Chapter: II

2. Literature Review

The satellite remote sensing frameworks can be used to screen the current situation prior or after any disaster event. Technology can be used to give standard information against which future change can be pondered, while the GIS technology gives an appropriate tools for analyzing the dataset. The observation and evaluation of the dry season require consistent information and real-time data and additionally assembling information with respect to the dry spell progressively. It is impractical to viably gather consistent information about drought utilizing regular techniques. Generally checking and appraisal of dry season require a lot of in situ information in regards to climate and atmosphere conditions alongside agricultural measurements, which frequently neglect to speak to the spatial pattern of drought conditions at various climatic conditions. The remote sensing and GIS advances offer astounding potential outcomes of gathering this crucial information for propel investigation. Recent development of Spatial Sciences, in support with information technology with open source development in the field of disaster management plays key role to benefit society and livelihoods. Open source stage was utilized for the advancement reason. Truly strategies have been created for checking dry season utilizing remote detecting information and spatial innovations. Some of these procedures and techniques have been considered and are introduced here. Different Decision Support Systems for drought have been produced across the globe. In any case, their destinations and advancement stages are much fluctuated. A short audit of these frameworks is introduced here. Open source stage is quick turning into a most loved among engineers because of its different points of interest over restrictive programming and numerous data frameworks have been produced utilizing the same. The objective is to make the framework accessible, through Internet, to all researchers, planners, decision makers, professionals and students. It could be utilized as a drought monitoring and management tool.

2.1. Role of Remote Sensing and GIS in Drought Studies:

The study first investigated the historical pattern of droughts using remote sensing that started in early 1980s with the sensors mainly in the domain of optical wavelength range (Campbell and Wynne, 2011). For drought monitoring, assessment and prediction, remote sensing and GIS technologies are capable to cover the Earth surface, better than traditional techniques. A number of new methodologies have been created to generate information from near real time and historical data for drought analysis and management. A new dimension to derive geospatial information for drought assessment with consistent temporal and spatial resolution has been made available for monitoring and mapping of various land resources. Popular and commonly used drought indicators and indices are discussed.

2.1.1 Multispectral Drought Indices

Among various entrenched mainstream satellite-based indicator of drought, the NDVI has been utilized widely as a fundamental index for monitoring and mapping of drought condition (Tucker, 1979; Kogan 1991, 1995; Ji and Peters 2003; Wan et al., 2004), NDVI index uses red and near-infrared (NIR) bands. The NDVI index is accounted for as a decent pointer of green biomass, while the NDVI-inferred Vegetation Condition Index can be utilized for both local/global scale (Kogan 1995, 1997). Unlike the NDVI, it has the capability to separate short-term weather-related fluctuations from long-term ecological changes (Kogan 1990, 1995). NDVI saturates in high biomass vegetated areas (Huete et al., 2002). NDVI, Standardized Precipitation Index (SPI), Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) are commonly used for drought detection and assessment of weather impacts on vegetation (Unganai and Kogan 1998, Kogan et al. 2003). VCI suggested by Kogan (1990) effectively shows, distance and closeness of NDVI for the given period from past years (Singh et al. 2003; Rahimzadeh et al. 2008; Bhuiyan and Kogan 2010). Some single condition drought indices including Precipitation condition index (PCI), Soil moisture Condition index (SMCI) are also important indices for Drought condition analysis (Prakash S., 2018), The TCI (Kogan, 1995) can detect drought before the degradation of biomass. However, TCI indicates the long-term maximum and minimum temperature identified over the period of records. TCI determines the temperature-related vegetation stress; it is formulated as the reverse ratio of VCI (Karnieli et al., 2010). Although the VCI increases with NDVI, the TCI decreases with LST based on the hypothesis that higher LST indicate soil moisture deficiency and therefore, stress in vegetation canopy (Kogan, 1995; Kogan, 2000). Moreover, other factors such as rainfall and temperature are taken into consideration while formulating enhanced drought index (EDI). Other than satellite-based indicators of drought, a meteorological drought index has also broad attention in recent years. In spite of the fact that there are numerous meteorological components identified with drought, with the help of precipitation only several drought indices can be generated for drought monitoring and analysis for example, the percent of typical (PN), Standardized Precipitation Index (SPI) (McKee et al. 1993) are precipitation based drought index and they are adoptable for drought at variable time scales; they can be used for monitoring agricultural and hydrological variables for drought, where, SPI can monitor dry as well as wet situation. The indices dependent on precipitation information are not just easy to generate, however were found to perform better contrasted with more difficult hydrological indices (Oladipio, 1985). The SPI is comparable over the wide range of climatic zones because of the SPI is independent in magnitude of mean rainfall. The SPI has the benefits of being simple in computation (Agnew 2000). Pai et al. (2011) stated that SPI is more suitable index as compared to PN for identifying the meteorological drought monitoring. A further study done by Patel et al. (2007) demonstrated that the SPI at a 3-month timescale is viable in catching seasonal drought variation in Gujarat. The VCI is useful for monitoring the spatial and temporal analysis of drought and it also has the advantages of quantifying the weather impact on vegetation (Kogan 1995; Hayes and Decker 1998; Thenkabail et al. 2004; Jain et al. 2010; Li et al. 2013). Palmer Drought Severity Index (PDSI) has been created by Palmer (1965), utilizes precipitation and temperature information to upgrade SPI drought index. PDSI is more compressive than precipitation indices alone. Evapotranspiration and soil moisture are also considered in PDSI, whereas, it uses sophisticated computation and less applicability in extreme climatic regions (Zargar et al. 2011).

The other remote sensing based indicator is Enhanced Vegetation Index (EVI) (Kogan, 1997, 2000) an enhancement of the NDVI to better account for soil background and atmospheric aerosol effects, however, the index cannot be fully expressed as a ratio index because of the soil adjustment factor. The Vegetation Temperature Condition Index (VTCI) (Wang et al., 2001) is site and time specific index thus; it cannot be used at country level for drought monitoring. Standardized Vegetation Index (SVI) (Peters et al., 2002) is a useful near real-time indicator of onset, extent, intensity and duration of the vegetation stress; although it is a good indicator of vegetation response, it is useful for a short-term weather conditions.

The major focus of this study was to determine the frequency, spatiotemporal extent and intensity of drought in study area using long term satellite-based, meteorological and temperature information.

Satellite remote sensing and derived products plays an important role in drought monitoring and analysis(Tucker and Choudhury, 1987; Liu and Kogan, 1996). Several remote-sensing drought indices have been applied to drought monitoring in recent decades (Bhuiyan, Singh, and Kogan 2006; Gebrehiwot, et. al., 2011; Rojas, Vrieling, and Rembold 2011) Drought index generally defines the intensity, duration, magnitude, severity and spatial extent of drought. Quantification of drought at various space-time scales is essential and a necessity in the coming decades (Tatli and Turkes, 2011). Remote sensing is a powerful technique in terms of the methodologies adopted for the drought monitoring. Several satellites are available for weather forecasting, land surface observations, monitoring and assessment (Lillesand et al., 2014). The improved data quality allows the development of new satellite based indices to improve the accuracy of assessment of the vegetation conditions under future climatic conditions (Delbart et al., 2005). With the advancement of remote sensing technology, historical indices are being over-powered by the newly developed indices from remote sensing data that are considered real time data. Drought indices discussed in the introduction are very less; however, many more drought indices have so far been proposed and identified (Niemeyer et al., 2008). The data available from various Earth observation satellites such as MODIS, IRS-P4, P6, NOAA/AVHRR, SPOT, METEOSAT, GOES, INSAT, IRS/AWiFS, TRMM, RESOURCESAT, Jason-1, Sentinel series, FY series, METOP, MTSAT, ADEOS and LANDSAT satellite are being used for monitoring and assessment of drought around the globe.

Most of the drought indices use optical and thermal radiances from the Earth surface in electromagnetic (EM) wavelength spectrum. A glimpse of traditionally used and recently developed remote sensing based indices for drought assessment and monitoring are given in the Table 2.1.

Table 2.1 Drought Indices based on multispectral remote sensing data

SN.	Indices	Strength	Weakness
1.	Normalized Difference Vegetation Index (NDVI) (Tucker, 1979)	Good indicator of greenness of vegetation, leaf area index and patterns Of production.	Effective in homogeneous terrain; In heterogeneous terrain interpretation becomes more difficult.

2	Enhanced Vegetation Index (EVI) (Kogan, 1997, 2000)	Improved monitoring with less atmospheric Influence.	The index cannot be expressed as the ratio vegetation index functions because of the soil adjustment factor 'L'.
3	Standardized Vegetation Index (SVI) (Peters et al., 2002)	Useful tool capable of providing a near real-time indicator of onset, extent, intensity and duration of vegetation stress.	Effective indicator of vegetation response for short-term weather conditions.
4	Crop Water Deficit Index (CWDI) (Moran et al., 1994 et al., 1994)	It is indicator of crop water stress, applied for irrigation scheduling.	Efficient when the vegetation cover is low. The influence of other factors, in crop consumption not addressed.
5	Normalized Difference Water Index (NDWI) (Gao, 1996)	Complementary to NDVI; determines stress in vegetation water content.	The soil background effect leads to misinterpretation in case of partial vegetation cover.
6	Vegetation condition Index (VCI) (Kogan, 1990)	Normalizes the NDVI, hence result is a consistent index for diverse land cover types, water stress conditions identified better than NDVI in non-homogeneous areas.	The index appeared to be less sensitive to short-term precipitation deficiencies.
7	Soil Adjusted Vegetation Index (SAVI) (Huete, 1988)	It minimizes soil influences on canopy spectra by incorporating a soil adjustment factor, L, to NDVI.	The constant, L, factor used results in the loss of vegetation dynamic Responses.
8	Modified Soil Adjusted Vegetation Index (MSAVI) (Qi et al.,	It further minimizes the soil background influences, than SAVI resulting in greater vegetation sensitivity as	The index does not take in to consideration the atmospheric and bi-directional effects.

	1994)	denoted by a vegetation signal" to "soil noise" ratio.	
9	Perpendicular Drought Index (PDI) (Ghulam et al., 2007)	The index is effective in bare soil application and early growth stage of vegetation growth.	The index performs poor in densely vegetated area and non- at topography with varying soil type.
10	Modified Perpendicular Drought Index (MPDI) (Ghulam et al., 2007)	It has finer spatial details and a greater accuracy than PDI index. It shows potential utility for use in different topographic conditions with different eco-systems	The plant/soil multiple scattering effect is not taken into consideration in MPDI
11	Normalized Multi-Band Drought Index (NMDI) (Wang and Qu, 2007)	The index is well suited to estimated soil and vegetation Water content.	The index may yield inaccurate results for bare soil or weakly Vegetated areas.

2.1.2 Thermal Drought Indices:

As discussed in section 2.1 optical and thermal bands were mostly used for drought monitoring. The remotely sensed land surface temperature (LST) derived from the spectral information of the thermal band provides stress information before drying out of the biomass. The Thermal Infra-Red (TIR) data is found to be sensitive to the surface moisture condition (Anderson et al. 2011, Gutman, 1990), thus, providing an insight of vegetation water stress and soil moisture deficiency. The various indices have been developed using thermal band namely VHI, TCI, TVCI etc. are the common and operationally used for drought indicators mentioned in table 2.2.

Table 2.2 Drought Indices based on thermal remote sensing data.

SN.	Indices	Strength	Weakness

1.	Vegetation Health index (VHI) (Kogan, 1997, 2000)	The index helps to detect the drought 4-5 weeks earlier in any corner of the globe with impact of reduction in grain diagnosed before the harvest.	The index is mainly used during growing season of the crop.
2.	Vegetation condition Index (VCI) (Kogan, 1990)	Normalizes the NDVI hence result is a consistent index for different land cover types, water stress conditions, identified better than NDVI in non-homogeneous areas.	The index appeared to be less sensitive to short-term precipitation deficiencies.
3.	Temperature condition index (TCI) (Kogan, 1995)	The index can detect drought before the degradation of the biomass.	The Index cannot normalize variation in daily and seasonal meteorological conditions.
4.	Vegetation Temperature Condition Index (VTCI) (Wan et al., 2004)	Used to analyze drought event at a local level for a particular time of year and detect the spatial variation of drought.	The Index is site specific and time-specific.
5.	Temperature Vegetation Dryness Index (TVDI) (Sandholt et al., 2002)	The index is suitable to monitor situation of wet, normal and light dry conditions.	The index cannot portray the situation of water storage, for drought assessment.
6.	Vegetation Condition Albedo Drought Index, (VCADI) (Ghulam et al., 2008)	It has a potential of monitoring vegetation water stress, soil moisture deficiency and crop specific drought events.	The calculation of index requires a large number of remote sensing data and area with varying soil moisture conditions.

2.1.3 Microwave Drought Indices

Microwaves have the capability to penetrate clouds and provide continuous information of climatic and land parameters, so they can operate in all weather conditions and regions. As it is well known that, microwave measurements have the benefit of being largely unaffected by cloud cover; Microwave remote sensing has the capabilities to be used in agricultural drought assessment. Various passive microwave products are available globally for the analysis. The advantage of passive microwave remote sensing derived products is the global coverage and high temporal resolution. However, the global coverage and high temporal resolutions comes at the cost of low spatial resolution of the order 25 to 100 km. In recent years 10 km microwave global products are also used for soil moisture analysis. Wavelength ranges from a few millimetres to several meters are highly sensitive to the moisture content and the depth of penetration is function of moisture content in the soil. Remote sensing measurements from space give us the chance of acquiring successive, worldwide soil moisture over an enormous portion of the Earth's land surface. The information is derived from active microwave, passive microwave of the combination of both data (Wilson et al., 2001; Entekhabi et al., 2010). This microwave based soil moisture indicators are used for monitoring the soil moisture stress. However, at present, the temporal frequency of the microwave data is lower than the optical-based products.

Soil moisture monitoring is commonly a prevalent leader mean for farming drought assessment than precipitation (www.fao.org).

Precipitation is mainly important parameter for the rain fed areas where agricultural practices have strong relationship between rainfall amount and soil moisture. The precipitation is not having much impact on agriculture where an alternative source of irrigation (canal, ground water, storage tank, rainfall harvested and rain-fed water) is available. Hence, the condition of soil moisture at different areas following different water supply dependency explains the agricultural drought occurrence. Direct or indirect impact of soil moisture affects temperature, evaporation, compaction and biological activities of soil.

The soil

Soil moisture straightforwardly or by implication influences physical, and organic properties of soil. Thus soil moisture is an important parameter to identify the drought conditions. Few recently developed soil moisture indicators from satellite microwave data are Empirical Standardized Soil Moisture Index (ESSMI) (Carrao et al., 2016), AMSR-E Soil Moisture Index (AMSRE SMI) (Chakraborty et al., 2012) and microwave vegetation water index (MVWI) (Wang et al., 2008), standardized soil moisture index (SSI) and multivariate standardized drought index (MSDI) were used to assess the meteorological and agriculturaldroughts (Hao, Z. and AghaKouchak, 2014; Farahmand, A. and AghaKouchak, 2015) etc.

2.2 Global Scenario:

In the recent scenario many of the countries, regional organizations, continental groups, national agencies and state governments developing drought assessments techniques and methods to analyses natural drought disaster and to prevent calamities from pre-and post drought disaster events.

The U.S. Drought Monitor, established in 1999, is a weekly map of drought conditions that is produced jointly by the National Oceanic and Atmospheric Administration, the U.S. Department of Agriculture, and the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln. The U.S. Drought Monitor website is hosted and maintained by the NDMC (http://droughtmonitor.unl.edu). NDMC uses the key indicators for the composition of these maps are PDSI, SPI, present normal precipitation, USGS daily stream flow percentile and Climate Prediction Center (CPC) soil moisture.

The South Asia Drought Monitoring System (SADMS), established in 2014, is a weekly map of drought conditions that is produced and maintained at the International Water Management Institute (IWMI). The key parameters used for the drought assessment by SADMS are Integrated Drought Severity Index (IDSI), SPI, and Soil Moisture Index. In tandem, these indices not only paint an accurate picture of any drought episode, but provide invaluable decision-making tools (http://dms.iwmi.org/).

Through the SADMS website, the International Water Management Institute (IWMI) provides a wide array of precipitation and related information garnered primarily from the freely available satellite imagery to improve current capabilities in drought monitoring and prediction and provide regional to district scale information about drought's effect on agriculture.

The drought severity maps that are produced deliver continuous geographic coverage over large area for the first time, and have inherently finer spatial detail (500m resolution) than other commonly available global drought products such as NESDIS NOAA, MODIS Global Terrestrial Drought Severity Index using different data and approaches.

Famine Early Warning System Network (FEWSNET) issues a monthly food security report for decision makers in Africa and USA (http ://ltpwww.gsfc.nasa.gov) by integrating climate data, soil data, satellite derived products (rainfall, NDVI), ground information, civil interest, health, market prices and field observations on agriculture. The generally used drought Indices are SPI, PDSI, Drought Severity Index, Reconnaissance Drought Index, Crop-specific Drought Index, Keetch-Byram Drought Index and Crop Moisture index (CMI).

In Africa, the Horn of Africa is inclined to outrageous climatic conditions, for example, drought and floods, with extreme negative effects on the socio-economic conditions. Climate Prediction and Applications Centre (ICPAC) is a specialized institution, which is responsible for climate monitoring, prediction, early warning, and applications for the reduction of climate-related risks in the countries in greater horn of Africa (Omondi, 2011). It uses the SPI approach to monitor effects of agricultural droughts in the sub-region. The NDVI derived from the geostationary satellite Meteosat Second Generation (MSG) covering the African continent, with a temporal resolution of 15 min offers complimentary information for NDVI monitoring which is used for early warning system (Fensholt et al., 2006) over the region.

2.3 Indian and Regional Scenario:

In Indian scenario, drought assessment and monitoring is done using various indices which includes agricultural, meteorological and hydrological parameters. Indian Meteorological Department (IMD) is the designated agency for providing drought early warning and forecasting. Agricultural Meteorology Division, Pune provides advisories and bulletins on the real and expected weather conditions and its impacts on the different everyday agricultural practices. Drought Research Unit, Pune provides Crop Yield Forecasts. The National Centre for Medium Range Weather Forecasting, a constituent unit of the Ministry of Earth Science (MoES) provides, in consultation with IMD, ICAR and State Agricultural Universities, agro-meteorological advisory service at the scale of agro-climatic zones to the farmers and decision makers, based on specific conditions and locations specific medium range weather forecasts. The Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad and the All India Coordinated Research Projects on Agri-Meteorology and Dryland Agriculture (AICRPAM and AICRPDA) each of them having 25 centres across the country, take part in drought studies pertaining to assessment, mitigation, risk transfer and development of decision support software for drought prone States. Central Arid Zone Research Institute, Jodhpur for assessing agricultural drought situation in 12 arid Districts of western Rajasthan and disseminates bi-weekly crop-weather agro-advisory bulletins to the farmers. Ministry of Earth Sciences in collaboration with ICAR has set up 89 centres for short and medium range monitoring and forecasting of weather. National Agricultural Drought Assessment and Monitoring System Developed by the Department of Space for the Department of Agriculture and Cooperation monitors vegetation cover through satellite data based helping in drought assessment by comparative evaluation of vegetation cover with those of previous years. It prepares State-wise monthly reports. There are institutional mechanisms for drought monitoring and early warning at national and state levels. However, these are considered to be inadequate for meeting the demands of drought management and their capacity needs to be strengthened for the purpose of data collection, analysis and synthesis of information. Crop Weather Watch Group (CWWG), an inter-ministerial mechanism of Central Govt. meets once a week during rainy season (June-September).

2.4 Drought Assessment using geospatial techniques:

Generally dry season evaluation and checking requires the quantitative data of soil moisture, precipitation, crop condition and their intuitive impacts in both spatial and temporal scale, which are restricted in the district, frequently erroneous and, in particular, hard to acquire in close constant. In recent years, the space technologies of Geographical Information Systems (GIS) and Remote Sensing (RS) have assumed a critical part in examining various kinds of hazards. The RS and GIS innovation has the capacity of gathering information in computerized structure at worldwide and territorial scales quickly, repetitively and can be used to monitor the situation before, during or after an event (Tucker *et al.* 1985, Alonso *et al.* 1997, Nagarajan 2004, Tadesse *et al.* 2004).

GIS software package has the ability to combine, integrate data, and perform statistical analysis or spatial queries and create analytical models. RS and GIS technology allows customizing the display of maps and analyses. The technology can handle large data and develop automated processing and analysis tools for operational purpose. The ultimate goal of the technology is development of a spatial decision support system for issuing early warnings, drought assessment, taking precautionary measures for food security and give decision-makers time to prepare and take preventive action.

Monitoring of agriculture condition and drought assessment is very important issue, because of the increasing drought events worldwide. Many advanced system has been developed using RS and GIS technology for drought monitoring at local level as well as global scale. The dynamic nature of drought requires high quality data and advanced tools to monitor and capture the complexities of drought at both spatially and temporally.

2.5 Open Source Technologies for SDSS development:

In recent years there has been a growing interest in the application of GIS for the development of spatial decision support systems (SDSS). GIS is very powerful tool for analysing spatial data to establish process for decision making activity. To support the decision makers or planners and managers, a system that can generate different scenarios is required. The DSSs were traditionally developed for single users, which involved data management, model management and the user interface component to reside on the same machine. This requires platform specific development, a costly, and a non-extensible alternative. Now rapid growth of the internet technology over the past decade has opened up new methods to supply and share data, models, tools and other information to potential users (Wallace et al., 2001). According to Black and Stockton (2009), a generic DSS architecture must include a knowledge base, analysis tools, and inference engine. The application of DSS in the field of agriculture provides a new and efficient method for improving the management of regional food production mode and decision-making for the management of food security (Cao et al. 2007). Through the advancement of technologies, the SDSS are developed for different applications such as crop growth monitoring and food security strategies (Wang and Chen, 2010).

Spatial decision problems in agriculture and other areas often require that a large number of alternatives are evaluated based on multiple criteria. Geographic Information Systems (GIS) are a powerful tool for analysing spatial data and establishing a process for decision support.

2.5.1 Evolution and Trends of SDSS:

SDSS are "explicitly designed to provide the user with a decision-making environment that enables the analysis of geographical information to be carried out in a flexible manner" (Densham 1991, p. 405). In the past three decades, SDSS have experienced tremendous growth and evolved from stand-alone desktop applications to web-based and service-based SDSS (Sugumaran and DeGroote, 2011). Research on SDSS has mainly originated from two different discipline DSS and GIS (Keenan 2006; Peterson 1998; Sugumaran and Sugumaran 2007). Into the early 1980s, GIS and spatial processing software use was generally limited to those with high levels of computing and spatial sciences expertise, and letter on an intelligent system were evolved in early nineties. Rapid growth in technological development in the field of GIS and remote sensing evolved desktop and Web based Spatial Decision Support System. Now the recent trends in SDSS are distributed and service based support system.

The continuous cost decline of computing power in concert with the rapid expansion of computer power has been the dominant technological drivers for the successful implementation of GIS, DSS, and SDSS (Peterson 1998).

The growth of spatial decision support technology has also been driven by the availability and accessibility of spatially related data. Over the last few decades, there has been a surge in data availability. In the 1980s and 1990s, there was a huge effort to convert hard-copy maps to digital data through scanning and digitizing. Also over the last decades, the amount of spatial data derived from satellite and airborne remote sensing as well as Global Positioning Systems (GPS) has grown greatly.

Improved computer processing power and affordability led to the expansion of spatial applications into a variety of disciplines. Into the early 1980s, GIS and spatial processing software use was generally limited to those with high levels of computing and spatial sciences expertise. Primarily, this use was in academics and some government agencies. With the widespread development of desktop or personal computer-based systems with more user-friendly and standardized interfaces, the variety and number of GIS and SDSS consumers increased greatly.

Spatial decision support systems can be utilized by individuals, groups, or entire enterprises. The evolution of hardware, software, and networking technology has led to a movement from individual expert-driven SDSS use to the inclusion of a much broader set of stakeholders.

Earlier hardware and software configurations of SDSS generally were characterized by fairly complicated command-line-driven GIS and modelling software. These systems required someone with significant experience in the spatial sciences and also often in computer programming because the person who developed and programmed the SDSS was likely the person who would operate it. In the 1990s, the introduction of graphical user interface-based computing and the development of GIS and modelling software with more intuitive graphical user interfaces greatly increased the number of organizations using these types of software. In addition, the number of individuals able to use and understand at least the basic functionality of GIS rose greatly during this time period as more training and formal educational opportunities became available. The number of students enrolling in courses associated with GIS and related topics at universities and colleges saw an upsurge in this time period. In addition, GIS software in the 1990s began to come packaged with programming languages that allowed the development of customized user interfaces and analysis routines. Using these systems, an expert GIS user and programmer could develop customized applications that could be used by people with much less expertise. These functionalities also allowed the development of routines that could interact with other software applications such as modelling programs. This allowed for the building of SDSS applications with GIS software at their core.

SDSS techniques have evolved over time for application in a wide range of disciplines. The complexity of spatial decisions and the uncertainty inherent in information used for spatial decision-making processes have led to the inclusion of a wide variety of techniques in SDSS. Some of the earliest spatial approaches to land suitability analysis used hand-drawn overlays, which evolved into digital GIS overlay operations (Keenan 2006) in the 1960s. Automated spatial overlay and other spatial analytical operations developed in GIS software were powerful but still fell short in the ability to capture or represent many physical or biological processes in the environment and also human preferences and criteria relevant to spatial decisions. These shortcomings led to various SDSS developments that usually incorporated functionality from GIS software coupled with other techniques that frequently had evolved separately from GIS.

The complexity of issues in which SDSS are utilized often calls for domain or expert knowledge to be built into the SDSS to assist users. These systems attempt to capture expert knowledge, which can then be used in automated fashion within the system. By building domain or expert knowledge into an SDSS, more effective decisions by users regarding data selection, model selection, and scenario evaluation can be made. There have been many efforts to build expert systems or domain knowledge into SDSS. According to Sugumaran and DeGroote (2011), key components of SDSS are described in figure 2.1. Dataset, spatial models, domain expertise are the primary drivers used in SDSS framework. Secondary elements are required for the development of User Interface (UI), Information and communication technology and finally end users and various applications are the components of SDSS.

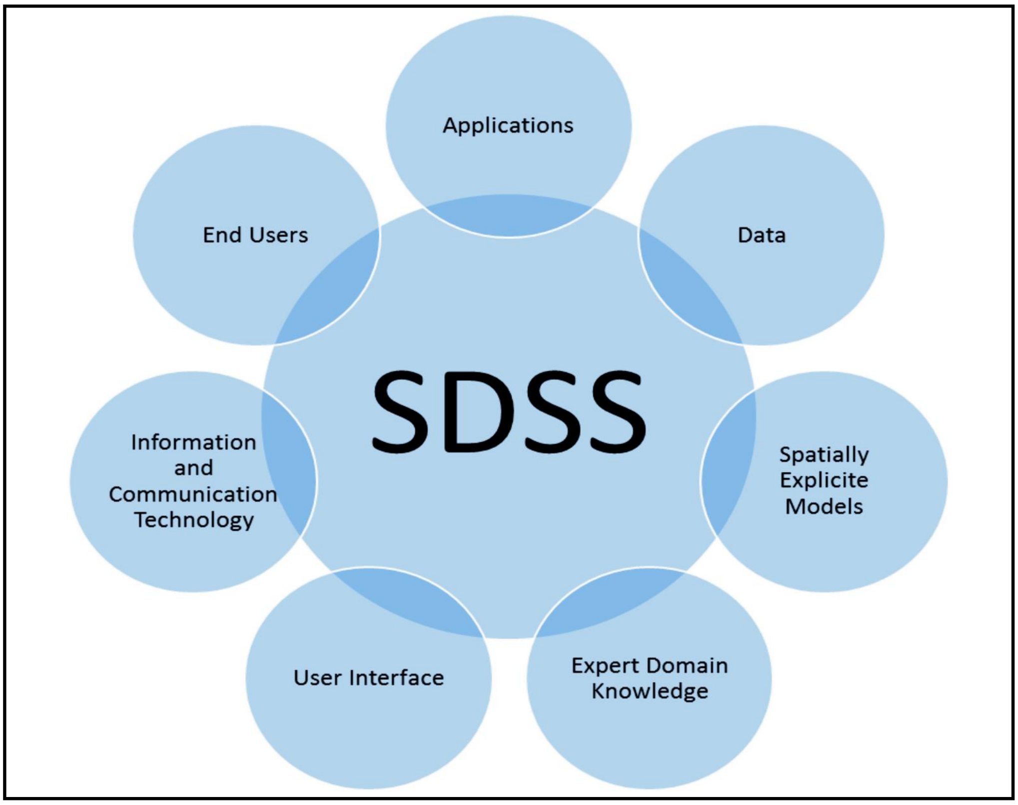

Figure 2.1 Core drivers of Spatial Decision Support System (Sugumaran and DeGroote, 2011)

The spatial decision-making process involves (1) identifying the issue, (2) collecting the necessary data, (3) defining the problem, including objectives, assumptions, and constraints, (4) finding appropriate solution procedures, and (5) solving the problem by finding an optimal solution (Keller, 1997). At the most basic level, there are three major components: database, model, and user interface. However, the number and exact description of components mentioned in the SDSS literature varies. Figure 2.2 represents the evolution components of SDSS.

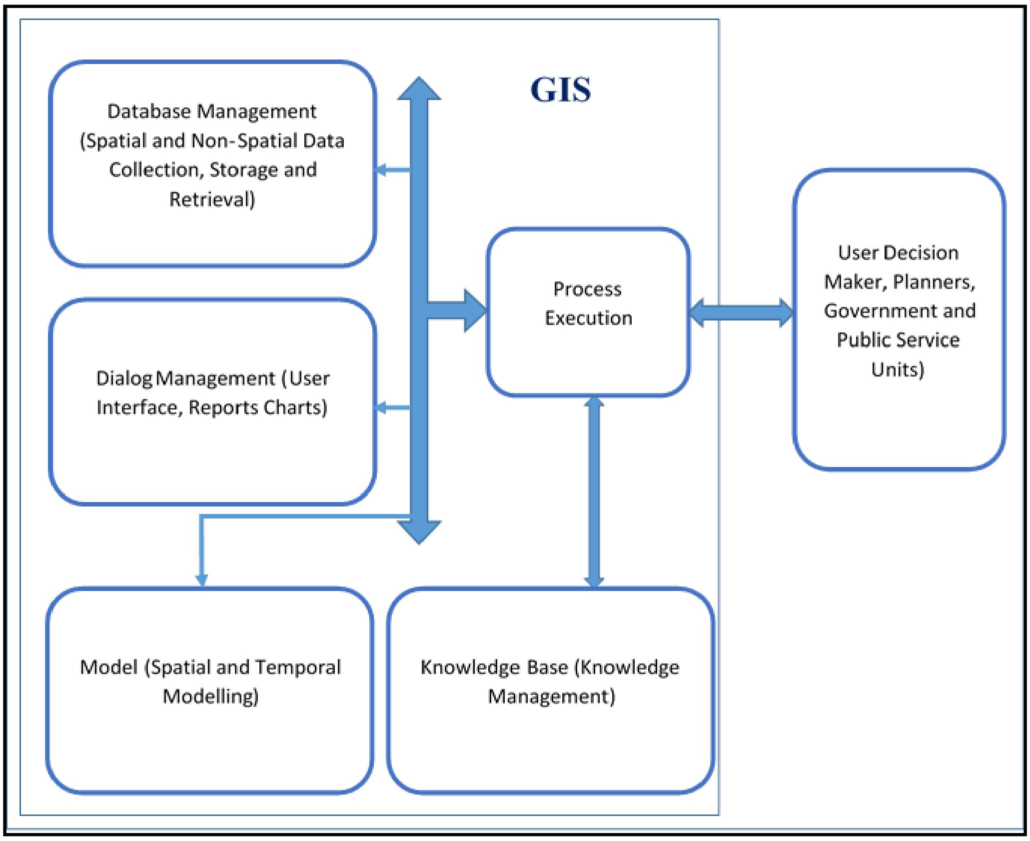

Figure 2.2 Evolution Components of SDSS (Sugumaran and DeGroote, 2011)

A wide variety of spatial modelling techniques have been utilized in spatial decision-making processes and in SDSS. Many of these models are not inherently spatially explicit but are adapted for spatially explicit use in an SDSS. Some examples include mathematical models, statistical models, simulation models, prediction models, spatiotemporal models, land suitability models, and dynamic models.

A key to any successful SDSS is the development of effective mechanisms for user interaction with software components. These mechanisms are termed the dialog management component (DMC). The DMC provides the interface between the user and the rest of the components of any SDSS. It provides mechanisms whereby data and information are input to the system from the user and output from the system to the user.

An important aspect of decision systems, that is traditionally not explicitly discussed in DSS literature and SDSS literature specifically, is the role of the stakeholders and decision makers.

In a spatial decision-making situation, there are a wide variety of individuals and organizations that might have a stake in the potential outcomes. The successful application of an SDSS to a spatially dependent problem is dependent upon the effective involvement of a wide array of potential players.

A knowledge management system (KMS) is not an essential component of an SDSS but has been included in many SDSS. The purpose of a knowledge management component (KMC) is to provide expert knowledge that can aid users in finding a solution to the specific problem or to provide guidance to novice users in the overall decision-making process and also in selection of analytical models. Knowledge management systems are computer programs that manipulate a knowledge base to solve problems.

2.5.2 Applications of SDSS:

The objective of this section is to demonstrate the differences in use of SDSS to various spaces alongside definite contextual analyses of unique SDSS developed within these application ranges. The vast majority of the SDSS were created for different applications utilizing assorted advances. A look at generally utilized and developed Spatial Decision Support Systems for Various applications is given in the Table 2.3. Some of the developed SDSS for agriculture monitoring and drought assessment are listed in table 2.4. These examinations provide enough detail for researchers to get a feel for the entire process of conceiving, developing, and applying an SDSS in a particular application domain. In spite of the fact that these created SDSS are not exhaustive rundown in the field of spatial sciences, these are a portion of the framework which was recorded amid writing overview.

Table 2.3 Contextual examples of various SDSS from different application domains

No	Purpose	Platform	Tools	Authors
1	Natural Resources Management (Land Use Planning)	Desktop Intelligent	Arc Info	Zhu et al. 1996
2	Natural Resources Management (Habitat Site Development and Restoration)	Desktop Collaborative	ArcView	Jankowski et al. 1997

3	SDSS for integrated regional planning.	Desktop	ArcGIS Engine, VB.NET	He, J. and Sun, Y. 2015
4	SDSS for accessibility analysis	Web-based	Geoserver, Open Layers, Geoext	Burdziej, J. 2012
5	SDSS for tourists of Great Smoky Mountains National Park	Desktop	ArcGIS	Dye, S. and Shaw, S. 2007
6	SDSS for Emergency Service Station	Desktop	ArcGIS	Esmaelian et al., 2015
7	SDSS for Flood Risk Management in Brazil	Web-based	Geoserver, PostGIS, Java	Horita et al., 2015
8	Cooperative SDSS for Controlling Animal Diseases Outbreaks in Egypt	Desktop	ArcGIS, Arc Objects	Bakr, M. et al., 2015
9	Multi-criteria SDSS for planning sustainable industrial areas in Northern Spain	Desktop	ArcGIS	Ruiz, M. C. et al., 2012
10	Typhoon insurance pricing with spatial decision support tools	Desktop	ArcGIS, SQL Server	LI, L. et al., 2005
11	Nuclear Waste Storage Site Selection	Web-based	Various Spatial Web Services	Huang and Sheng, 2006.
12	Multi-criteria SDSS for the assessment of environmental sustainability of dairy farms	Web-based	ArcGIS	Silva, S. et al., 2014.
13	An environmental DSS for the management of water pollution in a tidal river network	Desktop	Arc Info	Leung, Y. et al., 2005.

14	Spatial Expert Support System in Selecting Suitable Sites for Water Harvesting Structures- A Case Study of Song Watershed, Uttaranchal, India	Desktop	Arc Info	Rao, et al., 2003.

Table 2.4 Developed SDSS for vegetation monitoring and drought assessment

	Purpose	**Platform**	**Implementation**	**Authors**
1	Rural Land Use Planning	Desktop	Smallworld	Matthews et al. 1999.
2	Modelling Crop Yields Using Imprecise Soil Data	Desktop	Arc Info and Map Objects	Lagacherie et al., 2000.
3	Data Integration in a Farm SDSS	Desktop	ArcView	Jones and Taylor, 2004.
4	Farm-level Agronomic Decision Making	Web-based	ArcIMS	Sha and Bian 2004.
5	Selection of Forage Species for Farmers	Desktop	MapObjects	O'Brien et al. 2004.
6	Agricultural Land Evaluation and Site Assessment	Desktop	ArcGIS	Dung and Sugumaran, 2005.
7	Agricultural Pest Control Planning	Desktop	ArcGIS	Cohen et al. 2008.
8	Precision Agriculture	Desktop	ArcGIS	Thorp et al., 2008.
9	Real-time Crop Yield SDSS	Web-based	MapServer, ERDAS IMAGINE	Kaparthi and Sugumaran, 2009.
10	SDSS for crop residue energy potential			Escalante et al., 2016
11	Integrated Drought Watch	Web-Based		Mendicino, G. and

	System			Versace P., 2006.
12	Geospatial Decision Support for Drought Risk Management	Web-Based	Arc Plot and GRASS, Java	Goddard, S. et al., 2005

The increasingly powerful space technologies such as RS and GIS give robust and viable support to monitor the drought condition. In the field of drought monitoring, agricultural information or inputs are required from various sources for their processing and dissemination to planners, policymakers, researchers, and administration. By using different RS datasets and meteorological information, spatial planners can investigate the effects of different natural or man-made events and provide information to take decisions. To allow the user to easily adapt the system the interface allows for an intervention i.e. simple modification. Managers use computerized DSS not only for accessing important information and the principles of decision making but also to model and implement business intelligence tools to support decision making (Turban et. al, 2007). GIS Database Management Systems (DBMSs) are used to support cartographic display and spatial queries. Database of a SDSS must support spatial data display, spatial query and analytical approach. In this setting, SDSS has to combine spatially explicit observational data and replication of physical processes with a representation that is suited for communication with non-specialist decision makers and other users. GIS provides a familiar interface paradigm for specification of decision scenarios and presentation of maps and time series charts provide the means for scientific analysis of decision scenarios (Taylor et.al, 1999).

The open-source Software or model is a decentralized improvement demonstrates that empowers open collaboration. A primary rule of open-source tools or technology advancement is peer generation, with items, for example, source code, outlines, and documentation unreservedly accessible to people in general. The open-source development in programming started as a reaction to the restrictions of exclusive code. Open source advances all-inclusive get to through an open-source or free permit to an item's outline or diagram, and widespread redistribution of that plan or blueprint. Before the expression open source turned out to be broadly embraced, designers and makers utilized an assortment of different terms. Open source picked up hold with the ascent of the Internet. Generally, open source software is a PC program in which the source code is accessible to the overall population for utilize or adjustment from its unique plan. The developed SDSS is based on the open source GEOSERVER, which is used as a main spatial Service provider. The spatial data are published as a Web Map Service (WMS). The interactive web user interface is built using the ExtJS and the GeoExt frameworks with the OpenLayers libraries which are used as a main map client. Finally, a dynamic Styled Layer Descriptor (SLD) is generated with uDig (The User-friendly Desktop Internet GIS) open source software script and has been incorporated for creating interactive and user oriented maps. Detailed description about tools and technology used for the development of SDSS-DM (Spatial Decision Support System-Drought Management) has been mentioned in chapter-5. The mitigation of the impacts of disasters requires significant and real time information for planning and preparedness. Also, the possible prediction and monitoring of the disaster requires rapid and continuous data and information generation and or gathering. Collection of information in timely manners with respect to the disasters from conventional methods is very difficult. In recent days the remote sensing tools offer exceptional potential of collecting this critical dataset. The remote sensing technology has capability of collecting data at global and regional scales rapidly and repetitively and the data is collected in digital form. The technology further provides an excellent communication medium.

The fundamental objective of worldwide farming is to take care of 6 billion individuals, a number prone to twofold by 2050 (Kogan, 2000). The first requirement of living creature is food, and a setback in agricultural and fodder production leads to socioeconomic unrest especially in developing countries. Therefore, management of natural resources in developing as well as developed countries requires information on the state and changes in a range of biophysical variables. Drought has been viewed as such a disaster where in a shortfall in precipitation has led to substantial reduction in production levels there by leading to condition which causes large scale migration and death of men and animals. Hence, there is need for appropriate measurement of drought effects and monitoring and detailing of drought improvement in environmentally and ecologically touchy areas. The impact of drought on society and agriculture is a real issue but it is not easily quantified. To analyse the impact of the drought for decision making processes, reliable indices required to detect intensity of drought in spatial and temporal scale (Seiler et. al.1998).

the development and advancements in space technology, to address issues like drought detection, monitoring and assessment have been dealt with very successfully and helped in formulation of plans to deal with this slow onset disaster.

This chapter has provided an overview of application domains or disciplines in which SDSS have been most commonly applied. In addition, detailed case studies were provided from a variety of disciplines, which highlighted important application domains, technological approaches, modelling techniques, software integration methods, and the role of stakeholders. Listed SDSS in table 2.3 and table 2.4 focused on the use of computers in specific domains such as the environment, agriculture, emergency planning and hazard response, transportation, business, utility/communications/energy, and public health or urban studies with a focus on GIS or geospatial technology.