timely sowing of field crops.
- Aqua–fertilizer drill, designed and developed at the IARI, New Delhi, has been proved useful for seeding and placing the fertilizer along with adequate moisture at a proper depth which results in proper germination.
- Use of organic molasses and dust-mulching are proved very effective from better water use efficiency point of view.
- Efficient weed control save the crops from transpiration losses. Yields are drastically reduced if weeds are not removed within 3-4 weeks of emergence.

After experiencing the drought effects in agricultural fields, it has become essential for the administration to work for efficient drought–management practices that include:

- Operation of an early warning system mainly to mitigate forthcoming drought of any kind.
- Drought preparedness measures–a look for implementation.
- Conservation of water through water–budgeting measures. Judicious use of limited irrigation water. Rain water harvesting through all possible means including *in–situ* rain water harvesting. Management of underground water by way of infiltration tanks, check dams etc.
- To adopt integrated watershed approach for maximizing rain water use. To adopt drip–farming.
- Recycling of runoff water after rain water harvesting and drainage.
- Resource management for stabilizing crop production. Implementation of long term strategy of fodder banks. To have a check on evaporation and transpiration losses.
- Assurance to the affected population of physical and economic access to food and preservation of farmers' assets to enable them to recover quickly after the resumption of the normal monsoon.
- To promote adoption of drought–tolerant crops for the survival.
- Institutional mechanism for arrangement of quality seeds, chemical fertilizers and pesticides etc. to stabilize yield (Jakhar, 2002).

**Drought Assessment and Monitoring**

The Hanumantha Rao Technical Committee on Drought (April, 1994) worked out the Moisture Index (MI) to assess the extent of aridity which is the ratio between the precipitation received and the water requirement of the plants under the given agro-climatic conditions (MRD, GOI, 1994). As per Committee report except for Punjab and Kerala, other parts of the country are prone to drought in one or the other year (Khanna and Khanna, 2011).

The Indian Meteorological Department (IMD) gave an early warning system about the possibilities of impending drought. Many states in India have now developed a sophisticated monitoring system to manage drought. The Weather Watch Group in the Ministry of Agriculture, Government of India is working since 1979. The expert meets every week, particularly during rainy season of each year to take stock of the rainfall, its effect on the crops growing in the fields (Gautam, 2012).

Drought Index is denoted by Palmer Index as:

(i) Mild = 1 – 1.99
(ii) Moderate = 2 – 2.99
(iii) Severe = 3 – 3.99
(iv) Extreme = more than 4.00

The National Agricultural Drought Assessment and Management System has been developed by Ministry of Space for the Department of Agriculture and is primarily based on monitoring vegetation status through National Oceanic and Atmospheric Administration Advanced Very High Resolution Data. The drought assessment is based on a comparative evaluation of satellite observed green vegetation cover of a district in any specific time period with that of any similar period in previous years.

**Future action plans for managing droughts in India**

Creation of databank for scenario of major drought in the past is essential for future drought–mitigation planning. The Central Government now has permanent arrangements for Calamity Relief Fund for reducing the impact and severity of drought. Some of the sponsored programmes include (*i*) Rural Works Programme (RWP), (*ii*) Drought Prone Area Programme (DPAP), (*iii*) Desert Development Programme (DDP), (*iv*) Food For Work Programme (FWP), etc. In addition to these relief programmes, the Crop–Weather Watch Group and Technology Mission are already established to tackle the droughts. The crop insurance schemes to rice, wheat, millets, oilseeds and pulses are being implemented to give a sustainable life to those who face drought very often. Developing the dryland areas (mainly drought prone) is also a national obligation because they are home to the most marginalized and poverty stricken people in India. Getting them out of poverty, hunger and malnutrition, efforts are to be made for achieving a few of the Millennium Development Goals (MDG). These areas are also rich in agro-biodiversity and holds valuable genes that would be needed to cope with the adverse effects of predicted global climatic change. Therefore, action–plan is essential and is highlighted as below:

- Efforts should be made for reliable monsoon predictions as well as proper agro–meteorological analysis of climate–soil–crop relationship for efficient crop planning and management.
- Crop improvement (field crops and horticultural crops) should be made in relation to minimum water requirement and to suit varied local ecological situations.
- Funds for catchment treatments are meager and they should be increased.
- Ensure that every new source of water should have recharge system.
- Government should think of subsidizing to irrigated marginal farmers for not sowing paddy in future (it will save the irrigation water).
- Relief funds should be through *Gram Sabha* in cases of emergency. Provide some monetary relief to farmers for increased cost of production in the drought season and to farmers who are losing animals because of drought. There should be provision of compensation for the areas left un-cropped due to drought.
- Century–well should be provided in each village. This well should be used only in drought years for rational use of groundwater and to avoid moisture–stress situations.
- Community Seed Banks should be created for drought–prone rainy seasons.
- Community development of pastures and grazing areas and provision of supply of Urea–Molasses–Mineral fodder packs to save animals in acute drought situations.
- Completion of incomplete irrigation projects and reclamation of water–logged areas. By 2030, there is a plan to put 69 million ha under micro–irrigation.
- Diversification in cropping system (including Agro–forestry and Agri–horticulture) for saving water and for efficient water management. Promote the cultivation of drought–tolerant crops and cultivars.
- Popularization of resource-–conservation technologies and conservation agriculture practices on large scale may be helpful in enhancing resource use efficiency and crop productivity in drought prone areas. These technologies also assist in mitigating the effects of drought and climate change.
- Modified method of sowing such as aqua-fertilizer drill, zero-tillage drill and FIRB system should be adopted for better crop stand, saving of energy and more water–and fertilizer–use efficiency.
- Laser leveling of fields for check on irrigation water losses. Conjunctive use of water for proper water management.
- On–farm rainwater harvesting and efficient utilization and also on-farm generation of organic matter should be adopted for better farming under dryland areas. Proper adoption of agronomic practices for conservation and utilization of moisture under rainfed conditions.
- Improvement in the contingent crop planning for major aberrant weather conditions and mainly to mitigate drought effects.
- Bring back ecological balance by afforestation and developing silvi–pastoral and horticultural system. Also to develop livestock for generating rural employment.

- Nationwide Watershed Development Programme for rainfed agriculture should be strengthened. To start with, there are ways of storing the run-off from rainy periods for use during dry spells. These include the tanks, ponds and earth dams used for supplementary irrigation.
- Developing Weather Insurance products specific to regions and crops.

Since each drought has its unique features, the emphasis of drought management in today's context is to prevent the drought from deteriorating into famine conditions. It is essential to ensure timely delivery of necessary critical agriculture inputs at the farm level to support contingency crop planning. This includes water budgeting in the reservoirs, energy management, delivery of seeds, fertilizers and agro–chemicals and relaxation of agricultural credits etc. The traditional drought–relief approach entails transfer resources in the form of drinking water, food, fodder and income from the surplus areas to drought–affected areas. If a separate Drought Monitoring and Mitigation Centre at the national level is created under, it will definitely help in the programmes like training, documentation, research and coordination. It is now time to scale-up investment in agricultural research and extension through focused targeting and advanced planning on strategic and applied aspects in an integrated approach that can raise agricultural sector of India to a well–organized planned industry rather than adhering to its being the largest unorganized industry. Further, emphasis is required in drought–prone areas to adopt all possible techniques related to maximum rain water-harvesting, moisture conservation *in–situ* and efficient utilization of this conserved moisture in timely management of most suitable rainfed crops in the dryland fields. This step will definitely contribute in stabilizing the yield of major field crops in future. Thus, occurrence of drought like situation may be ignored for a while.



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