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DROUGHT INDICATOR AND VULNERABILITY

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ABSTRACT *The perception of drought varies with people engaged in different fields (e.g. meteorology, water resources, agriculture, socio-economy etc). Indicators of the impending droughts need to evaluated and categorized so that these can be used to alert stakeholders. Hence, there is a need to create a geo-information base on spatial and temporal information and integrate it using GIS in estimating drought vulnerability.*

Key words Drought indicators; vulnerability; water demand; management; drought rating.

INTRODUCTION

The non-availability or deficit of water as and when required (crop watering, drinking, etc.) is termed as drought. This deficit could happen even during a flood, when the excess flow is non-usable in nature for human consumption or utilization. The impacts of drought vary with affected sector, thus leading to different definitions of drought relevant to specific affected groups. As water is vital to all, the perception of drought also varies with the profession of people concerned, viz. meteorology - deficit in rainfall amount; water resources - low river-flow level or reservoir storage level or decreased ground water level; agriculture - water deficit or no water during critical crop watering time leading to growth deficiency and poor crop yield (grouped according to the normal sowing time and crop growth stage viz. early, mid and late season); economy – loss in profits; and commerce - food items are in short supply and cost is high. The prevalence of similar situation of drought has been reported in ancient literature of India and other parts of the world. Synergistic analyses (rather than individual parameters) of information from various sources indicate its regularity (2 to 7 years of recurrence) in India. It is often the result of many complex factors acting and interacting within the environment. Hence, there is a need for observable/ measurable indicators in realizing the process. Drought occurs in the biosphere that may damage hydrological and biological domains due its varied magnitude, frequency, duration, area of extent, speed of onset, spatial dispersion and temporal spacing.

Drought indices that are being used nowadays, portray the relative and/or absolute change in the parameter under consideration over a period of time. In rainfed agriculture areas, twenty one non-rainy days often enough trigger drought like conditions.The timing of drought is, therefore, important. A late season drought, after harvest, may not be important to cropping farmers. It is important to distinguish between dry land and irrigated agriculture. This could help in quantifying economic impacts from potential changes in agricultural production and possible ways of dealing with the situation such as enhanced groundwater abstraction and modifications in irrigation scheduling. As the drought risk is not only due to meteorological event but also due to socio-economic and technological changes, the ideal index should be derived from a biophysical model having strong linkages to social and economic outcomes. Severe drought conditions can also trigger changes in species and ecosystem. In the past, drought intensity was most often measured via the departure of a climatic variable from normal and closely linked to duration in determination of the impact (Wilhite, 1993). This method was limited in its ability to accurately characterize an event due to dependence on the 'average season' and assumed that seasonal climate in the region followed a normal distribution, which is rarely the case.

The drought index needs to have the following features: (1) universal i.e., applicable to all parts of the terrain and agro-climatological zones for both nation-wide and regional analyses; (2) sufficiently versatile to cope with varying thresholds or scales of severity; (3) easily interpretable by the concerned people; (4) usage of readily available data to enable calculation of anomaly and recurrence statistics; (5) represent the duration and intensity of drought (6) linked to decision-making pointers; (7) future scenario generation with the existing information, which enables the planners to impart suitable advice to farmers for land use planning; and (8) should have potential for further research.

As drought indicators are inherently complex due to multiple causes (leading to drought), processes and impacts of drought, the difficulty of obtaining relevant data series, and, modeling the interactions between natural processes and human responses, typically leads to oversimplification of drought assessment studies.

In New Zealand, rainfall deficit of a representative climate station, for a consecutive three-month period and one in 20 year low is considered for drought relief measures. It is expected that the situation would lead to economic consequences in terms of loss of gross farm income, production loss, expenditure pattern changes, loss of value of feed stocks, erosion of savings, changes in stock numbers, GDP losses and environmental consequences. However, the Australian Government adopts a policy of 'Drought Exceptional Circumstances for Intervention' (Laughlin and Clark, 2000) based on meteorological, hydrological, agronomic and stock conditions, water supplies, environmental impacts, farm income levels, and spatial scale of the event. The characterization of drought accounts for the effects of environmental and climatological variation on agriculture using rainfall analysis; remote sensing; soil moisture analysis; and plant growth simulation (Stafford-Smith and McKeon, 1998). Each of these methods has their own merits and demerits, particularly in the analysis of output results and availability of input data. These are dependant on the cause, the availability of data, the agricultural system affected and the requirement for further evidence when an event appears to be marginal in its rarity and/or severity. Due to the fact that no single technique or indicator can be considered as 'perfect', a selection of these are most often incorporated in an analysis.

The drought assessments and declarations need to be appropriate and accurate for the affected localities since the regional assessments of drought are too general. Trigger points of drought need to be defined for a particular region and specific issues need to be identified, as they are part of planning process and response of the system. It should be both supply-type, reflecting moisture deficiencies caused by acts of nature (lack of rain, excessive temperatures), as well as demand-type, reflecting drought impacts to enable the estimation of costs, expected frequency and risk of drought (USDA, 2000). The events that are both rare and severe (occur once in every 20-25 years) with severity of a significant scale, lead to severe downturn in farm income over a prolonged period, and, are not predictable or manageable through normal risk management strategies available to farmers, are termed as 'Exceptional Circumstances'.

The global climate models predict trends about broad climate patterns across the Pacific/Indian ocean etc., but do not take account of the effect of local topography or local climate. The local changes are inferred from the coarser-scale information of the global climate models by a statistical technique known as 'downscaling'. Statistical downscaling starts with historical observations, and calculates 'downscaling relationships' between broad regional climate patterns and local climate observations. The downscaling relationships are then applied to the broad future regional patterns predicted by the global models, in order to provide more locally-detailed projections (Mullan, 1995).

DROUGHT INDICATORS

Drought can begin or end quickly or slowly. Deciding when a lack of precipitation has become a threat to water supply is determined by: (1) amount of water in storage; (2) anticipated water demands; (3) severity of precipitation deficit; and (4) specific water sources in a region. Often, the ability of government planners to manage the situation is made difficult by not having a methodology to compare the severity of drought in different parts of the state/country and communicate this information to the public. To overcome these difficulties, drought indicators are devised to monitor regional water supply sources. The indicators are designed to: (1) integrate large amounts of data about water supply sources; (2) communicate to the public and decision-makers accurate information; (3) based on real-time data; and (4) distributed quickly over the public awareness campaign modes including television and internet.

Precipitation, stream flow, reservoir levels, and groundwater levels are dependable realistic drought indicators for situation/event planning. Even though these indicators are not the triggers or causative parameters, they can change the estimated drought status significantly. Each of them is assigned with one of following four conditions: (1) near or above normal, (2) moderately dry, (3) severely dry, or (4) extremely dry. These need to updated weekly during dry periods and the results can be made available to concerned people. Water supply planners evaluate the data with best professional judgment and input from surveyors and recommend an appropriate drought status for each region as per the following categories: normal, watch, warning or emergency (Table 1).

The difference between the actual amount of precipitation measured during a month and the historical average for that month is either a negative or positive number, indicating a deficit or surplus, respectively. The monthly surplus or deficit

Table 1 Drought indicators and classification (based on departure from historical average).

Drought condition	Precipitation index	Stream flow index
Normal	1 month below normal	1 month below normal
Advisory	2 months cumulative < 65% of normal	2 out of 3 consecutive months below normal
Watch	3 months cumulative < 65% 6 months cumulative < 70% 12 months cumulative < 70%	4 out of 5 consecutive months below normal
Warning	3 months cumulative < 65% & 12 months cumulative < 65% 6 months cumulative < 65% & 12 months cumulative < 65% 3 months cumulative < 65% & 6 months cumulative < 65%	6 out of 7 consecutive months below normal
Emergency	As that of warning and previous month warning or Emergency	> 7 consecutive months below normal
Drought condition	**Reservoir index**	
Normal	Level at normal for this time of the year	
Advisory	Small index reservoirs below normal	
Watch	Medium index reservoirs below normal	
Warning	Large index reservoirs below normal	
Emergency	Continuation of previous months conditions	

1990 base-periods, which sample primarily the warm nights during the year; and can vary significantly from month to month and is not a good indicator of a water-supply drought. A better method is to use a running 3-month total. This number is the surplus or deficit in a given month added to the values of the two previous months. To use this indicator on a daily basis, precipitation during the previous 90 days is compared to the average in past years. Drought predictions are based over a long-range of monsoon rainfall using multiple regression, parametric and power regression models. Multiple-regression model is based on the 500 hPa April sub-tropical ridge over India, 50 hPa East-West extent of trough-ridge system. Microlevel variations in the system control the prediction accuracy that is required for drought management. Depending on the geographical area of the analysis, satellite images and ground measurements can be used in the assessment of the drought, individually or synergistically (Table 2). Drought is defined in terms of a number of climatic factors, including rainfall, temperature, and wind speed. Potential evapotranspiration deficit (PED) is a measure of drought, which incorporates all three of the above climatic factors.

The European Climate Assessment (ECA) group has prepared a rationale for preparing the base line data for evaluating climate change scenarios worldwide. The indicators are based on daily minimum and maximum temperature series, as well as daily totals of precipitation, and represent changes in all seasons of the year. Temperature related indicators are: (1) Frost Days (FD) - measures air frosts, which samples the winter half year in all extra-tropical regions, particularly the beginning and end of the cold season; (2) Intra-annual Extreme Temperature Range (ETR) - spans the most extreme high temperature event of the summer season and the most extreme low temperature event of the winter season; (3) Heat Wave Duration Index (HWDI) - samples the daytime maxima throughout the year in most climates; (4) Tn90 - percent of observations exceeding the daily 90^{th} percentile for the 1961-

Table 2 Information requirement for drought assessment and source.

Information	Remote sensing	Ground based	Indices
Temperature Rainfall - monthly and annual Evaporation Humidity	♦ ♦	♦ ♦ ♦ ♦	Meteorological Indices: Dryness Index, De Martonne's Index, Pluvothermic Quotinent, Bhalmey & Mooley Index, Rainfall Anomaly Index, Mean Monthly Rainfall Deficit, Rainfall Deciles, PDSI, Relative Drought Resistance
Soil moisture	♦	♦	Crop Moisture Index, Soil Moisture content
Vegetation cover Crop area & type	♦ ♦	♦	Vegetation Condition Index, NDVI, Soil Adjusted Vegetation Index, Stress related TM based Vegetation Indices, Stress Degree Days, Crop Yield Estimation, Water Demand Analysis
River flow Surface water storage area / volume Aquifer type Groundwater level	♦ ♦	♦ ♦ ♦ ♦	Low Flow Analysis, Total Surface Water & Groundwater Availability
Population Population density Human & Livestock population		♦ ♦ ♦	Food and Water Demand Analysis
Agriculture dependant people Gross Income		♦ ♦	Purchase Capacity and Target Relief
Food storage facility Medical facility Transportation network	♦	♦ ♦	Relief/ Mitigation Camp Selection and Functioning

1990 base-periods, which sample primarily the warm nights during the year; and (5) Length of the Thermal Growing Season Length (GSL) - samples spring and fall anomalies in the higher latitudes. Precipitation related indicators are: (1) Maximum number of Consecutive Dry Days (CDD); (2) R10 - number of days with precipitation greater than 10 mm; (3) Simple Daily Intensity Index (SDII); (4) R5d - greatest 5 day precipitation total of the year, represents some of the more extreme precipitation events of the year; and (5) R95T - fraction of annual total precipitation due to events exceeding the 95th percentile.

Stream flow gages representing each region are used to measure stream flow. Using 7-day average flows, the median flow for the evaluation period is compared with low flows representing historical occurrence frequencies of 25%, 10% and 5% for the same date for the period of record. A 25% frequency equates to a one in four year occurrence, 10% frequency a one in 10 year occurrence and 5% frequency equates to a one in 20 year occurrence. The daily stream flow can fluctuate greatly from the impact of recent rains and also due to various storages/lift irrigation operations. Daily stream flow is not a good indicator of water-supply droughts. However, when daily values are listed over a period of at least 90 days and compared to historical values, daily stream flow values become a more valuable indication of how wet or dry a region is. For each stream flow gage, the cumulative flow over the previous 90 days is compared to the average for that month of the year. The difference is then calculated and ranked on a percent scale where 0% is the lowest deficit ever measured for that month, and 100% the greatest surplus. This is calculated for three gages in each region and the results are averaged. If the average is less than 10% then the stream flow drought indicator for that region is classified as extremely dry. An average between 10% and 30% is severely dry, between 30% and 50% is moderately dry, and over 50% is near normal.

Groundwater drought indicator of a region is based on the status of all wells in that region and that of wells in nearby regions installed in similar aquifers. Ground water levels in confined aquifers are responsive to pumping stresses at distances. Percentile frequencies of groundwater levels for confined aquifer system and its impacts are analyzed as a departure from the long-term downward trend in water levels. A network of real-time groundwater observation well levels can be analyzed to calculate the median, lowest 10%, and lowest 30% level for each well and month. The groundwater drought status in each well is determined by graphically comparing current reported groundwater levels to the calculated statistics. The four lines on the plotted graph represent the observed water level (drawn in purple color), the median water level (green), the 30% frequency line (orange), and the 10% frequency line (red). When the observed water level (purple) falls below the red line on the graph, the groundwater condition in that well is set to extremely dry. When it falls between the red and orange lines the condition is severely dry, between orange and green is moderately dry, and above the green line is considered near normal.

Reservoir storages are designed to provide adequate storage when demand exceeds reservoir inflow. As the stream flows are lowest during the summer period and demand is greatest, the most critical time begins at the onset of summer. Adequate storage is presumed to last for a four-month period or 120 days. Water supply problems in smaller reservoirs are taken into account when evaluating problems related to specific water supplies. These reservoirs are too small to indicate overall water supply conditions. Reservoir water levels are normally high immediately after monsoon period in India and low in the fall. A 'rule curve' is a graph that shows the normal storage in a reservoir during the course of a year. This kind of graph may also show expected storage at the beginning of a drought watch, a warning or an emergency. Drought indicator information should include:

- environmental information (precipitation, water supply sources, impact of soil loss and sediment deposition, impacts on surface and groundwater, effects of dust storm, wild life and plant etc);
- economic information (economic linkages, trends and awareness programmes, loan and insurance schemes, etc.); and
- social information (public health and safety, perception of drought, diversity, Government/NGO interactions, policy implementation and political perspective on drought, etc.).

These indices may also be improved based on the following:

- Accumulated deficit - consecutive occurrences of water deficiency to be accounted in calculations alongwith the departure from climatological mean for a predefined period.

- Time step - as the water deficit could be overcome by just a day's rainfall, daily, weekly and monthly steps should be calculated.
- Water storage term - drought indices should characterise both soil moisture and other water resource (e.g. lakes, groundwater) storages as separate features.
- Time dependent reduction function - daily water resource depletion through runoff, evapotranspiration and other factors should be included while accounting for the water availability.

Attempts should be made to overcome the following drawbacks:

- Problems with modelled or estimated data - oversimplification of data, for example soil moisture content, which is inevitable because of variability in topography and other soil characteristics.
- Lack of other information - Drought indices fail to provide good information on the duration of drought, how much deficit of water has occurred, when the drought is likely to end, and how much rainfall is needed to return to normal conditions.

It has been observed that the drought indices currently in usage are not precise enough to detect the onset, the end, and the accumulated stress of drought. Researchers have suggested that the following aspects of droughts should be highlighted: (i) causes - atmospheric processes that lead to drought; (ii) frequency and severity - characterizion of probability of drought events and scenario; (iii) impacts - quantifying the direct or indirect costs and losses associated with drought, including economic, social and environmental consequences; and (iv) responses - means of impact reduction by way of preparedness and mitigation strategies (Table 3).

Table 3 Drought area zonation and management strategies.

Status	Description	Return Period	Demand side	Supply side
Normal	Non-drought condition	<5 yrs	Business as usual	
Zone 1	Drought alert	5-10 yrs	Raising awareness, Water efficiency, Conservation practices	Enhance operation monitoring, Change operational practice for efficiency
Zone 2	On-set or recession condition	10-20 yrs	Interaction with large users, Identify & rectify large leakage zones	Prepare drought order, Demand large supply & logistics
Zone 3	Middle stage of serious drought	20-50 yrs	Reduce demand, Enforcement of restrictions	Implement drought ordinance, Seek support from disused sources, Emergence orders
Zone 4	Severe drought situation	>50 yrs	Ban non-essential use, Call for water emergency	Seek private supply source, Overland transfer solutions

Note: Based on pre-determined threshold conditions.

VULNERABILITY ASSESSMENT

The potential impacts of drought are many and varied, and can affect a wide range of economic, environmental and social activities. There is a need to analyze the available information and identify regions of vulnerability and the anticipated intensity. The relative vulnerability or risk exposure usually depend on the types of water demands, how these demands are met, and corresponding water supplies available to meet these demands. Human and natural resource activities depending solely on rainfall and soil moisture, such as dry-land farming, ranching, and some environmental water uses, are at extreme risk from drought. These activities can suffer discernible effects even with droughts of short duration. The water use activities that depend on stream flows such as direct flow irrigation, recreational water uses, aquatic, wetland and riparian environmental communities are also at extreme risk. Many urban and agricultural water users who rely on surface water reservoir supplies or on groundwater resources that are not dependent on high rates of aquifer recharge or adversely affected by concentrated levels of high pumping, are at moderate risk. The level of risk, which includes vulnerability and hazard, needs to be synergized in the Drought Plan towards planning, mitigation, and response activities.

Vulnerability expresses the degree of susceptibility to a hazard either as the result of varying exposure to the hazard or because of variations in the ability to cope with its impact. Areas that have high exposure and low coping capabilities have the highest risk from a given drought event and those with low exposure and high coping abilities have the lowest risk as observed from the past.

In the present study, the drought scenario is derived from number of standardized variables. Vulnerability index is developed as a linear combination of set of standardized variables. These are scaled down to common numeric index and assumed to follow a normal distribution. Weights assigned to each parameter reflect its importance in the event-occurrence, together with the rating for the individual classes that denote the event intensity. The class intervals are derived from the observed event severity of the past and from the natural contributory nature. The weights and class intervals are derived from the past events. The various parameters of significance are grouped into: Frequency of events (historical), climate (time series of rainfall, rainfall fluctuation, evaporation, aridity), resource availability (vegetation cover; food - crop area, cash crop; and water - surface and groundwater), demand (population density, growth, industry), distribution loss (surface storage, medical facility, system efficiency) and sharing of resources (proximity to infra-structure facility) etc. Even though all these factors are inter-related, the weights of these factors are assigned based on the observed deficits.

Period of difficulty (PD) (anticipated) is calculated from annual rainfall data of 100 years. Time series analysis of rainfall indicates periods of low, normal and excess rainfall. This cyclic pattern (long-term) is used in evaluating the deficit, normal or excess monsoon rainfall. If the year under consideration falls in the deficit rainfall period, then it is assumed that PD for the forthcoming period is very high. This parameter is grouped into five classes in accordance with historical events of the region. Moving average method is used in identifying the onset of exceptional drought conditions based on climate and pastoral conditions. The observed frequency of events (FE) during the past provides significant information, in ascertaining the forthcoming/ expected drought event. It is observed that parts of Indian sub-continent undergo drought condition once in 1-2, 3-5, 5-7 and 9-10 years. This cyclic pattern of event occurrence is noticed for the past 200 years. The year under consideration, if it falls on the probable year of drought, is grouped under the category of very high and low, accordingly.

Distribution of monthly rainfall (MRF) within a year affects the desired soil moisture, crop yield, etc. A major shift /fluctuation in the monthly rainfall pattern would lead to drought and necessitates external irrigation of crops even during the monsoon period. Unprecedented rainfall is also damaging to the crop. Hence, fluctuation during the past ten years is considered. Aridity Index (ArI) indicates the dryness of the region and takes into account the temperature and rainfall of the region. It has been grouped into four classes. Palmer Drought Severity Index (PDSI) indicates the actual and required rainfall for the region. It is one of the widely estimated indices. It takes into consideration, rainfall, soil moisture, etc. and has been grouped into five classes. Evaporation (Eva), from the surface water bodies is an important factor in conservation and depends on the temperature and humidity prevailing in the region. It is grouped into five classes.

Land vegetation cover is estimated using Normalized Difference in Vegetation Index (NDVI) from the satellite data (coarse and finer ground resolution) in understanding the healthy growth of regional vegetation. Higher the NDVI greener the surface, and lower the NDVI degraded is the cover. It is grouped into five classes. Total crop area (TCr) in a village indicates the excess water demand during summer. Groundwater draft will be high during the rainfall deficit periods. Further, the distribution of water for irrigating the crops needs to be worked out. Hence, the crop area in a revenue division is grouped into five classes based on its share within the village boundary. Cash crops (CaCr) such as sugarcane, banana, etc. are water intensive in nature, but the high economic returns drive the farmers to go for these crops. Ratio of the cash crop amidst the normal crop area indicates the race for water in region. This ratio has been grouped five classes. The demand will be high from the high ratio villages and vice-versa. Crop Moisture Index (CMI) indicates the availability of soil moisture in the short term that is required for sustainability of crops. Meteorological approach is used to monitor week-to-week crop conditions. It responds rapidly to changing conditions and is grouped into five classes.

Surface water storage (SWS) in the form of lakes/ponds is widely used in conservation of surface run-off. The water-spread area demarcated from the satellite images indicates the conservation practice of the region. The presence of such areas with reference to total area of investigation indicates the existing conservation practices and scope for improvement. Lesser the water surface area in reservoirs, higher the probability of water deficit. This parameter is grouped into five classes. Size and number of perennial river (PeR) passing through the area and its proximity to the affected region indicates the water resource support at the time of drought. Lift irrigation from the river is one amongst the relief measures that could be utilized during drought conditions. The flow condition indicates the emergency resource location. Alluvium of the streambed could be used for moisture preservation. The flow level in the river is grouped into four categories.

Type of aquifer (AqT) that is present in a region gives an idea of its dependability. It is grouped into three classes of possible availability of water and recharge efficiency. Groundwater level fluctuation (GWF) derived from the observation wells indicates the excess pumping (drawdown) or recharge condition of the aquifer. Lower groundwater level observed during pre monsoon indicates the total draft from the aquifer. Rise in the water level after monsoon reveals the amount of recharge that took place due to rain. The maximum and minimum levels of the wells are grouped into five classes.

Population density (PoD) of a region governs the total resource demand. It is observed that higher the density, higher the risk of starvation deaths/ ill health. This parameter is grouped into five classes. The growth rate of human and livestock (HLG) population is a significant parameter in planning for the future. Higher growth rate implies higher risk. This parameter is grouped into five classes. People who are affected by drought are mostly agriculture dependant laborers (OcAg) and small landowners. Their concentration in a village decides the relief and subsidy distribution strategy. The percentage of people dependant on agriculture is grouped into five classes. The purchasing capacity of the population depends on their income (Inco). Even though, it may vary from place to place, the gross national income used in demarcating the poverty status of the region can be considered in identifying the households that need assistance. This parameter is grouped into five classes.

Suitable relief material storage (Stor) and distribution is another important aspect. The availability of facilities to store food, medicine and sheltering of relief workers within a settlement or its proximity to the distribution centre has been grouped into five classes. For nearby relief shelters, the lifting of material and distribution through volunteers is faster when compared to far away places that requires transportation facilities. The availability of trained medical fraternity (MF) /establishment (primary health care center) and its proximity to the relief settlements enhances the performance of relief workers. Surface transport network (TrN) within the region and its proximity to the settlements improves the overall efficiency of relief activities. The proximity of transport networks to individual settlements is grouped into five classes.

Table 4 details the various parameters, classes and assigned weights of individual parameters that indicate the drought intensity. Weights are assigned to each parameter to reflect its importance in relation to the occurrence of drought. Rating for individual classes denotes the degree of hazard intensity. A class value is then obtained by multiplying the figure denoting the importance of the main parameter and that for the degree of hazard represented by the particular class. The vulnerability of a region depends on the cumulative effect of individual parameters /classes, and is estimated as follows:

Drought Vulnerability (DV) = Assessment + Mitigation

$$DV = \sum_{I=1} [\ PD + FE + ARF + ArI + PDSI + Eva + NDVI + TCr + CaCr + CMI + SWS + PeR + AqT + GWF + PoD + HLG + OcAg] + [Inco + Stor + MF + TrN\ ]$$

Table 4 Weighting and ranking of drought parameters.

Criteria	Class	Class value	Weight
Period of difficulty Time series Analysis (anticipated) (PD)	>10 years 7-10 5 - 7 3-5 1-2	0 1 2 3 4	5
Frequency of Event (FE)	1-3 year 4-6 8-10 10>	4 3 2 1	5
Annual Rainfall Fluctuation (ARF)	Very high High Moderate Low	4 3 2 1	8
Aridity Index (ArI)	> 2 1.5-2 1.0-1.5 < 1	4 3 2 1	2
Palmer Drought Index (PDSI)	> + 4 0 to +3 -0.49 to 0 - 1.0 to - 2 -2 to -4	0 1 2 3 4	8
Evaporation (monthly in mm) (Eva)	> 300 200-300 150-200 75-150 < 75	5 4 3 2 1	2
Land Vegetation cover (NDVI)	Very high High Moderate Low Very low	0 1 2 3 4	9
Total Crop area (TCr)	> 70% 50-70% 30-50% 10-30% < 10%	5 4 3 2 1	12
Cash crop (Ratio cash crop / cultivated) (CaCr)	> 0.7 0.7 to 0.4 0.2 to 0.1 0.1 to 0.2 < 0.1	5 4 3 2 1	12
Crop Moisture Index (CMI)	< 1 1-2 2-5 5-7 >7	5 4 3 2 1	10
Surface water storage (% of area) (SWS)	> 20% 15-20% 10-15% 5-10% < 5%	1 2 3 4 5	10
Perennial river (PeR) Flow	High Moderate Low Dry	1 2 3 4	2
Aquifer type (AqT)	Alluvium Soft rock Hard rock	1 2 3	2
Ground water level fluctuation (Pre & post monsoon) in meters (GWF)	0-1 1-2 2-4 4-6 > 6	1 2 3 4 5	4
Population density (people/km^2) POD	> 100 50-100 30-50 10-30 < 10	5 4 3 2 1	3
Human & Livestock growth (% per year) (HLG)	> 20 10-20 5-10 1-5 < 1	5 4 3 2 1	3
Occupation - agriculture dependent or unorganized sector (%) (OcAg)	> 75 50-75 30-50 10-30 < 10	5 4 3 2 1	5
Income - (compared to Gross National Income) (Inco)	> 75% 50-40 % 25-40 % 15-25 % < 15%	1 2 3 4 5	3
Food storage (existing facility) (Stor)	< 2 km 2-10 km 10-20 km 20- 50 km > 50 km	1 2 3 4 5	3
Medical facility (MF)	< 2 km 2-10 km 10-20 km 20- 50km > 50 km	1 2 3 4 5	5
Transportat-ion network (distance from village) (TrN)	< 1 km 1-3 km 3-10 km 10-30 km > 50 km	1 2 3 4 5	5

Steps for calculation for a grid / polygon:

1) identify concerned parameter shown here and group into class value
2) Multiply the class value into weights and derive parameter influence
3) Add all the parameter influence

The drought vulnerability is estimated by: (1) collection of information on various parameters and distinguishing different classes based on historical events; (2) overlaying different map layers and deriving a polygon representing surface-cover; and (3) assigning class ratings for the polygon and estimating the cumulative class value. The cumulative DV is truncated into vulnerability categories such as very high, high, moderate and low vulnerability depending on the complexity and requirement. This procedure can be used in the vulnerability assessment for drought as well as for relief operations individually or in totality. DV computed using other methods such as neural network, Fuzzy, ANN, etc. can also be used.

The Geographical Information System (GIS) is a set of computer-aided tools for collecting, storing and retrieval of information, and transforming and displaying spatial data from the real world. Spatial data represent the objects that have physical dimensions in space. These physical features are represented on a map by way of points, lines and polygons with parametric table. These maps, text and tabular information can be digitized or keyed in for the creation of geo-information base using GIS. GIS helps in integrating the data for understanding the geography, physical characteristics and relationship of adjacent features. Figure 1 shows the various modules available for this purpose.

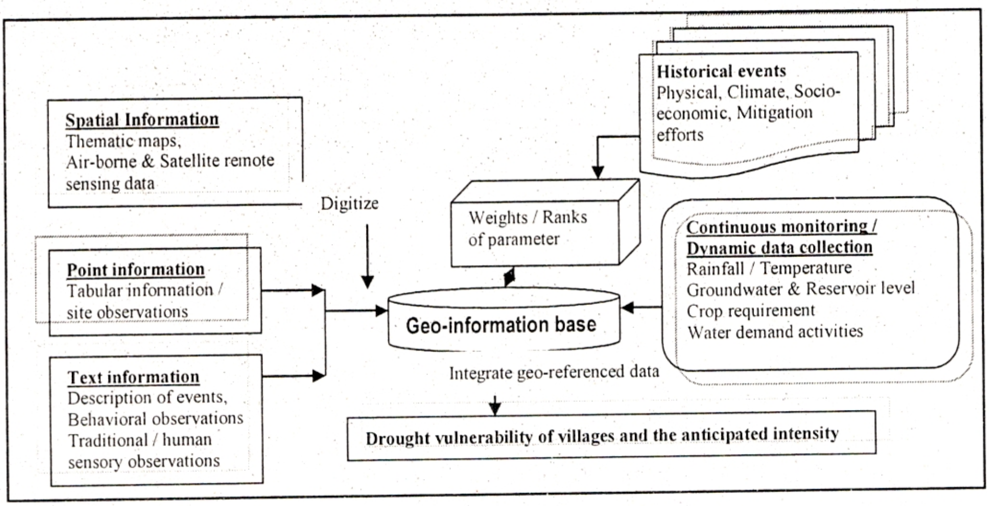

Fig. 1 Flow chart showing drought vulnerability estimation using Geographic Information.

Geo-information base has the critical information and knowledge required for developing a Decision Support System (DSS). The knowledge base is transformed into a number of facts and rules with suitable actions/operations corresponding to different combinations of each objective's attributes. Rule Based System can be grouped into various stages of development such as: (a) problem definition and expert selection; (b) knowledge engineering (climatological, hydrologic and hydro-geologic attributes, agriculture attributes, and socio-economic attributes); (c) inference engine; and (d) verification and validation.

CASE STUDY – JHOD NADI

A study was carried out to identify drought vulnerable villages within the Jhod Nadi watershed in Nanded, Maharashtra. Total water demand from the individual settlements and for crop cultivation (using crop calendar and field estimates), and the availability of surface water from rainfall (assumed based on the past record) was used in identifying vulnerable areas. Availability of infrastructure in storage and transportation of material has been considered for sharing the resources. Contribution of different parameters in the initiation of drought phenomenon was weighted and ranked. Figure 2 shows the drought vulnerable villages in the event of monsoon rainfall of 500 mm and its impact on agriculture and drinking water.

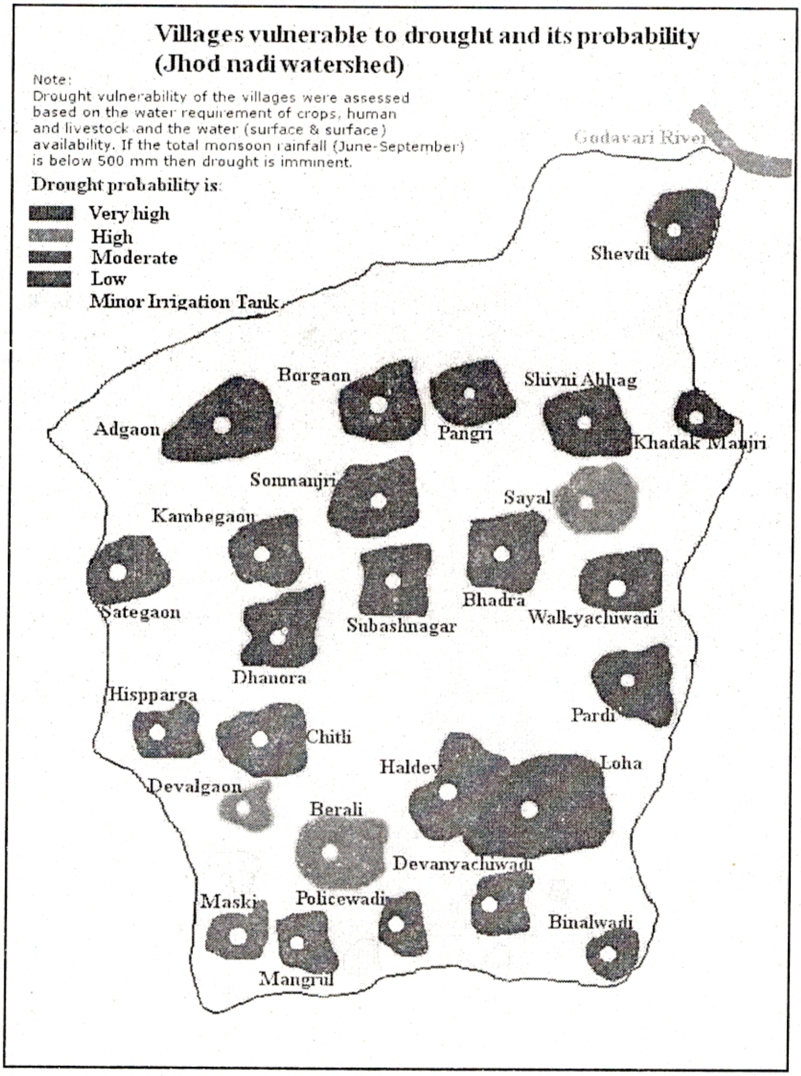

Fig. 2 Drought vulnerable villages within the Jhod Nadi watershed in Nanded, Maharashtra.

It may be mentioned that the drought indicator issued by an expert from a particular subject need to be understood before other experts can use it in evaluating the scenario in their respective specialization. Information imparted to the public should highlight the conditions, drought effects and suitable measures that need to be adopted to cope with drought.

SUMMARY

Drought is often the result of many complex factors acting and interacting within the environment. There is a need for observable/measurable indicators in realizing the occurrence of drought. The potential impacts of drought are many and varied, and can affect a wide range of economic, environmental and social activities. To mitigate the devastating impacts of drought, it is essential to analyze the available information and identify regions of vulnerability and the anticipated intensity of drought of a given region. In the present study the drought vulnerability of villages in Jhod Nadi watershed in Nanded, Maharashtra, has been assessed using the water requirement of crops, human and livestock population and the water availability.

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