Drought characteristics Over Deccan Plateau Region of India

G. Srinivasan and S. Jothiganesh
Contributing Authors: KJ Ramesh, Anshul Agarwal, DS Pai, Ramakrishna Nemani and AR Subbiah

Key messages

- A persistent hazard - challenge to livelihoods of the most vulnerable communities, with cascading impacts on overall national development
- Technical aspects – monitoring, early warning and improvements – ongoing and planned – need to focus on “practical” tools that can be embedded and sustained in operational systems that capture dynamic vulnerability and strengthening existing systems
- Changing morphology of droughts in the Indian context – large-scale slow onset low-frequency to high-frequency localized impact – flash droughts
- Institutional arrangements & challenges, relevance and consequences in the future context

Droughts are one of the most frequent climate hazards in India, with significant drought conditions occurring almost once in every 3 years (Misra and Singh, 2010). As agriculture-based livelihoods form a major proportion of the socio-economy, India is amongst the most vulnerable and drought prone countries. Historically, the Indian sub-continent has experienced major droughts with prolonged impacts on water resources, agriculture and rural livelihood. The estimated impact of severe droughts on India’s Gross Domestic Product (GDP) is estimated to be about 2-5% (Gadgil and Gadgil, 2006). Indian economy underwent substantive changes in the 1990s that accelerated growth in industry and services. This reduced the share of agriculture in GDP to shrink to less than half of what it was a few decades ago (from ~32% to 15%) while the country continued to become self-sufficient in food and agri-commodities and gain greater resilience in absorbing the impact of drought.

Mishra (2020) identified five “most severe” meteorological and hydrological droughts using long-term data from 1887-2018 using standardised precipitation index (SPI) and standardised runoff index (SRI) as indicators (Figure 1). Drought severity is then quantified based on duration, intensity, and spread throughout the country. Although the most recent meteorological and hydrological drought of 2015 is not among the severe top five but is identified as one of the longest durations in the entire record lasting over 41 months ending in 2018. Hydrological droughts were driven largely by meteorological droughts caused mainly due to the deficit in the monsoon season precipitation **(Table 1**).

Table 1 Major Meteorological Drought spells in India (based on Mishra, 2020)

Peak time	Start (Year/month)	End (Year/month)	Duration (months)	Areal extent (mean area)
1900/06	Jul, 1899	Aug, 1900	13	34.5%
1877/09	Jun, 1876	Jul, 1878	25	20.5%
2003/06	Sept, 2000	Sept, 2003	36	14.8%
1918/10	Sept, 1918	Aug, 1919	11	25.9%
1966/04	Jul, 1965	Aug, 1967	25	12.7%
2016/06	July, 2015	Dec, 2018	41	8.7%

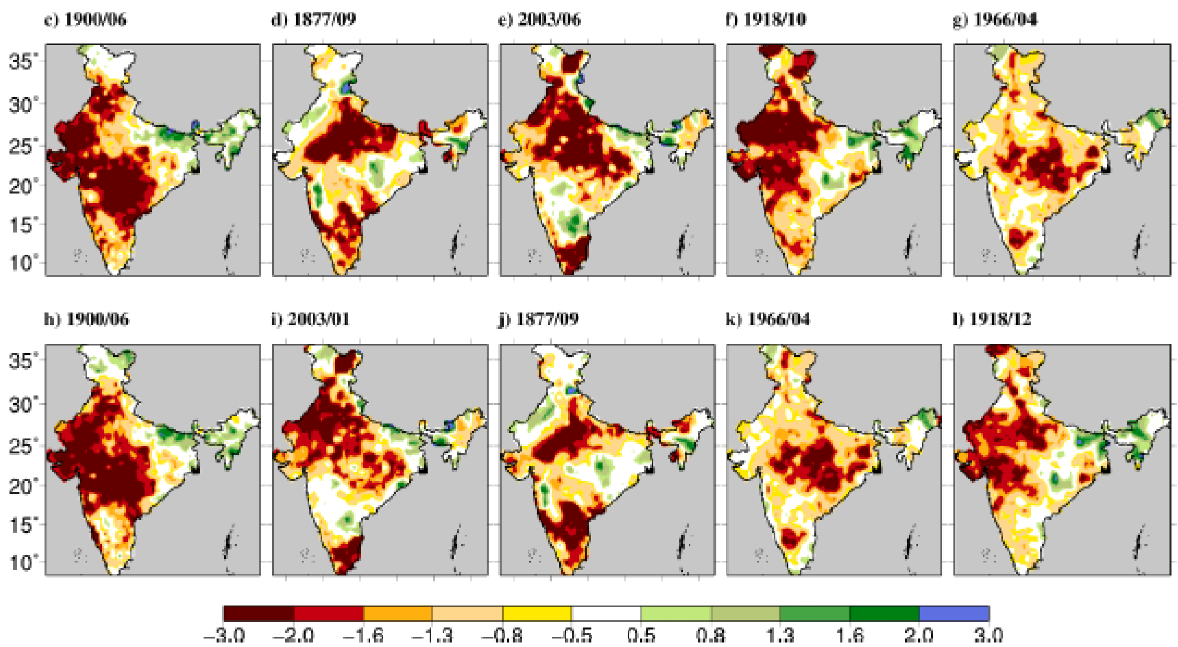

Figure 1 Areal extent of top five meteorological (top) and hydrological (bottom) droughts. Color scale shows maximum intensity as Standardized Precipitation Index (SPI)/Standardized Runoff Index (SRI) values. Source: Mishra (2020)

Longer dry spells and higher temperatures that are becoming common can, however, enhance evaporative demand affecting drought at shorter time scales. Of the 20 major hydrological droughts since 1980, the most frequently affected areas in India have been the northwest, adjoining central and its diagonal extension into the peninsular south. The highest probability of droughts of moderate and above intensity was observed over many districts from northwest India and neighboring central India and interior parts of southern Peninsula (Pai et al., 2010).

Geographical distribution of rainfall over India shows that over 68% of India is vulnerable to drought with 33% of the cropped areas that receive less than 750mm of annual rainfall (low rainfall zones) are chronically drought prone areas and 35% of the cropped areas that receive rainfall in the annual range of 750-1125 mm (medium rainfall zones) are drought prone zones.

The persistence of drought in warm seasonal climates, such as India, seem to be more challenging as noted by Van Loon et al. (2014) where they examine the effect of rainfall seasonality on droughts. In the hot dry season, rain spells will be lost to soil moisture storage and evapotranspiration, but high rainfall events may recharge the groundwater, making the variability of hydrological drought characteristics higher and the predictability of the persistence of the hydrological drought lower. Also, the linear relationship between duration and deficit may not hold good in a warm seasonal climate as sensitivity of drought deficit changes with duration.

Occurrence of moderate and severe droughts affect the agricultural crop production, with adverse effects on the crop production at national levels when the area affected by moderate drought is more than 20% (Niranjan Kumar et al., 2013). Below-normal rainfall in 1979 caused an overall reduction in food grains by 20% in India. India suffered financial losses of US$ 1 498 722 due to droughts during the period 1988–2009, and over 350 million people were affected (Singh et al. 2009). In 2017 Tamil Nadu State received 62% below normal rainfall that resulted in 87% crop damage and the Government of Tamil Nadu to declare 13,305 revenue villages out of 16,682 to be affected by drought (GoT, 2017). In Maharashtra State, a survey of the farmers in moderately drought prone areas indicate about 80% experienced severe drought once in 5-10 years, with 95% believing that it is becoming more frequent in their locality during the recent 10-12 years (Udmale et al., 2014). Despite this experience, a majority (67%) said that they have no means to prepare or mitigate drought impacts.

In the hot summer months that get prolonged due to delay in monsoonal rains, droughts impact irrigation, energy generation, and drinking water supply. For example, a precipitation deficit during the monsoon seasons of 2002 and 2009 in India caused post monsoon groundwater levels to drop dramatically and reservoirs that dried up during the monsoon season did not refill until next years' wet season (Bhuiyan et al., 2006, 2009). In 2002 this wet-to-dry-season drought caused large-scale ecological damage, mass migration, and death (UNDP, 2002).

The case study area

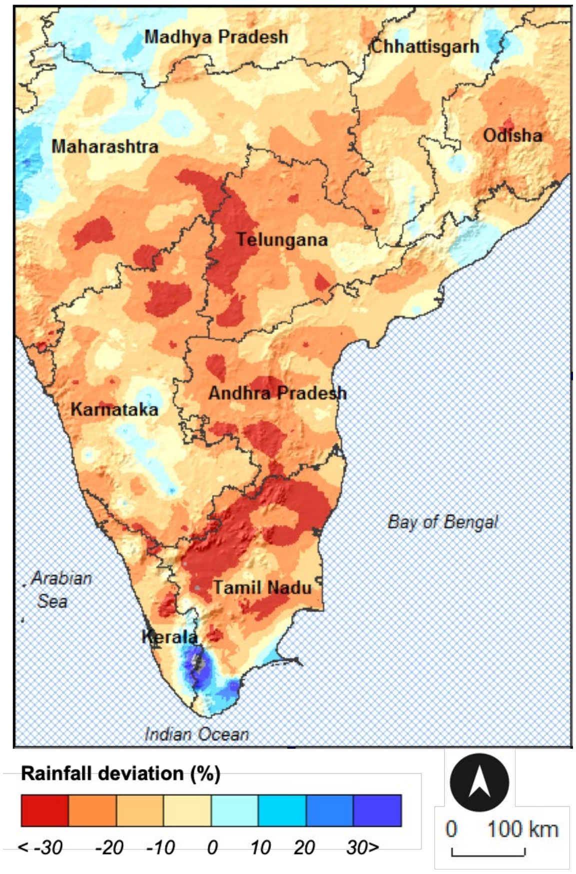

Figure 2 The Deccan plateau case study area showing composite rainfall deviations from climatological normal (1981-2010) during June-Sept. of very dry years (2002, 2004 and 2015)

The Deccan plateau is a large triangular region that covers about 43% of India, and spans eight states – Andhra Pradesh, Maharashtra, Karnataka, Kerala, Tamil Nadu and Telangana. Nestled within peninsular India, it is bound by the western and eastern mountain ranges, called “the Ghats”, that run parallel to the coast. The region therefore lies in a perpetual rain shadow, devoid of rain bearing winds during both the southwest and the northeast monsoon seasons. A large proportion of this area receives less than 750 mm of annual rainfall in less than 100 days which makes it vulnerable to drought. Despite this low rainfall climate, Deccan represents an agriculturally important and vibrant socio-economic context providing a testimony of human adaptation to climate as evidenced by its rich history. These characteristics make this case study region an ideal test-bed to examine drought in its multifarious dimensions. The highest frequency (>6 %) of the severe droughts (SPI -1.5 to -1.99) are observed in the Deccan region. Figure 2 shows the rainfall deviations over the region during the very dry years. In this case study, we examined transitioning of the drought signal from deviant meteorological conditions into soil moisture and/or hydrological droughts that translates into disastrous socio-economic consequences over a classically prone region of India.

Socio-economic linkages

In the Deccan case study area, rain-fed agriculture is the dominant source of food production and droughts are ingrained into society and the economy. The fraction of lands with access to irrigation are also ultimately affected as surface water needs to be replenished by rainfall. The timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains (i.e., rainfall intensity, number of rainfall events) determine drought impacts. Thus, each drought year is unique in its climatic characteristics and impacts. In most years with delayed rains during the onset phase of the monsoon combined with a previous dry year has led to severe impacts resulting in crop failure, livestock losses and water scarcity for domestic and drinking. In the summer of 2019, villages in districts of Maharashtra and Karnataka States in the heart of the Deccan area were reported to be deserted as families left due to acute water crisis. Specific press reports mentioned the village of Hatkarwadi, in Beed district of Maharashtra state, that became deserted with only 10-15 families remaining out of a population of more than 2,000 (Guardian, June 2019).

The immediate shock of monsoon failure resulting in drought is experienced in agriculture sector. During 2016-2017, 87% of crops were damaged in the 1564 surveyed villages due to 62% deficient rainfall (GoT, 2017). Further, the cascading impacts is likely to pass on to industry and service sectors through backward and forward linkages. For instance, Drought 2001-2003 and 2012-2013 experiences show, a 20 percent reduction in primary sector caused over 5 percent drop in industry sector and 3 percent reduction in service sector. (UNDP BCPR, 2013)

While droughts are triggered by climate factors, their further amplification or damping is controlled by human dimensions, as much in terms of preparedness and response as in enhancing vulnerabilities through unsustainable development planning (Van Loon et al 2016). Subsistence farmers are the worst and the first to be affected by droughts even when such events are not severe. In the Indian context, Choudhury and Sindhi (2017) document the changing drought ecosystems of poor farmers and also argue that the present paradigm of agricultural development and what it means for small farmers needs to be critically evaluated for better drought resilience outcomes.

Drought impacts in growing urban centers with increasing population and limited water supplies also need special attention. A recent crisis in one of the mega cities in the study area, Chennai provides an illustrative example. Extreme water crisis reported on 19th June 2019 in Chennai Metropolitan, where a “zero day” was marked by every tap in the city running dry. Chennai, the capital city of the Indian state of Tamil Nadu, is a densely populated city which mainly depends on reservoir water, to meet its water needs (Shankar et al., 2021). The city has a well-balanced water supply system which critically depends on normal monsoon for recharge. A slight change in annual rain may make a huge difference in the water availability in next dry season. Shortfall of North East monsoon rains in 2018 caused 55% of water deficit in Chennai and 23% deficit over Tamil Nadu State. Moreover, a major heat wave affecting the region during May to June 2019 further exacerbated the problem and left the city total dry in June 2019. Rapid urbanization and industrialization in past years resulted in a dried-up ground water system without proper pace of replenishment. Over dependence on the ground water resources and lack of water retaining structures make cities highly vulnerable during severe drought events like of 2015-2019 in India.

Information for Preparedness

In India, at a national level, drought is monitored through the National Agricultural Drought Assessment and Monitoring System (NADAMS) by the Mahalanobis National

Crop Forecast Centre (MNCFC) of the Department of Agriculture and Cooperation (DAC). It uses remote sensing and in situ hydro-meteorological data using a multi-criteria approach. The India Meteorological Department (IMD) provides both rainfall data and derived indices like the SPI. Agricultural conditions are monitored using daily-observed coarse resolution (1.1 km) NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very High-Resolution Radiometer) observations. The data from AWiFS (Advanced Wide Field Sensor) on-board Resourcesat-2 (56 m spatial resolution) are also being used for finer scale assessment of agricultural drought over limited areas within semi-arid tropics (SAT). The shortwave angle slope index (SASI), Normalized Difference Wetness Index (NDWI), Normalized Difference Vegetation Index (NDVI), Soil Moisture Index (SMI) from water balance and rainfall deviation from in situ gauge measurements, number of dry weeks are presently used to diagnose drought affected area (Vyas et al., 2015). Figure 3 outlines the national drought monitoring process currently being followed.

In India drought related decisions and policies are made at National and State levels. Department of Agriculture, Cooperation and Farmers Welfare (DAC & FW), Ministry of Agriculture and Farmers Welfare, Government of India is the main authority at national level to collate information to monitor drought conditions, issue advisories, coordinate with other ministries of the Central Government, State Governments and relevant agencies to respond and mitigate drought impacts. “Drought declaration” is the most important step in governmental response to a drought situation.

The declaration of drought in a particular administrative unit - *Gram Panchayats, Blocks, Mandals/Tehsil/Taluks*, Subdivision and Districts, is the responsibility of the State governments. To facilitate and standardize this process, the DAC & FW has issued guidance (DAC, 2016) to be followed using objective parameters to declare drought over a clearly specified administrative unit. It also suggests that this assessment of drought be made without delay so that relief assistance and support can be provided to drought affected communities well in time. The implementation of objective parameters for drought declaration is however, not followed uniformly as some states still use traditional approach to estimate crop damage and drought. DAC (2016) states that “There is substantial variance in the quality of drought monitoring and the methodology and parameters adopted in the declaration of drought among States.”

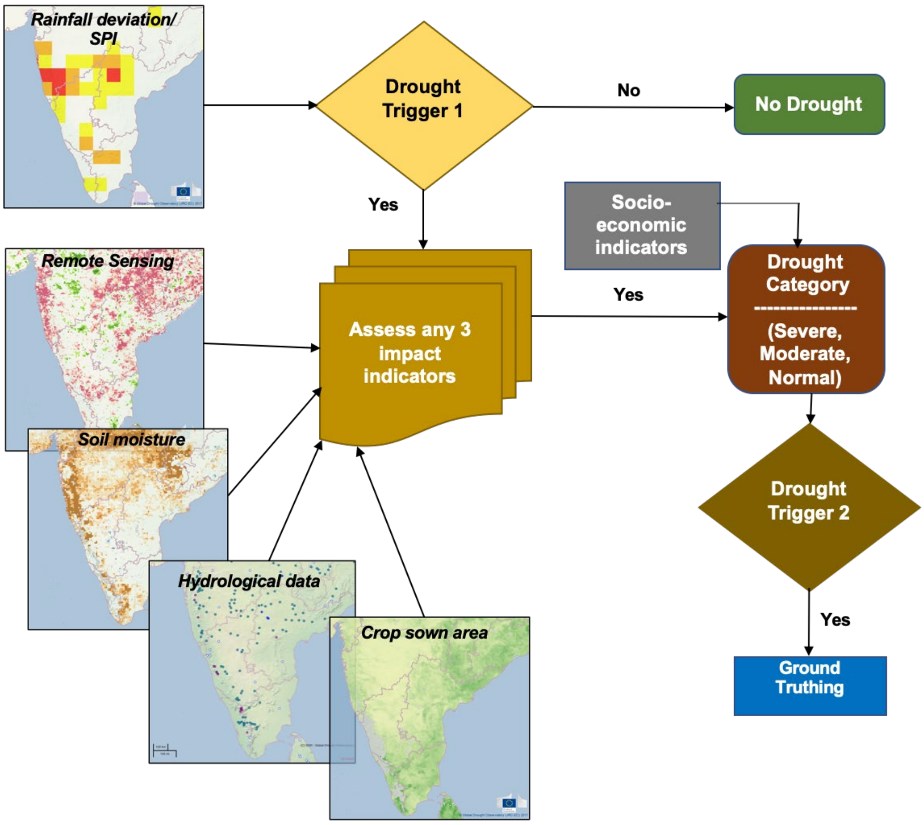

Figure 3 National Agricultural Drought Assessment and Monitoring System (based on https://ncfc.gov.in/nadams.html) operated by the Mahalanobis National Crop Forecast Centre (MNCFC)

Once the State Governments declare drought, relief operations in drought affected areas begin by using funds available under the State Disaster Response Fund (SDRF). When a severe drought of a severe nature, the State Government may seek assistance from the Central Government including financial assistance from National Disaster Response Fund (NDRF). The DAC at national level also dispatches inter-ministerial teams to carry out assessment of drought and recommend the quantum of relief. This is done after the State Government issues a notification of drought and submits a Memorandum for financial assistance from the NDRF. Delay by State Governments in assessment of drought and its declaration often causes a train of lags that impedes much needed relief reaching affected population in time.

Specific Characteristics

Low average annual rainfall of 750 mm over most of the Deccan plateau area and high variability in rainfall exceeding 30% of the average cause frequent droughts. DoA, 2016 states that over-exploitation of ground water and sub-optimum conservation and storage capacity of surface water leading to inadequate water availability for irrigation in the years of rainfall deficiency also exposes the region to recurrent droughts. The per capita water availability for humans and animals has declined making the area sensitive to bear even the normal climate variability that is inherent to the location. Further, pressure on resources in surrounding regions is created by the exodus of cattle and other animals from drought hit areas, contributing to widespread impacts. Without access to irrigation, the dependence of agriculture in such areas is totally on rainfall resulting in rapid transitioning from rainfall deficit to drought. In an overall sense the socio-economic ecosystem is rendered highly sensitive to rainfall deficiencies and even small and short-term variations enhance vulnerability and cause huge impacts. As a corollary to this and due to the inherent heterogeneity in rainfall distribution, notwithstanding the extremes due to climate change, have perhaps resulted in higher frequency of low impact drought events. As the drought monitoring systems are not designed to resolve such granularity, such events are only reported in the local or provincial press ultimately getting lost in data aggregation and macro statistics of a big country.

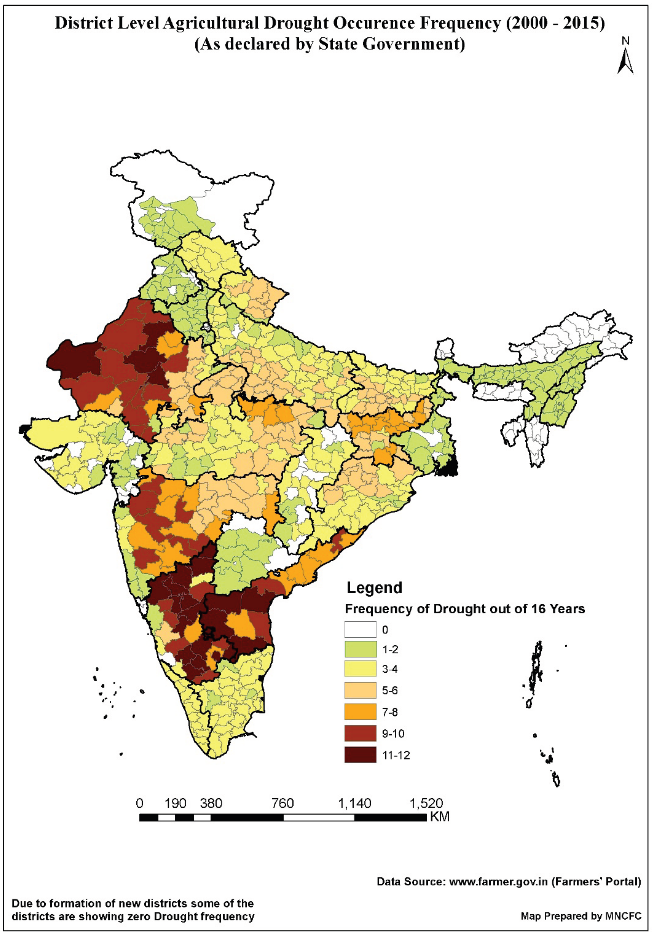

Figure 4 Frequency of Droughts in districts during 2000-2015

Figure 4 shows the frequency of drought occurrences in districts-based occasions when droughts were declared in such districts by State Governments during the 15-year period from 2000 to 2015. As seen, the Deccan plateau area is particularly susceptible to drought episodes.

Changing Morphology of droughts

Semi-arid region of Andhra Pradesh, India (Figure 5) is threatened by chaotic rainfall variations which leads to meteorological, agricultural and hydrological droughts. semi-arid region of Andhra Pradesh was experiencing flash droughts, a condition where dry spells along with increased soil temperature and evaporation dries out the soil moisture on a rapid phase. Such flash droughts during the critical growing stage of crops, affect crop growth and production. During the 2018 South

West Monsoon season, India Meteorological Department gridded rainfall data averaged over region (76.75 - 79.75 E, 12.75 - 16 N) indicated -32.6% deficit over June-September months when compared to seasonal average during 1981-2010. Monthly rainfall departure indicates the season suffered much larger deficits during July and August (Figure 5 a, b). After witnessing the normal rainfall in June, farmers are sowing the crops expecting the optimal rainfall condition during the upcoming months, which resulted in 75% cropping area were sown[1] (Figure 5b). However, fast onset of dry condition evolved during July and August, which overlapped with critical growing stage of summer (*Kharif*) crops. Daily variation of parameters rainfall, soil temperature, evaporation showed that the soil temperature and evaporation has been raising rapidly after the wet spells (Figure 5 c, d). The drying out of moisture from the soil during the growing stage of the crop resulted in severe stress for the crops, which in turn affected the yield and production.

Such extended flash droughts between the months extended even after the southwest monsoon season, i.e., October, which resulted in the sowing of the winter (*Rabi*) crops. Further such recurrent drought over a period affects the ground water level, and therefore ground water irrigation would also be helpless for farmers to save their crops

[1] http://www.apagrisnet.gov.in/weekly_report.php

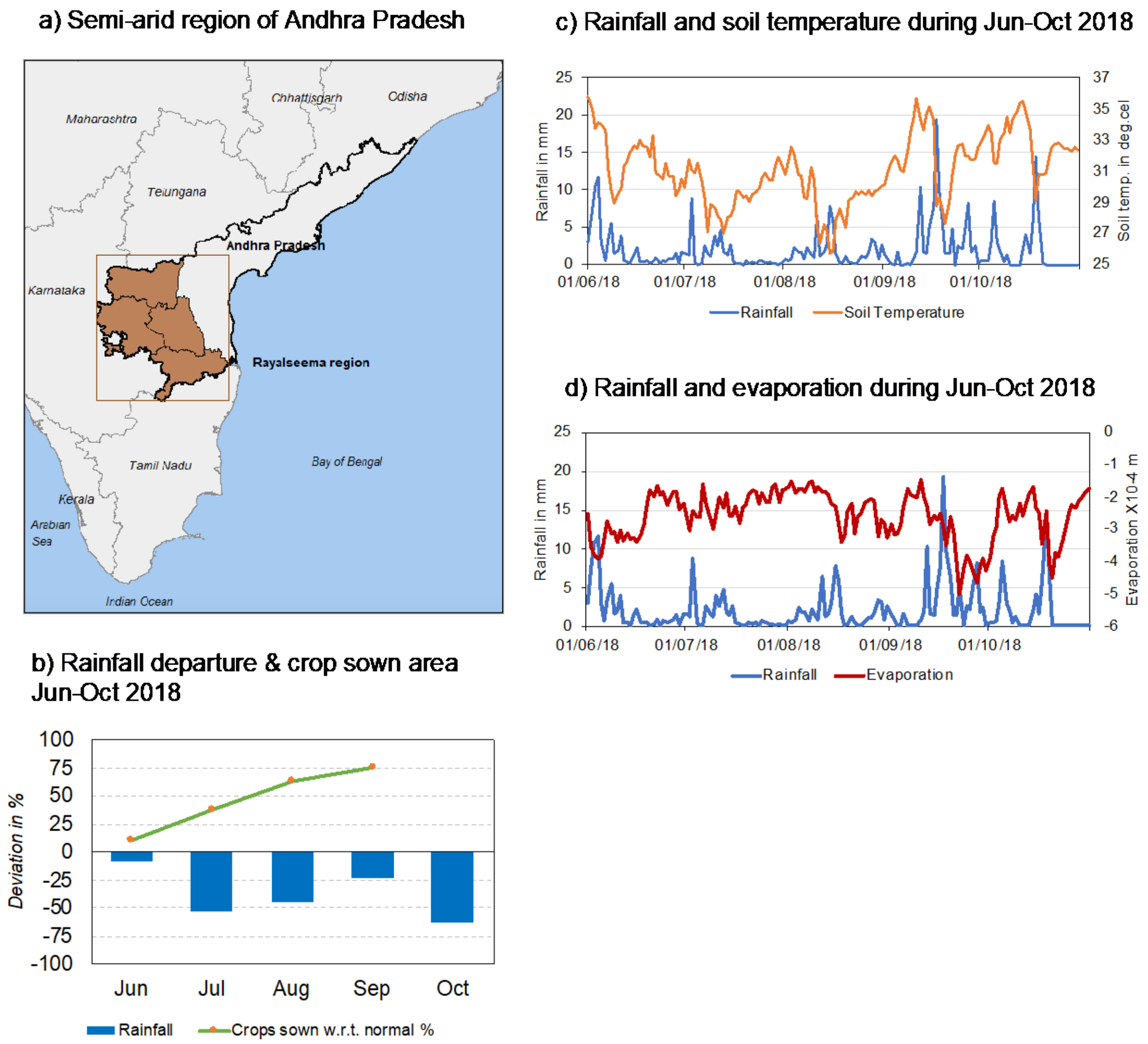

Figure 5 Rapidly changing drought situation in Andhra Pradesh a) the semi-arid region of Andhra Pradesh; b) impacts of rainfall departures on crop sown area; c) rapidly increasing soil temperatures during dry-spells and d) rapid increase in evaporation during dry-spells (Data source: Pai et al., 2014 and ERA5 Reanalysis)

Strategies for mitigation

Drought response and relief measures are sector-specific requiring coordination among various departments. For the main affected sector which is agriculture, preparedness is built-in currently at two levels:

1. Crisis management plan - before the commencement of each major cropping season a plan is prepared identifying phases of the crisis, and strategic response to each of these. The activity plans include critical steps that need to be taken in different times of the year with respect to drought preparedness, drought reporting and drought response, and the agencies responsible for actions.
2. Drought contingency plans – District Agricultural Contingency Plans. The District Agriculture Contingency plans guide intervention to the agriculture department and their stakeholders, and farmers, for saving the crop season at district level during climate shocks including drought. The contingency plan guides the steps to be taken during initial preparedness, real time response to weather aberrations, relief and rehabilitation. For instance, Karnataka farmers following contingency planning to

minimize the impact of late onset of monsoon, saved them losing crop by going for transplanted finger millet, which increased additional income of 70US$/ha. (Rao et al. 2015).

At farmer's community level there are several coping strategies that are in place. Under rain dependent conditions, the farmers have adapted to keep their cropping practices flexible so that corrective measures can be introduced, depending on the type of weather aberrations. Normally, the following kinds of aberrations are observed under rain-fed conditions:

I. delayed onset of monsoon rains;
II. long break in rainfall during the middle of the rainy season;
III. lack of rainfall during the post-rainy season;
IV. and high soil temperature at sowing time (in case of post-rainy season crops).

In response to late onset of rainfall conditions, farmers change from long-duration high-yielding crop varieties to short-duration low-yielding varieties.

The mid-season correction for each aberration varies from place to place, depending on the rainfall pattern, soil type, choice of crop, and so forth. Corrective measures include reducing the plant population by thinning crops to reduce crop competition for available moisture and providing supplemental irrigation in case there is a long break in rainfall during the crop season.

In the event of droughts, farmers undertake activities to raise and harvest at least one crop. This practice caused crop failures leading to repeat planting.

Madhya Maharashtra - example four river basins

Some areas of the Deccan plateau experience consecutive 10 dry weeks, out of the total of about 15 weeks of the rainy season, once every three years on average. Such frequent water scarcity events adversely affect agricultural productivity all through the year, and many a time cascade into the next year, despite the year being near normal in rainfall. Todmal (2019) analyzed drought and its agricultural impacts over four river basins in the drought prone Madhya Maharashtra area in the core of the Deccan plateau area. These basins receive annual precipitation between 500 and 750mm, about 90% of which falls during the five months (June–October) of the southwest monsoon season. Although these basins are part of the same climatic zone, they exhibit notable spatial variation in monsoon rainfall (Sina 584 mm, Man 453 mm, Agrani 313 mm, Yerala 502 mm, and Karha 490 mm). During the period of analysis (1981-2013), the authors found that the study basins exhibit region-wide consistency of SPI during the extremely wet and dry years. Droughts of different intensities were observed in the years 1986, 2003, and 2012. The remaining dry, wet, and near-normal years do not display agreement with respect to space and time. Amongst the droughts, the intensities from SPI < -1.5 to -2.5 examined, the 2003 was the most severe and widespread. Even during this extreme dry year, the Sina river basin which is the largest (12365 Km2) was moderate. The study clearly illustrates the spatial variability in rainfall and consequently meteorological droughts. Drought monitoring, assessment, response and relief has to therefore to be planned carefully, considering heterogeneity of the rainfall climate and vulnerabilities that are dynamic and evidence-based making use of on ground data gathering using a blend of conventional and non-conventional sources.

Deccan plateau agriculture – crop suitability

In the core area of the Deccan plateau, most of the agriculture is rain dependent. Cultivation of short-duration and drought-tolerant crops (sorghum, pearl millet, gram pigeon pea) is the traditional characteristic of agriculture. Sorghum and pearl millet are the dominant crops, which cover about 50%–60% of the cropped area. Because of their lower market value, the traditional crops in this region have been replaced by cash crops such as sugarcane, maize, and onion (World Bank 2008). To assess the impacts of drought on crop productivity, Todmal (2019) compared drought severity and crop productivity over 37 talukas of central Maharashtra in the vicinity of the four river basins mentioned. In the three decades of the study period (1981-2013), the extreme drought of 2003 caused maximum decline in productivity of sorghum, sugarcane, and wheat (Standardized Crop Productivity Index (SCPI) = -2.32, -3.26, and -2.13, respectively). Traditional crops of the area like pearl millet, gram, and pigeon pea (SCPI = -1.32, -1.83, and -0.52, respectively) were less affected. Even the sugarcane crop, grown under irrigation from surface water resources suffered due to acute rainfall deficiency for two consecutive years with maximum decline in productivity (SCPI = -3.26). Almost all the crops exhibit below average hectarage in 2003, which was an extreme meteorological drought year, preceded by a moderate to severe hydro meteorological drought year (2002). The study also reestablished the fact that the cropped area under rainfed crops in Maharashtra is getting replaced by high water-requiring crops (Todmal and Kale 2016). Creation of surface irrigation facilities have contributed to enhanced cultivation of high water-requiring crops (sugarcane and wheat) after 1995 at the cost of the rainfed crops (sorghum and pearl millet).

Andhra Pradesh - coping strategies in irrigated agriculture

In the south eastern parts of the Deccan plateau study area, the Krishna river basin experiences declining water availability downstream as upstream water use is not adjusted to reflect rainfall fluctuations. Venot et al. (2010) have documented strategies of downstream farmers who are increasingly vulnerable to water supply shocks from the Nagarjuna Sagar (NJS) irrigation project in the state of Andhra Pradesh. NJS also serves as the major hydropower dam for Andhra Pradesh and acts as a balance reservoir for irrigation in the Krishna delta further downstream (Venot et al., 2007). The case is an illustration of the need for holistic irrigation planning and sustainable agricultural development in the face of increasing variability in current rainfall patterns and future impacts of climate change. Krishna waters are shared by three states: Andhra Pradesh, Karnataka and Maharashtra within the Deccan plateau. The study documents the wide range of adjustments adopted by managers and farmers in Nagarjuna Sagar command area during a period of fluctuating water availability (2000–2007) along with a critical background of the various complex issues of drought management in the hydrological and agricultural contexts. Developments of hydraulic infrastructure have placed higher demands on the available water and groundwater abstraction in secondary upstream basins have significantly increased in recent decades. Biggs et al. (2007) note that river runoff has decreased for all probability levels exposing downstream irrigation practices to risks, catalyzing the progression of a meteorological drought into an agricultural crisis.

It is with this background that Venot et al. (2010) examine coping mechanisms adopted by farmers to meet critical water demands of standing crops. Farmers responded to changing conditions through: (a) crop diversification, (b) shifting calendars, (c) conjunctive use, (d) suspending cultivation, (e) sale of livestock, (f) out-migration, and (g) tampering with the irrigation system. These findings actually re-emphasize and confirm farmer’s response to droughts and dry spells exhaustively documented in the past (Subbiah, 2000; 2006). Venot et al. (2010) also find that adaptive strategies are more diverse in the tail-end than in the head-end of the canal network and local adjustments are often uncoordinated.

Pointers for the future

Evolving vulnerabilities of drought prone regions need to be captured at village level through appropriately designed dynamic systems, powered by state-of-the-art technologies. In the absence of such an approach it will be difficult to provide timely interventions that can mitigate transitioning of drought into a socio-economic crisis. The illustrations provided by the case study clearly highlight the facets of drought in India and the complex fabric of vulnerabilities that present unique circumstances at each instance.

Pre-existing vulnerabilities get exacerbated during droughts. Whereas people manage risk by treating drought as an integral part of risk institutions treat drought as a discrete, episodic and outlier events and respond only when drought emergencies arise. This leads to perpetuation and aggravation of drought vulnerabilities leading to agrarian crisis and natural resources degradation. Policies and institutions designed to manage drought as a discrete event therefore face challenges when situation. The better time to fight drought is when it is not there: Institutions, policies and plans need be designed to deal with drought as a continuing threat /risk regardless of rainfall deviations and associated physical parameters.

On ground, drought plans, and policies need to be implemented under diverse drought scenarios that prevail in India. Effectiveness in drought risk reduction has to be borne out by verifiable data sets served through a transparent system of accountability, participation, feedback mechanism, monitoring and evaluation (Mishra and Tayal, 2018).

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