Agricultural drought assessment and management in Arjunanadhi and Kousiganadhi sub basins

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***Abstract*—** Agricultural drought is the shortage of precipitation (relative to the normal precipitation for that location) sufficient to have an adverse effect on crop production or range production. It occurs when the soil moisture is insufficient to meet the needs of a particular crop at a particular time. The study area for this thesis is Arjunanadhi and Kousiganadhi sub basins of Vaippar river basin. The taluks covered in the sub basin are Srivilliputhur, Sivakasi, Sattur and Virudhunagar of Virudhunagar District and Peraiyur of Madurai District. The objectives of the study are identification of drought prone areas according to Government of India norms, assessment of agricultural drought severity and preparation of drought management plan. Using the criteria published in Technical Committee under the Chairmanship of Prof. C.H.Hanumantha rao the rainfall datasets and climatic data of stations Kavalur , Srivilliputhur, Satur, Virudhunagar , Watrap , Thirumangalam , Kovilpatti and Periyakulam were analysed and characterized into climatic zones which was later prepared as a map using arc gis. . SPEI values are derived from rainfall data and evaporatranspiration calculated from climatic data of from 1984 to 2015 for quantitative measurement of drought events over the 30-year period. Agricultural Drought Severity Index(ADSI) is calculated from NDVI data collected using multitemporal Terra MODIS Vegetation Indices Product (MOD13Q1) and mapped as Agricultural drought severity map.Rainwater Harvesting is proposed as a measure in the drought management plan. The strategy for management of Agricultural Drought using Rainwater Harvesting comprises of two phases namely detection of agricultural drought using indexes and the delineation of RWH locations potentially suitable for the management of agricultural drought in the region using a GIS decision support system (DSS). The potential-suitable areas for RWH were identified based on three criteria were selected soil type, land cover and land use and surplus precipitation.

I. INTRODUCTION

Agricultural drought is the shortage of precipitation (relative to the normal precipitation for that location) sufficient to have an adverse effect on crop production or range production. It occurs when the soil moisture is insufficient to meet the needs of a particular crop at a particular time. 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. Early detection of droughts is important for managing emerging crop losses to prevent or mitigate possible related famines.Scientific agricultural drought assessment becomes inevitable.Drought management is carried out through impact minimization programs and not through increasing the supply or reducing the demand aspect

II. REVIEW OF LITERATURE

(Sehgal & Dhakar, 2016)More frequent and severe droughts are expected in spatial and time scales in the study area , Rajasthan State of India. The harm associated with expected frequent and severe droughts can be minimized by accurate assessment of the vulnerability of the drought .This study arrived at a methodology to assess and map agricultural drought vulnerability at local scale using conceptual model of vulnerability based on variables of exposure, sensitivity, and adaptive capacity. Hazard exposure was based on frequency and intensity of gridded standardized precipitation index (SPI). Agricultural sensitivity was based on soil water holding capacity as well as on frequency and intensity of normalized difference vegetation index (NDVI)-derived trend adjusted vegetation condition index (VCIT adj). Percent irrigated area was used as a measure of adaptive capacity. The high spatial resolution remote sensing and other datasets of biophysical factors in a GIS environment best suited fine scale assessment of agricultural drought that can be presented as maps which are more relevance to agencies which are formulating and implementing mitigation schemes at ground level.

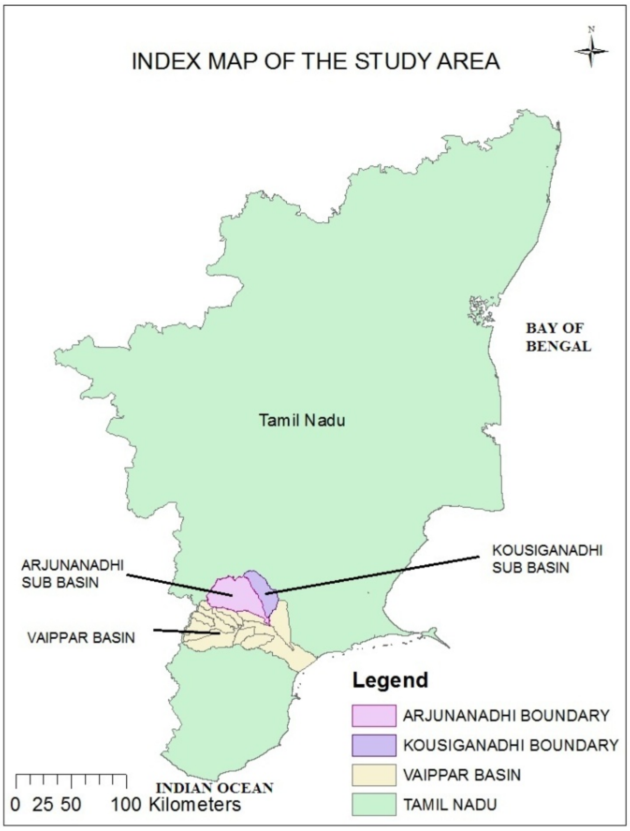
(Thavorntam, Tantemsapya, & Armstrong, 2015)Drought causes serious problem for agricultural activities, economies and environment in northeastern region of Thailand. , this necessiates characterization of drought events in terms of drought severity, frequency and possibility of drought occurrence. The characteristics of drought and drought severity was examined for different land cover types using the Standardized Precipitation Index (SPI) and the Vegetation Condition Index (VCI). Drought indices from precipitation, the standardized precipitation index (SPI) quantifies precipitation deficits at temporal difference. SPI has also been used to determine drought severity levels and better distinguish between abnormal wetness and dryness. The satellite-based drought indices Normalized Difference Vegetation Index (NDVI) has been used for land cover classification, land use change detection, drought monitoring, vegetation dynamics observations and estimating ecosystem carbon and moisture fluxes and Vegetation Condition Index (VCI) has been used to detect the vegetation condition from extremely bad to optimal conditions .

(Hossain, Chowdhury, & Paul, 2016) The objective of this paper is to find out the adaptation measures practised by farmers to cope with climate change and agricultural drought in two drought- prone villages of the north-western Bangladesh. The study has found that agriculture of this area is recurrently disrupted by frequent drought events.The climate change may also increase both frequency and magnitude of extreme drought events . This paper identifies that the impacts of drought on agriculture are difficulties in irrigation, disruption in cropping pattern, depletion of ground water table, problem in fish cultivation . The analyses unveil that respondents practised a range of adjustment strategies to combat adverse impacts of drought such as adoptions of drought- tolerant crop varieties, rainwater harvesting, mango and jujube intercropping with rice, kitchen gardening, weed control and reducing water loss, constructing water control structures, irrigation and cultivation of fast-growing fish species. The present study recommends proper drought early warning system, reserving surface water, managing supplemental irrigation, tree plantation, re-excavation of canals and traditional ponds, credit support to the farmers, preparedness and awareness rising to ensure the future sustainable agricultural development in the study areas.

(Mahmoud, Adamowski, Alazba, & El-Gindy, n.d.) Human activities affect ecosystem dynamics, pose a continuous challenge to individuals and communities trying to survive in arid and semi-arid regions in Beheira Governorate, Egypt. Rainwater harvesting (RWH) is proposed as a method for the management of agricultural drought in arid and semi-arid regions .The development of a method to employ rainwater harvesting (RWH) in the management of agricultural drought in arid and semi-arid regions comprised two phases namely detection of agricultural drought using a normalized difference vegetation index and the delineation of RWH locations potentially suitable for the management of agricultural drought in the region using a GIS decision support system (DSS). The DSS model generated a RWH map with five categories of suitability: excellent, good, moderate, poor and unsuitable. Soil type, land cover and land use , slope (topography), runoff coefficient and surplus precipitation were the criteria used to determine the potential RWH sites for the study area using RS and GIS.

III. STUDY AREA

Vaippar river basin is located between latitude 8° 59‟ N to 9° 49‟ N and longitude 77°15‟ E to 78° 23‟ E having an area of 5423 sq.km .The Vaippar Basin has been divided into 13 sub basins and Arjuna Nadhi and Kousiga Nadhi are considered for study.The surplus course of Watrap Periyakulam is the origin of Arjunanadhi. Arjunanadhi Sub basin area is 1096 Sq. Km with a hilly area of 195 Sq. Km. The taluks covered in the sub basin are Srivilliputhur, Sivakasi, Sattur and Virudhunagar of Virudhunagar District and Peraiyur of Madurai District. It receives an annual averagerainfall of 895 mm, with its major share during North -East Monsoon. The main stream running in the reservoir catchment is KoushigaNadhi which is a tributary to Arjuna Nadhi. Kousiga Nadhi carries the flow mainly from the surplus waters of the irrigation tanks and those from its local catchment area. There are 63 tanks distributed within the catchment. This sub basin has a tropical climate. It has a hot summer and a mild winter.



IV. DATA COLLECTION

Rainfall data ,Tank details including Capacity, FTL, discharge, catchment area, type of tank ,Dem, Watershed boundary, Landuse map and Soil map collected from Institute for water studies, Tharamani. The area under irrigation and principal crop details collected from Department of Statistics and Economics, Teynampet. The groundwater level data is collected from Central Ground Water Board, Besant nagar. The satellite imaginery of the study area is downloaded from official website of United States Geological Survey

V. METHODOLOGY

The objectives of study is to carry out assessment of agricultural drought and put forth the measure for agricultural drought management. The agricultural drought assessment is carried out in spatial and temporal basis by computing three drought indexes MI, SPEI and ADSI using the rainfall data and climate data of a network of stations and remote sensed data of the study area , and drought severity map has been arrived based on corresponding indexes. Rainwater harvesting is proposed as a measure for agricultural drought management and the potential zones for rainwater harvesting is delineated.

Identification of drought prone areas according to Government of India norms

The Government of India constituted a Technical Committee under the Chairmanship of Prof. C.H.Hanumantha rao in April 1993. This committee studied technical parameters, requests from the states for inclusion and exclusion of areas and modification, if any, in DPAP and DDP and their implementation. The committee divided the entire nation into six climatic zones based on the concept of moisture index which is defined as follows:

Moisture Index (M.I) = [(P-PE)/PE]* 100

where P=Precipitation ,PE=Potential Evapotranspiration.

Classification of climatic zones

Sl. No.	Moisture Index	Climatic Zone
1.	-66.70	Arid
2.	-66.7 to –33.30	Semi-arid
3.	-33.3 to 0.00	Dry sub-humid
4.	0.0 to 20.00	Moist sub-humid
5.	+20.00 to +99.9	Humid
6.	100.0	Per-humid

(Technical committee on DPAP and DDP, 1994)

For inclusion of district / blocks under DPAP/DDP the Hanumantha Rao Committee has recommended the criteria of percentage area to the net sown area in three eco-system as given below

DPAP IDENTIFICATION CRITERIA

(Technical committee on DPAP AND DDP, (1994)

Moisture Index (M1)	**Programme Permissible**	**ECOSUSTEM**	**Irrigated Area(%) For inclusion of District**	**Block**
< -66.7	DDP	ARID	Upto 50	upto 30
-66.7 to –33.3	DPAP	Semi-Arid	Upto 40	upto 20
-33.3 to 0.0	DPAP	Dry-sub humid	Upto 30	upto15

Agricultural drought assessment using SPEI and ADSI

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) normalization 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.

Blaney criddle equation is used to model PET based on available data monthly average temperature and percentage of sunshine hours .

$ET_o = p \cdot (0.46 \cdot T_{mean} + 8)$

where ET_o is the reference evapotranspiration [mm day^{-1}] (monthly) ,T_{mean} is the mean daily temperature [°C] given as $T_{mean} = (T_{max} + T_{min})/ 2$ 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:

$D_i = P_i - PET_i$

which provides a simple measure of the water surplus or deficit for the analyzed month.The calculated D_i 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.

Agricultural Drought Severity Index (ADSI)

The vegetation condition reflects the overall effect of rainfall, soil moisture, weather and agricultural practices therefore can be used to assess the severity of agricultural drought It has been universally accepted that satellite derived NDVI can be used as an index to assess crop stage/condition (Tucker 1979, Ayyangar et al 1980, Singh et al 2003 and Lei Ji and Peters, 2003) . Here an attempt has been made to develop an Agricultural Drought Severity Index (ADSI) which involves crop land and fallow land that were delineated from remote sensing data using NDVI analysis. It is based on the crop condition associated with fallow land that forms the interrelationship with agricultural drought. Use of ADSI for drought analysis is different from the use of rainfall analysis as the vegetation cover find its presence in this index.

The total area under agricultural vegetation has been deciphered for the satellite images by eliminating the area under forest, barren lands and land put to non agricultural usage. In eliminating these areas different GIS layers have been used which were taken from the digitized landuse map of the study area. NDVI values have been generated for these satellite images which represent the area under agricultural vegetation using EARDAS IMAGINE 8.5 software package. The NDVI values for vegetation generally range from 0.1 to 0.6. The higher index values being associated with greater leaf area and biomass, and for bare soil and rocks the index values are near zero (Jeyaseelan 2002). All the NDVI values falling between 0.1 and 0.6 were grouped to obtain the spatial extent of vegetation or crop land area and the residual area was considered as fallow land. Fallow land is described as that which is taken up for cultivation but is temporarily allowed to rest, uncropped for one or more seasons, but less than a year. Block boundary map was overlaid on these images to obtain the block wise area of crop land and fallow land. The extent of area under crop land and fallow land associated with each block was used in formulating the ADSI which is given in equation.

$$\text{Agricultural Drought Severity Index (ADSI)}_i = \frac{(\text{Crop land})_i}{(\text{Crop land} + \text{Fallow land})_i}$$

where i denote the designated block and varies from 1 to 20 since the number of blocks are 20.

NDVI is calculated based on remote-sensing measurements of visible (red) and near-infrared (NIR) radiation. It is a measure of the greenness or vigor of vegetation. Among the vegetation indices, NDVI is operational, globally-based vegetation index with its ratio properties, which enable it to cancel out a large proportion of noise in remote sensing due to atmospheric conditions. Stressed vegetation or vegetation with small leaf area has positive but low values of NDVI. Therefore, NDVI is often used in research on vegetation dynamics and therefore it can be used for drought spatial monitoring

The Normalized Difference Vegetation Index (NDVI) is an indicator of the greenness of the biomass. It is not a physical property of the vegetation cover, its very simple formulation NDVI = (REF_nir – REF_red)/(REF_nir + REF_red) where REF_nir and REF_red are the spectral reflectances measured in the near infrared and red wavebands respectively, makes it widely used for ecosystems monitoring.

It is necessary to get the stretch value of NDVI Images between -1 to +1. For this a series steps was carried out. The atmospheric correction of TM images is done at first using ATCOR 3D utility.The 6th band from the resultant image was removed using layer stack utility. The resultant image was converted into reflectance using LANDSAT 7 reflectance utility.This resultant image was used to generate NDVI images. We get the stretch between -1 to +1. The LUT value and NDVI value will be the same in all NDVI images

Drought management plan

Drought management plan aims to provide a consistent restriction regime for all water supplies. The primary objective of this Drought Management Plan is to ensure continued water supply during drought conditions in order to meet water user, public health and firefighting needs.

This plan aims to ensure a robust, timely, efficient and affordable response to drought; facilitate the application of restrictions at a regional level and also at a local level for council-operated water supplies; provide a clear water restriction regime for all water users; and reduce the impact of water extraction on the available resource and other water users while minimising disruption to customers.

. The purpose of the Drought Management Strategy is to reduce water use or to increase water supply during a drought consistent with the goals and objectives of the Water Resources Management Strategy. The development of a method to employ rainwater harvesting (RWH) in the management of agricultural drought in arid and semi-arid regions

The strategy for management of Agricultural Drought using Rainwater Harvesting comprises of two phases: (i) detection of agricultural drought using indexes (ii) the delineation of RWH locations potentially suitable for the management of agricultural drought in the region using a GIS decision support system (DSS). Rainwater harvesting (RWH) provides an independent water supply during regional water restrictions and in developed countries is often used to supplement the main supply.

Rainwater harvesting provides water when there is a drought and reduces demand on wells, which may enable ground water levels to be maintained. As the main problem pressing the study area towards a significant agricultural drought is surface water scarcity, in the absence of alternative surface water sources, promoting RWH as a drought management solution could help alleviate the suffering associated with severe drought conditions, a problem compounded by a rising population.

Identification of suitable RWH locations for drought management

Rainwater harvesting (RWH) provides an independent water supply during regional water restrictions and in developed countries is often used to supplement the main supply. It provides water when there is a drought, can help mitigate flooding of low-lying areas, and reduces demand on wells, which may enable ground water levels to be maintained. Identification of potential sites for RWH is an important step towards maximizing water availability and land productivity in semi-arid areas (Mahmoud 2014b; Mahmoud et al. 2014a; Mahmoud and Alazba 2014).

The identification of suitable areas for RWH is a multi- objective and multi-criteria problem. In order to identify potential-suitable areas for RWH, three criteria were selected: (i) soil type, (ii) land cover and land use , (iii) surplus precipitation. The criteria used to determine the potential RWH sites for the study area using RS and GIS are measured on different scales; however, Spatial Multi-criteria evaluation (SMCE) requires that the values contained in the criterion map be converted to comparable units. Therefore, the criteria maps were re-classed into 5 comparable units of suitability classes: 5 (‘‘excellent’’), 4 (‘‘good’’), 3(‘‘moderate’’), 2 (‘‘unsuitable’’) and 1 (‘‘poor’’). The suitability classes were then used as a basis for criteria maps.

VI. ANALYSIS AND RESULTS OF AGRICULTURAL DROGHT ASSESSMENT AND MANAGEMENT

The proposed methodology as presented was applied to the study area for the Agricultural drought assessment and management. The results obtained are presented and discussed.

Identification of drought prone areas

The identification of drought prone areas in the study area is carried out according to identification criteria proposed by the Technical Committee under the Chairmanship of Prof. C.H.Hanumantha rao in April 1993.

Using this criteria the rainfall datasets and climatic data of stations Kavalur , Srivilliputhur, Satur, Virudhunagar , Watrap , Thirumangalam , Kovilpatti and Periyakulam were analysed and characterized into climatic zones which was later prepared as a map using arc gis as shown in Figure 1

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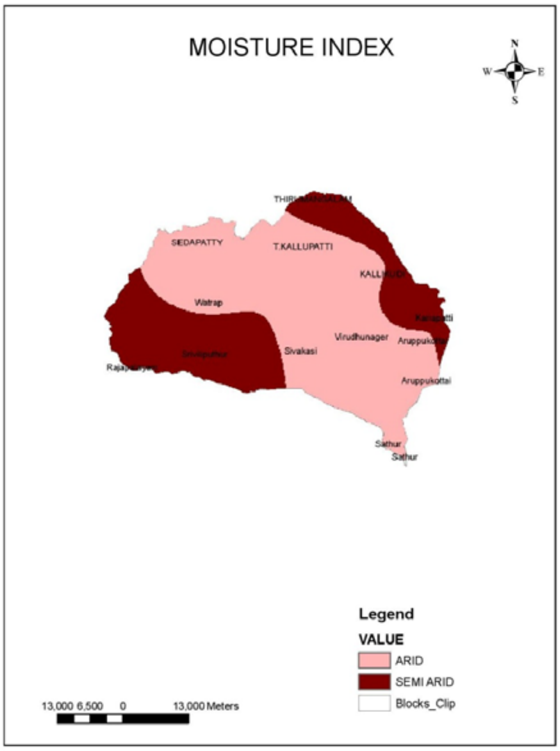


Figure 1 Agricultural drought severity map based on Moisture Index

The moisture index of influencing stations is interpolated to prepare the moisture index map in which the entire study area is categorized into six climatic zones.

Using the details of area under irrigation in district basis collected from Department of Economics and Statistics, Government of Tamilnadu, in the districts covered in the study in Madurai and Virudhunagar the percent irrigated never exceeded 40, therefore the climatic zone semi arid is taken as drought prone area

Agricultural drought assessment using SPEI

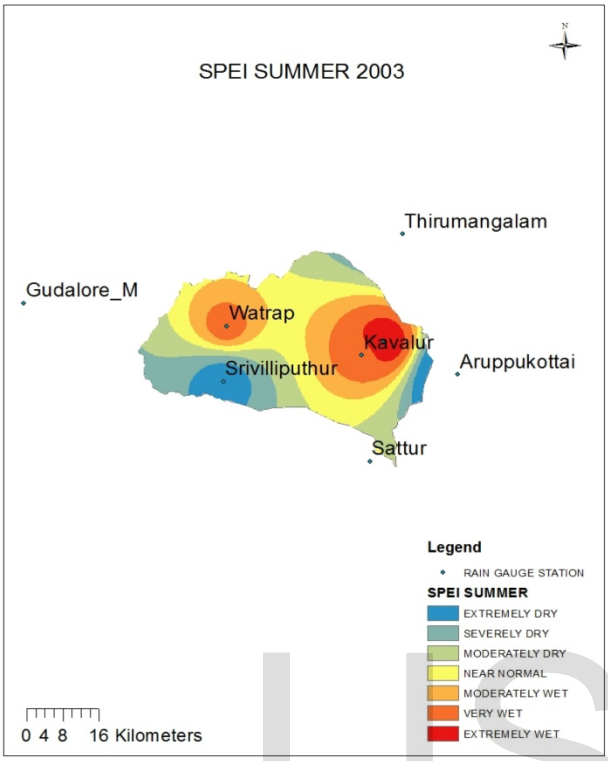
An examination of drought characteristics and drought severity using the Standardized Precipitation Evapotranspiration Index (SPEI) for which the monthly series of precipitation, and minimum and maximum air temperatures from 1984 to 2015 network of stations in the study area was used

SPEI is based on the climatic water balance (D) compares the available water with the atmospheric evaporative demand, and therefore provides a more reliable measure of drought severity than only considering precipitation.Rainfall datasets is collected and digitally encoded into a Geographic Information System database. SPEI values are derived from rainfall data and evaporatranspiration calculated from climatic data of Kavalur , Srivilliputhur, Satur, Virudhunagar , Watrap , Thirumangalam , Aruppukottai and Gudalore from 1984 to 2015 for quantitative measurement of drought events over the 30-year period.

SPEI values and corresponding severity classes is found out for eight stations for two seasons summer and kharif. From the results, he prevalent drought severity classes during summer for each of the stations can be inferred as for Kavalur moderately wet and near normal, for Srivilliputhur moderately wet, moderately dry and near normal, for Satur moderately dry and near normal, for Virudhunagar moderately dry and near normal, for Watrap near normal, for Thirumangalam moderately dry and near normal, for Aruppukottai moderately dry and near normal and for Gudalore near normal.

The prevalent drought severity classes during kharif for each of the stations can be inferred as for Kavalur moderately wet and near normal, for Srivilliputhur moderately dry and near normal, for Satur moderately wet and near normal, for Virudhunagar moderately wet,moderately dry and near normal,for Watrap moderately dry and near normal, for Thirumangalam near normal, for Aruppukottai moderately dry and near normal and for Gudalore moderately wet and near normal.

SPEI values of the network of stations during summer and kharif for the years 2003 and 2014 are interpolated and and plotted as Agricultural severity maps as in figures 2 and 3



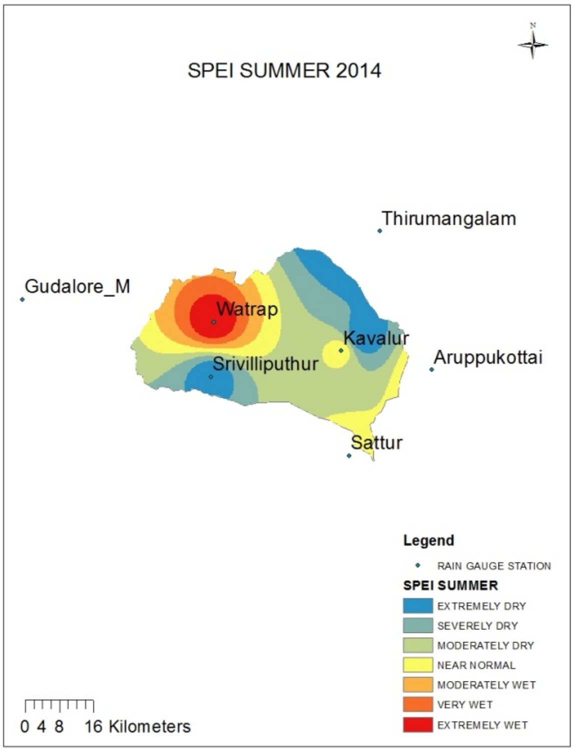


Figure 2 Agricultural severity map based on SPEI during summer 2003 and 2014

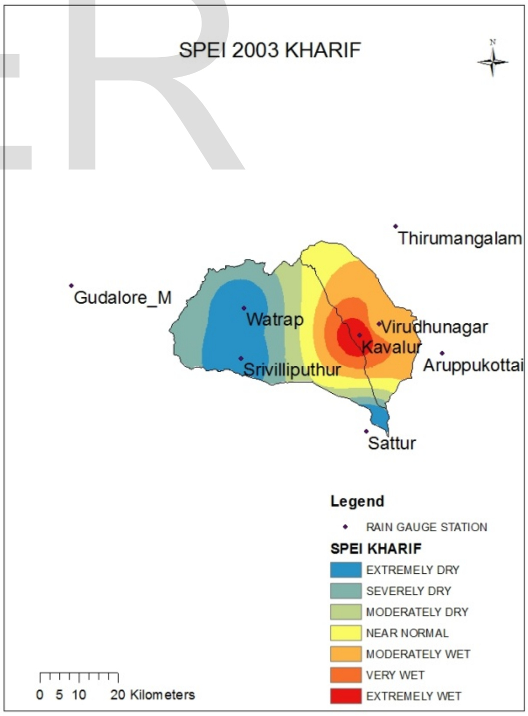


Figure 3 Agricultural severity map based on kharif during summer 2003 and 2014

Agricultural drought assessment using ADSI

Remotely sensed dataset during February 2015 of study area were used for agricultural drought assessment. Agricultural Drought Severity Index (ADSI) developed in this study, involving area under crop land and fallow land, delineated from remote sensing data based on the NDVI response during the crop season.

The total crop area mask under agricultural vegetation has been prepared for the NDVI images by eliminating the area under forest, barren lands and land put to non agricultural usage. In eliminating these areas, different GIS layers have been used from the digitized landuse map of the study area. All the NDVI values falling between 0.10 and 0.60 were grouped to obtain the spatial extent of crop land area and remaining NDVI values that are below 0.1 and near zero were grouped to obtain the spatial extent of fallow land area.

The block wise agricultural drought severity assessment in the study area is done. Out of 11 blocks, 1 was under no drought, 4 under mild drought, 3 under moderate drought condition and 3 under severe drought condition

The spatial extent of area under crop land and area under fallow land during February 2015 is mapped in GIS. From that the crop land area and fallow land area is computed consecutively ADSI and corresponding severity is computed for each of the blocks. , then the severity map based on ADSI is displayed in GIS.

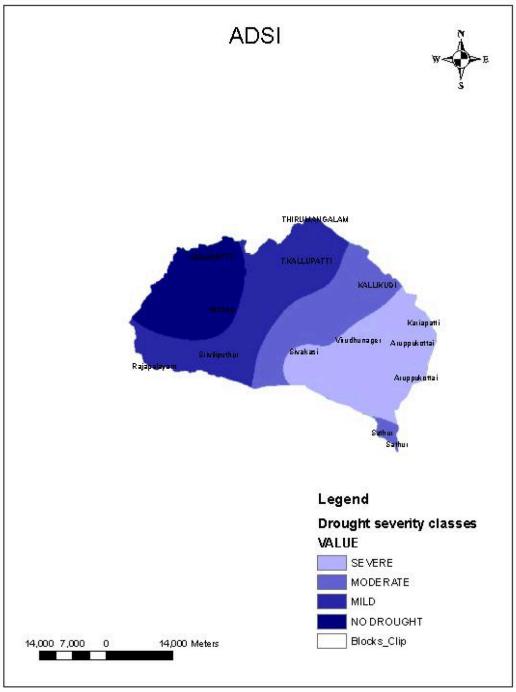


Figure 4 Agricultural drought severity map based on ADSI

Drought management plan -Identification of suitable RWH locations for drought management

The identification of suitable areas for RWH is a multi-objective and multi-criteria problem. In order to identify potential-suitable areas for RWH three criteria were selected soil type, land cover and land use and surplus precipitation. Spatial Multi-criteria evaluation (SMCE) requires that the values contained in the criterion map be converted to comparable units. Therefore, the criteria maps were re-classed into 5 comparable units of suitability classes: 5 (‘‘excellent’’), 4 (‘‘good’’), 3(‘‘moderate’’), 2 (‘‘unsuitable’’) and 1 (‘‘poor’’). The suitability classes were then used as a basis for criteria maps.

Table 4 Suitability classes for different factors

The weighted overlay is performed between the three criteria map i.e Landuse map, Soil texture and Rainfall Surplus and the Rainwater harvesting potential zone map consisting of five suitability levels excellent, good , moderate, unsuitable and poor is generated and displayed spatially in GIS

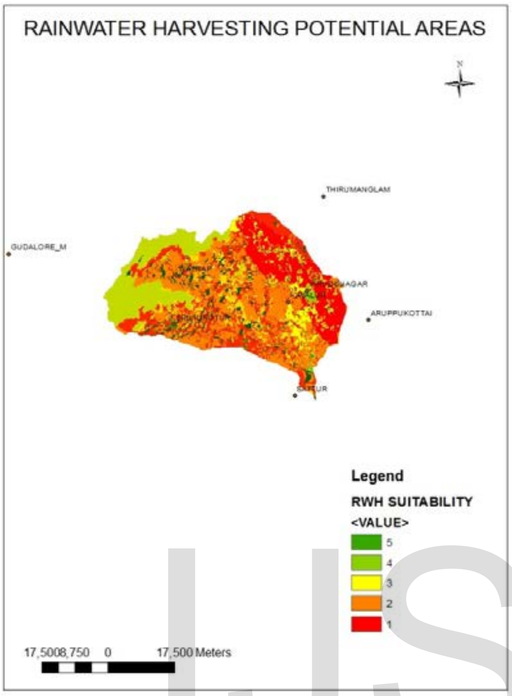


Figure 5 Rainwater Potential Areas map

VII. CONCLUSION

- Identification of drought prone areas for inclusion into DPAP have been carried out in the study area using the criteria given by Technical committee of DPAP and it is concluded that the area under climatic zone Semi arid is to be included under DPAP.
- SPEI values were calculated during two seasons summer and kharif from 1984 to 2015 and the corresponding drought severity class is arrived. This faciliates the study of variation of drought severity in the study are in spatial and temporal basis.
- From the NDVI image of the study are obtained from satelite imagery, the spatial extent of crop land and fallow land in each of the blocks is arrived from which ADSI is calculated and severity map is arrived correspondingly
- Rainwater harvesting is proposed as measure for Agricultural drought management as it can supplement the existing water supplies. The ares suitable for rainwater harvesting is delineated by performing weigjhted overlay among three GIS layers namely Landuse, Soil Texture and Rainfall surplus.

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