**ESTIMATING THE IMPACT OF DROUGHT (WATER DEFICIENCY) ON CROP YIELD USING MULTIVARIATE ANALYSIS**

V.Sellam1 and E.Poovammal2

**ABSTRACT**

Human lives revolve around nature’s flora and fauna along with climatic variations. Natural disasters arise due to disturbances / variations in air, water and land. Among these, flood (water surplus in a river) and drought (water deficiency) are hydrologic extremes that affect humanity in a large scale. The latter one has catastrophic effects over vast areas of earth leading to loss of human lives, livestock and reduction / loss of crop yields. Drought estimation and management lacks its effectiveness mainly because of the ambiguities in identifying the onset / termination of drought, in terms of the influential hydrologic factors. Droughts are estimated based on deficiency of rainfall, streamflow, evapotranspiration, groundwater levels, vegetation conditions, etc. In this study, these hydrologic and agro-climatic factors are analysed using Principal Component Analysis (PCA) which is one of the multivariate techniques to analyse the sensitiveness of the parameters involved (independent factors) towards crop yield (dependent variable). Data collected from Vaippar River basin in Southern Tamilnadu State, India is analysed.

**Key words:** Crop yield, Rainfall, Streamflow, evapotranspiration, groundwater levels, vegetation condition, Principal Component Analysis (PCA).

1. Asst Professor, Dept of CSE, SRM University, Ramapuram, Chennai – 600089, India, Corresponding Author, Email: [sellamveera@gmail.com](mailto:sellamveera@gmail.com)
2. Professor, Department of CSE, SRM University, Kattankulathur, Chennai-603203, India, Email: [hod.cse@ktr.srmuniv.ac.in](mailto:hod.cse@ktr.srmuniv.ac.in)

**INTRODUCTION**

Drought is an insidious natural hazard that results from lower levels of rainfall than what is considered normal. When this phenomenon extends over a season or a longer period of time, rainfall is insufficient to meet the demands of human activities (Agricultural, industrial and domestic water uses) and the environment. Droughts are regional in extent and each region has specific climatic characteristics. The amount, seasonality and form of rainfall differ widely between each of these locations. Drought is viewed in different ways by different constituency of water users. Hence, there is no single definition of drought (Wilhite and Glantz, 1985).

Droughts are usually related to climatic factors like rainfall, high temperature, high wind and low relative humidity. Depending upon the influential factors, the classification of drought definitions is given as: Rainfall based drought definitions, Evapotranspiration based drought definitions, Streamflow based drought definitions, Soil moisture based drought definitions and Vegetation based drought definitions.

Agricultural drought is the shortage of rainfall sufficient to have an adverse effect on crop production or range production. Agricultural droughts can occur for a variety of reasons, including low precipitation, the timing of water availability, or decreased access to water supplies. It is possible to suffer an agricultural drought in the absence of a meteorological drought The highest societal costs of drought are the hazard’s impact on agriculture. If severe enough, agricultural drought can cause widespread food insecurity and severe economic strain on farmers. It occurs when the soil moisture is insufficient to meet the needs of a particular crop at a particular time. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil.

A deficit of rainfall over cropped areas during critical periods of the growth cycle can result in destroyed or underdeveloped crops with greatly depleted yields. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. Agricultural Droughts develop gradually; they are referred to as slow-onset natural hazards. The drought-induced agricultural impacts include damage to crop quality; income loss for farmers due to reduced crop yields; reduced productivity of cropland; insect infestation; plant disease; increased irrigation costs; cost of new or supplemental water resource development (wells, dams, pipelines); reduced productivity of rangeland; forced reduction of foundation stock; closure/limitation of public lands to grazing; and high cost/unavailability of water for livestock

**LITERATURE**

The most immediate consequence of drought is a fall in crop production, due to inadequate and poorly distributed rainfall. In the Ethiopian highlands, stock are usually disposed of in the following order: sheep and goats, then younger cattle, with horses, donkeys and work oxen being sold as a last resort (Wood, 1976), since the latter are essential for land preparation. A report by the Relief and Rehabilitation Commission of Ethiopia for the province of Wollo in 1974 presents data showing almost all losses to have been due to deaths rather than sales: 71% dead from starvation, as opposed to 19% sold, leaving 2% disposed of by other means and 8% remaining (Wolde Mariam, 1984). By contrast, Wood's survey of farmers in the northern highlands of Ethiopia in 1974 found that most livestock losses were the result of distress sales in order to raise cash rather than deaths due to inadequate fodder (Wood, 1976).

JavadBazrafshan*et al*(2014) developed a new drought index for a set of SPI time scales. To solve this problem, a multivariate approach has been utilized for a study area in Iran. PCA is used to reduce the dimensionality of the several dependent variables in to fewer principal components. Li Q *et al*(2015) identified drought risk areas in the Huaihe river basin based on the Principal Component Analysis of precipitation, evapotranspiration, soil moisture and runoff. ZengchaoHao*et al* (2013) proposed a multivariate, multi- index drought modeling approach named as Multivariate Standardized Drought Index (MSDI). RezgarArabzadeh*et al* (2015) made a study using the multivariate technique of principal components analysis (PCA) for the regional analysis of the stream flow drought. The stream flow drought index (SDI) was calculated in the seven hydrometric stations of the Sefid-Rud basin in Iran. Sigdel*et al* identified the spatial and temporal variation and recurrence interval of drought using PCA. SPI was calculated for agricultural and hydrological aspects and is analyzed through PCA.

**STUDY AREA AND DATA COLLECTION**

Tamilnadu, being a semi-arid region also suffers from frequently occurring drought events. Seventeen districts of Tamilnadu, comes under the Drought Prone Areas Programme (DPAP) and among which Vidrudhunagar is one of the district which is quite severely affected by drought. Out of the seven blocks of the Vidrudhunagar district, which are considered by the DPAP, five blocks namely Virudhunagar, Sivakasi, Sattur, Aruppukottai and Kariyapatti lies in the Arjunanadhi and Kousiganadhisubbasins of the Vaippar basin. This project aims in assessing the severity of the meteorological and hydrological drought, in the Arjunanadhi and Kousiganadhisubbasins by using some of the widely-opted drought indices such as the Indian Meteorological Department (IMD) method, Herbst’s method, Standardized Precipitation Index (SPI) and Groundwater Resource index (GRI). The drought severity and the duration for the two subbasins are compared and the best suited index for the existing field condition will be determined.

The river Vaippar originates at an altitude of 1644 m in Vasudevanallur Reserve Forest on the eastern slopes of Western Ghats in Tirunelveli District and runs eastward for a distance of 112 km and finally empties into Gulf of Mannar near Vembar village, i.e., 18 km from Vilathikulam town of Thoothukudi District. The Vaippar river basin is located between latitude 80 59’ N to 90 49’ N and longitude 770 15’ E to 780 23’ E having an area of 5423 sq.km and is surrounded by Tamarabarani Basin on the South Western Ghats and Vaigai Basin on the west, Gundar Basinon the north and Gulf of Mannar / Bay of Bengal on the east.The Vaippar Basin has been divided into 13 sub basins and Arjuna Nadhi and Kousiga Nadhi are considered for study

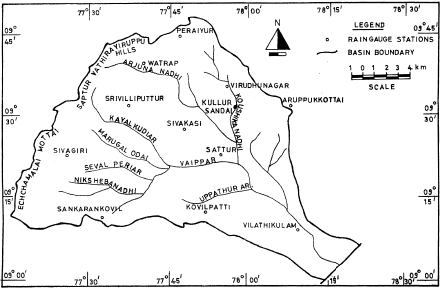
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Fig 2 Basin map of Vaippar

**Arjuna Nadhi**

The surplus cour se of Watrap Periyakulam is the origin of Arjunanadhi. Ithad two reservoirs Periyar and Kovilar prior to 1989. During 1989, two more reservoirs namely Anaikuttam reservoir and Golwarpatti reservoir were constructed across theArjunanadhi.Arjunanadhi Sub basin area is 1096 Sq. Km with a hilly area of 195 Sq. Km. Thetaluks covered in the sub basin are Srivilliputhur, Sivakasi, Sattur and Virudhunagar ofVirudhunagar District and Peraiyur of Madurai District. It receives an annual averagerainfall of 895 mm, with its major share during North -East Monsoon

**Details of Ayacut**

The details of ayacut area is classified as Direct Ayacut and Indirect Ayacut whichare furnished below.

**(a) Direct Ayacut :**

1 Periyar Reservoir 390.545 ha

2 Kovilar Reservoir 140.55ha

3 Anaikuttam Reservoir 1214.00ha

4 Golwarpatti Reservoir 1821.00 ha

**(b) Indirect Ayacut:**

1 System Tanks 3138.11ha

2 Non system Tanks 4481.57ha

3 Panchayat Tanks 1765.00ha

The total ayacut area under the sub-basin: 12950.78.0 ha

The total ayacut area under the maintenance of PWD: 11185.78.0 ha

Though the total registered ayacut under PWD control is 11186 ha.

**Soil Type and Crops grown**

The soil types found in this Sub Basin are combination of Inceptisol, Alfisol andVertisol..Crops grown in this sub basin area are Coconut, Sugarcane, Banana, Sapota,Amla, Guava, Mango as annual crops, besides Paddy, Cotton, Vegetables, Pulses,Fodder Cholam, Cumbu, Maize are grown during first season and Paddy, Cotton,Vegetables, Pulses etc. as second season crops.

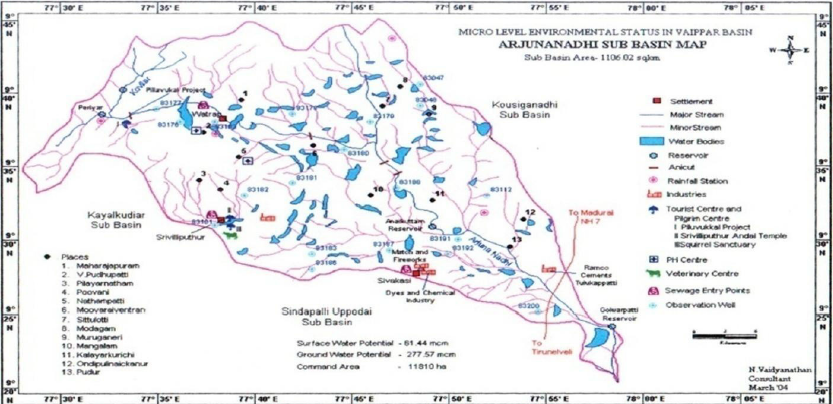


Fig 3 Skeletal view of Arjuna Nadhi sub basin

**Kousiga Nadhi**

The main stream running in the reservoir catchment is KoushikaNadhi which is a tributary to Arjuna Nadhi and then to the Vaippar. It originates at an altitude of about 200 m above MSL in Peraiyur area ofTirumangalam taluk in Madurai district. This is an ephemeral streamwhich is dry for long periods and the flow is taking place only during themonsoon periods. Most of the storm rainfalls become direct runoff with avery little infiltration.

Kousiga Nadhi carries the flow mainly from the surpluswaters of the irrigation tanks and those from its local catchment area. Thereare 63 tanks distributed within the catchment. These tanks are mostlyplaced in series and in several lines forming a cluster. The capacities of these tanks vary from 0.0566 M m3 to 0.98 M m3. With so many tankspresent in the Kullursandai catchment, the runoff process becomes all themore complicated and hence its calculation.

Kullursandaireservoir is located across the KoushikaNadhi near avillage by its name at 9°32’30" N Latitude and 77°58’20" E Longitude. Thefree catchment area at the reservoir site is 79.14 km2 and the interceptedarea is 277.23 km2. The combined catchment works out to 356.37 km2. Theentire catchment area is in the plains.

This sub basin has a tropical climate. It has a hot summer and a mild winter. Agroclimatically the area falls under the groupof semi-arid regions. The hydrometeorological data is available from Kavalur Weather Station located at about 13 km from the reservoir. Theclimate of the catchment is influenced by the monsoonic winds which ismainly responsible for most of the rains over the catchment with theNortheast monsoon accounting for the maximum amount of rainfall. Mostof the agricultural activities are centered around this season betweenSeptember and December. The ranges of the various climatic factors aregiven below.

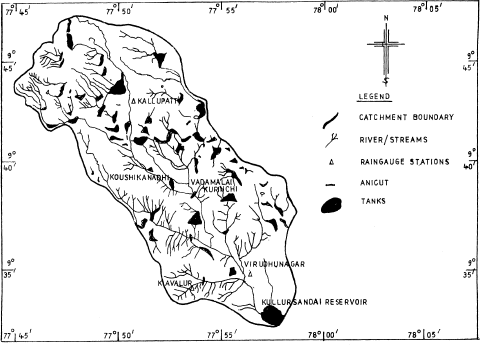


Fig 4 Kousiganadhi sub basin

**DATA COLLECTED**

The data utilized in this study comprises of both spatial and non-spatial data. The data needed for assessing drought can be grouped into three categories viz., meteorological, hydrological and agricultural. The data collected from various departments are detailed below.The study area maps i.e boundary map, block map, land use map, land cover map , drainage map are collected from the Institute for Water Studies (IWS), WRO, PWD, Chennai and India Meteorological Department, Chennai. Monthly rainfall data for eight rain gauge stations namely Kavalur , Srivilliputhur, Satur, Virudhunagar , Watrap , Thirumangalam , Aruppukottai and Gudalur for the period from 1984-2015. The remotely sensed dataset used in this study consists of Landsat 7 satellite imagery taken during February 2015 This data set is downloaded from <https://www.usgs.gov>,the official website of United Nations Geological Survey.

Monthly groundwater fluctuation data for 26 observation wells were collected from State Surface and Groundwater Resources Data Centre,Water Resources Organization in Public Works Department, Government of Tamil Nadu for the period from 1984 to 2015. Paddy is the main crop in the study area. Paddy is cultivated in two seasons namely, summer (January to March) and Kharif (October-December). The prevalent wet crops grown in the area includes Sugarcane and Banana Pulses and Millets are cultivated as paddy fallows. Cotton, Groundnut and Grains are dry crops cultivated in a considerable area. Details related to crop area were collected from Department of Economics and Statistics, Chennai.

**METHODOLOGY**

**METEOROLOGICAL DROUGHT**

It is a situation when there is a significant decrease in precipitation over an area (more than 25% from normal). There is often no direct ecological or economic impact and there is no effective human response.The meteorological drought is assessed by Standardized Precipitation Index (SPI)

## STANDARDIZED PRECIPITATION INDEX (SPI)

The Standardized Precipitation Index (SPI) was developed by McKee et al. (1993). It is primarily a tool for defining and monitoring drought events. It allows an analyst to determine the rarity of drought at a given time scale (temporal resolution) of interest for any rainfall station with historic data (Edwards and McKee, 1997). It can also be used to determine periods of anomalously wet event. The SPI is not a drought prediction tool. The SPI was basically proposed as an alternative to the Palmer drought severity index (PDSI) (Sims et al., 2002).

Mckee et al. (1993) designed SPI basically to quantify the precipitation deficit for multiple scales. Though the Palmer drought severity index (PDSI) is widely used in the United State of America, the SPI is also being used in USA as well as many other countries for drought monitoring. Sims et al. (2002) indicated that the SPI is more representative of short-term precipitation and soil moisture variation and hence a better indicator of drought The SPI is considered as simple and better drought index based only on precipitation. The SPI can be used to monitor drought condition on 1-, 3-, 6-, 12-, 24- and 48-month time scales. This temporal flexibility allows the SPI to be useful in both short-term agricultural and long-term hydrological applications.

### Classification of SPI

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median precipitation, while negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climate can be represented in the same way and wet periods can also be monitored using the SPI. Classification system given by McKee et al. (1993) is shown in Table 1, which is used to define drought intensities resulting from estimated of the SPI for various stations in the Tons basin.

Table 1.Classification of SPI

|  |  |  |
| --- | --- | --- |
| **Sl. No.** | **SPI Values** | **Drought Condition** |
| 1 | 2 and above | Extremely wet |
| 2 | 1.5 to 1.99 | Very wet |
| 3 | 1.0 to 1.49 | Moderately wet |
| 4 | - 0.99 to 0.99 | Near normal |
| 5 | - 1.0 to – 1.49 | Moderately dry |
| 6 | 1.5 to – 1.99 | Severely dry |
| 7 | - 2.0 and less | Extremely dry |

McKee et al. (1993) also defined the criteria for a “drought event” for any time scale. A drought event occurs any time when the SPI is continuously negative and reaches at intensity where the SPI is – 1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has duration defined by its beginning and end and intensity for each month that the event continues. The accumulated magnitude of drought is drought severity, and it is the positive sum of the SPI for all the months within a drought event.

### Determination of SPI

Computing of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a climate station. The gamma distribution is defined by its frequency or probability density function:

g(x) = χα - 1 e –x / β…(1)

The alpha (α) and beta (β) parameter of the gamma probability density function are estimated for each station, for each time scale of interest (1- month, 3-months, 6-months, and 12-months). The maximum likelihood solutions are used to optimally estimate α andβ:

= (1 + ) …(2)

β=…(3)

WhereA = ln (‾x) - 

n = number of precipitation observations

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given time scale for the station in question. The cumulative probability is given by:

G (x) = = …(4)

Letting t = x/β the Equation become the incomplete gamma function:

G (x) = =…(5)

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

H (x) = q + (1 – q) G (x) …(6)

Where, q is the probability of a zero. The cumulative probability H(x) is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI.

Z = SPI = - (t - ) for 0 < H (x) ≤ 0.5 …(7)

Z = SPI = + (t - ) for 0.5 < H (x) ≤ 1.0 …(8)

Where,

t =  for 0 < H(x) ≤ 0.5

t =  for 0.5 < H(x) ≤ 1.0

Co = 2.515517

C1 = 0.802853

C2 = 0.010328

d1 = 1.432788

d2 = 0.189269

d3 = 0.001308

(The above C and d are probability constants)

**HYDROLOGICAL DROUGHT**

Meteorological drought if prolonged, results in hydrological drought with marked depletion of surface water and consequent drying up of reservoirs, lakes streams and rivers, cessation of spring flows and fall in ground water level. This involves the management of water supply and demand aspects.The Hydrological drought is assessed by Groundwater Resource Index (GRI)

**GROUNDWATER RESOURCE INDEX (GRI)**

The GRI involves the calculation of mean groundwater level for month m

…(9)

Where, - observedmonthly groundwater level data

Then, GRI is computed as

…(10)

Where, - standard deviation

…(11)

Based on the GRI drought is classified as shown in Table 2.

**Table 2. GRI drought classification**

|  |  |  |
| --- | --- | --- |
| **STATE** | **DISCRIPTION** | **CRITERIAN** |
| 0 | Non-drought |  |
| 1 | Mild drought |  |
| 2 | Moderate drought |  |
| 3 | Severe drought |  |
| 4 | Extreme drought |  |

**AGRICULTURAL DROUGHT**

It occurs when soil moisture and rainfall are inadequate during the growing season to support healthy crop growth to maturity and cause extreme crop stress and wilt. This involves the on farm water supply and demand including crop-insurance, compensation and loss- sharing measures.The agricultural drought is assessed by STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX (SPEI).

**STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX (SPEI)**

The Standardized Precipitation Evapotranspiration Index (SPEI) is an extension of the widely used Standardized Precipitation Index (SPI). The SPEI is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought. In this study, the steps followed for the SPEI calculation were (i) the parameterization of potential evapotranspiration based on the monthly minimum and maximum air temperature, and extra-terrestrial radiation; (ii) a simple monthly water balance, calculated as the difference between monthly precipitation (P) and potential evapotranspiration (PET), and (iii) normalisation of the climatic water balance into a log-logistic probability distribution to transform the original values to standardized units that are comparable in space and time and to the various SPEI time scales utilized in the study area.

The SPEI fulfils the requirements of a drought index since its multi-scalar character enables it to be used by different scientific disciplines to detect, monitor and analyze droughts. The SPEI allows comparison of drought severity through time and space. A crucial advantage of the SPEI over other widely used drought indices that consider the effect of PET on drought severity is that its multi-scalar characteristics enable identification of different drought types and impacts in the context of global warming.

**Computation of the SPEI**

The SPEI is calculated using the monthly difference between precipitation and PET instead of monthly precipitation as input data as in SPI calculation.. This represents a simple climatic water balance which is calculated at different time scales to obtain the SPEI.Blaneycriddle equation is used to model PET based on available data monthly average temperature and percentage of sunshine hours.

*ETo* = *p* ·(0.46·*Tmean* + 8) …(12)

where*ETo* is the reference evapotranspiration [mm day−1] (monthly) ,*Tmean* is the mean daily temperature [°C] given as *Tmean = (Tmax + Tmin )/ 2* and *p* is the mean daily percentage of annual daytime hours.With a value for *PET*, the difference between the precipitation (*P*) and *PET* for the month *i* is calculated as,

Di = Pi – PETi, …(13)

which provides a simple measure of the water surplus or deficit for the analyzed month. The calculated *Di* values are aggregated at different time scales using a program, SPI\_SL\_6.exe developed by the WMO (World Meteorological Organization) downloaded from: <http://drought.unl.edu/monitoringtools/>downloadablespiprogram.aspx following the same procedure as for the SPI.Based on the SPEI, drought is classified as shown in Table 3.

**Table 3.Agricultural drought classification using SPEI**

|  |  |  |
| --- | --- | --- |
| **STATE** | **DISCRIPTION** | **CRITERIAN** |
| 0 | No-drought |  |
| 1 | Mild drought |  |
| 2 | Moderate drought |  |
| 3 | Severe drought |  |
| 4 | Extreme drought |  |

**Principal Component Analysis**

PCA is a dimensionality reduction algorithm that uses orthogonal transformation that converts set of observations mostly correlated values into a set of linearly correlated values. It is used to discover patterns in a given data set. In this type of analysis, the first principal component has the highest variance(deviation from original observation) and the other principal components succeeds according to their respective variance(highest order) under the condition that is orthogonal to the precedingcomponents. It is used as a means in exploratory data analysis and for making predictive analysis. When a multivariate is detected as a set of coordinates in a high dimensional data space, PCA ensures that it reduces it to a lower-dimensional picture when viewed from its most informative view point. The number of principal components is less than or equal to the number of original variables.The aim of PCA is to acknowledge the directions along which the variation in data is maximum.

Basic approach for PCA:-

• Collect and standardize the data Set

• Calculate the eigen values and eigen vectors from the covariance matrix

• Sort eigenvalues in descending order and choose the kk eigenvectors that correspond to the kk largest eigenvalues where kk is the number of dimensions of the new feature subspace (k≤dk≤d)/.

• Construct the projection matrix WW from the selected kk eigenvectors.

• Transform the original dataset XX via WW to obtain a kk-dimensional feature subspace YY.

**Covariance Matrix**

Matrix that represents the variance in data set and covariance among the components. By arranging the eigen vectors based on the eigen values in an decreasing order the principal components are respectively aligned on the basis of their significance.Covariance matrix helps us to relate two variables based on their positive, negative, or non-existing character of their covariance.

Eigen values estimates the variation retained by each principal component. In General, eigen values are maximum for first PC and keeps decreasing for the other principal components.Eigenvalues are simply the coefficients attached to eigenvectors, which give the axes magnitude.

An eigenvalue > 1 indicates that PCs account for more variance than accounted by one of the original variables in standardized data. This is commonly used as a cutoff point for which PCs are retained. This is applicable only when the given data set is standardized.

**XLSTAT**

XLSTAT is a software that deals with data analyses and is highly compatible with Microsoft excel. It primarily focuses on statistics and multivariate analysis. It is highly efficient in visualizing the data as histograms, 3-D Plotting, principal component analysis etc; It is easier to install and is user-friendly in nature.

**PCA(1)**

The first principal component is the linear collaboration of x-variables that has maximum variance(from the give set of data) so that it accounts for maximum variance in data.

**PCA in analyzing Drought**

The data collected is standardized. Inorder to analyze the effect of meteorological, hydrological and agricultural drought on the yield gained PCA is used. Since the data collected has raw factors, the principal components are to be chosen. The factors that affect the yield are meteorological, hydrological and agricultural drought and the area under cultivation. The data collected is from 1966-2012.

Procedure for PCA on given set of data

* 1.Install XLSTAT and enable it to work with excel environment.
* 2.Select the three principal components
* 3.Using the PCA option in XLSTAT, calculate the eigen value and vectors for the principal components.
* 4.The covariance matrix is calculated by the XLSTAT Software.
* 5.Plot the 3-D Scatter graph using the "3-D Graph" option.

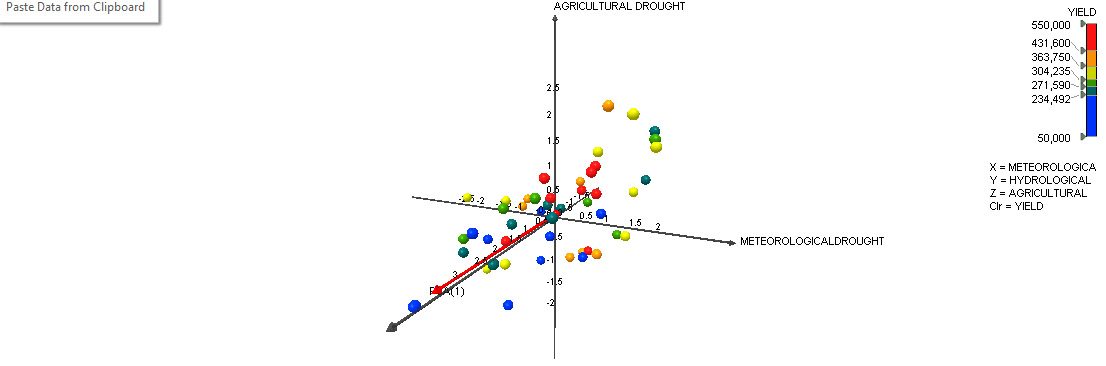
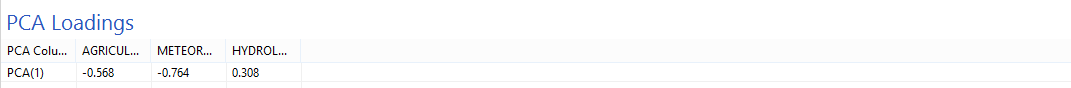


Fig 5 3-D Scatter Plot for three Principal Components



**Table 4 PCA Values**

From the 3-D graph, we can infer that the principal component hydrological component highly affects the yield of paddy crop in Arjunanadhi. The arrow indicates that the deviation in data is maximum towards hydrological drought.

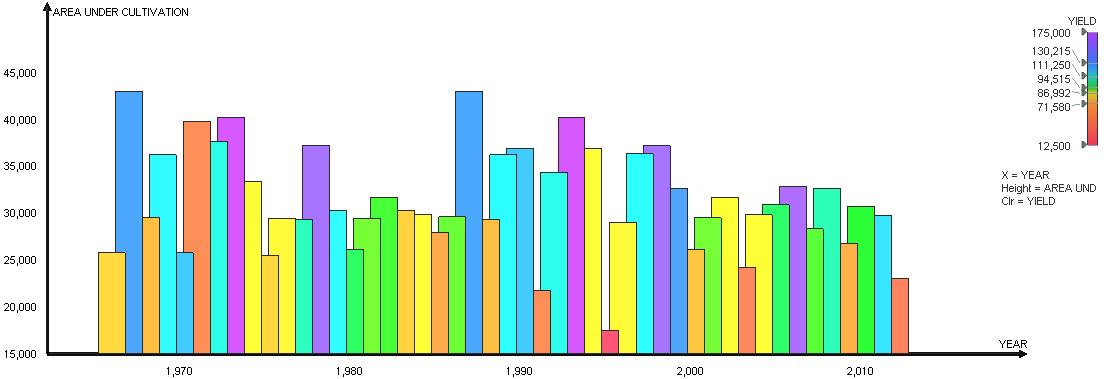


Fig 6 2-D PCA Plotting for Paddy Crop

The above graph illustrates the relationship between the yield obtained and the drought parameters(Meteorological,Hydrological and Agricultural) from the year 1966-2012 in Arunanadhi for Paddy crop. Along the y-axis Area under cultivation is taken as the parameter and along x-axis year is considered as the parameter. The Colour Coding is done on the basis of yield obtained.The graph is approximately Scaled to Standard value. Based on the computed PCA values considering Meteorological, Agricultural and Hydrological Drought as the three principal components , the inference is that higher the PCA value higher the drought, lower the yield.

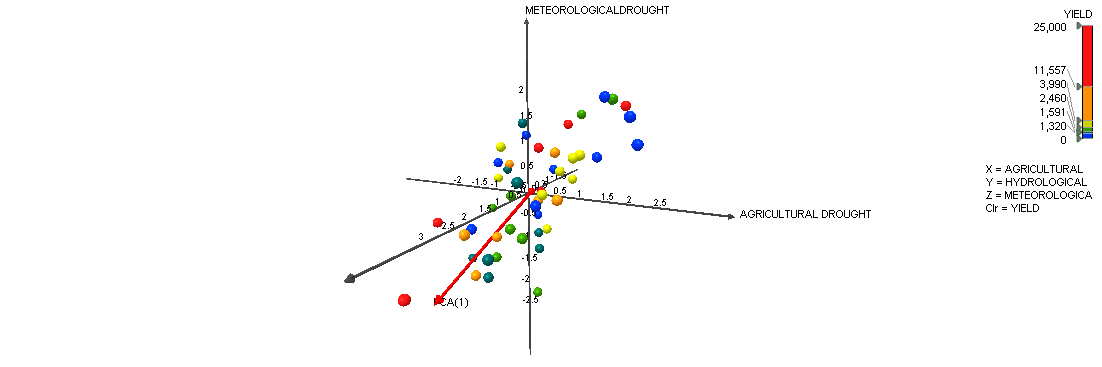
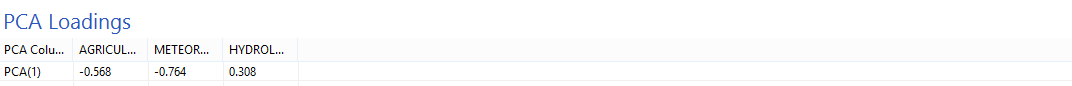
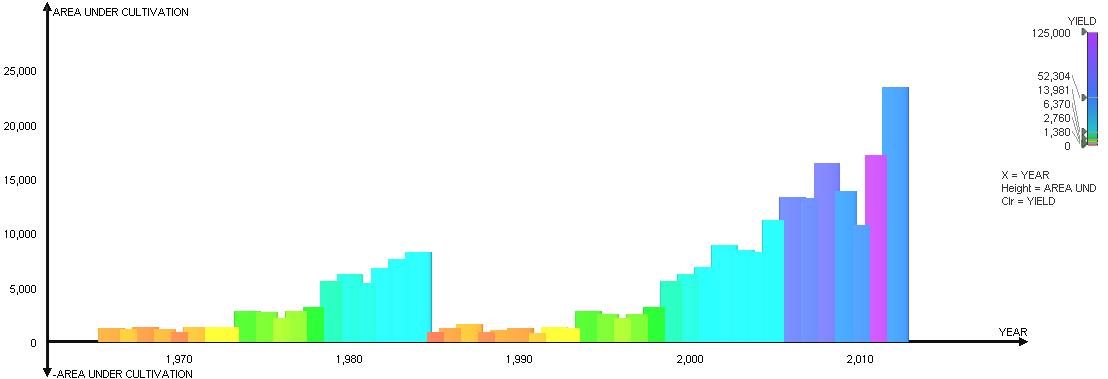


Fig 7 3-D Scatter Plot for three Principal Components



**Table 5 PCA Values**

From the 3-D graph, we can infer that the principal component hydrological component highly affects the yield of maize crop in Arjunanadhi. The arrow indicates that the deviation in data is maximum towards hydrological drought.

 Fig 9 2-D PCA Plotting for Maize crop

The above graph illustrates the relationship between the yield obtained and the drought parameters(Meteorological,Hydrological and Agricultural) from the year 1966-2012 in Arunanadhi for Maize crop. Along the y-axis Area under cultivation is taken as the parameter and along x-axis year is considered as the parameter. The Colour Coding is done on the basis of yield obtained. The graph is approximately Scaled to Standard value. Based on the computed PCA values considering Meteorological, Agricultural and Hydrological Drought as the three principal components , the inference is that higher the PCA value higher the drought, lower the yield.

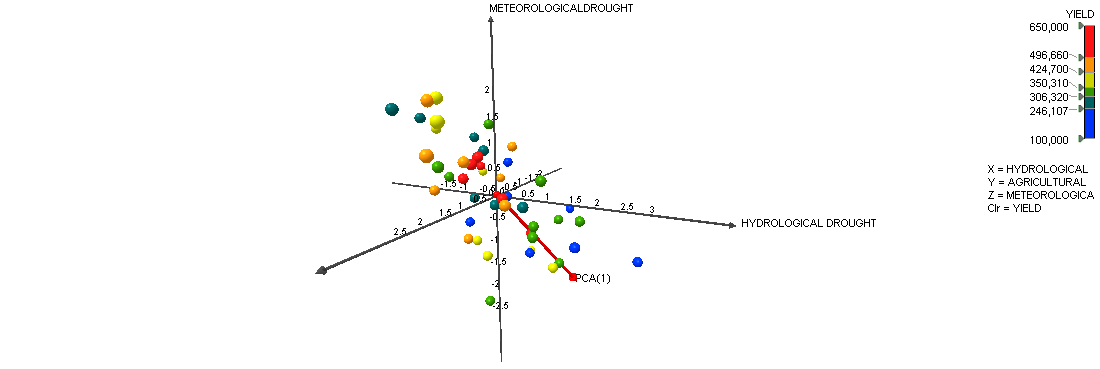
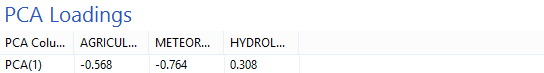


Fig 8 3-D Scatter Plot for three principal components



**Table 5 PCA Values**

From the 3-D graph, we can infer that the principal component hydrological component highly affects the yield of Cereals in Arjunanadhi. The arrow indicates that the deviation in data is maximum towards hydrological drought.

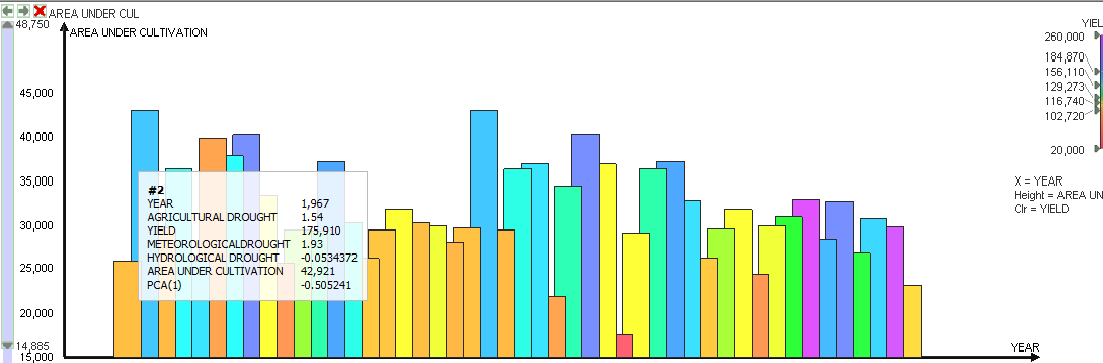


Fig 7 PCA Plotting for Cereals

The above graph illustrates the relationship between the yield obtained and the drought parameters(Meteorological,Hydrological and Agricultural) from the year 1966-2012 in Arunanadhi for Cereals. Along the y-axis Area under cultivation is taken as the parameter and along x-axis year is considered as the parameter. The Colour Coding is done on the basis of yield obtained. The graph is approximately Scaled to Standard value. Based on the computed PCA values considering Meteorological, Agricultural and Hydrological Drought as the three principal components , the inference is that higher the PCA value higher the drought, lower the yield.

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