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Role of GIS Based Technologies in Sustainable Agriculture Resource Planning & Management Using Spatial Decision Support Approach

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ABSTRACT
Decision Support Systems (DSS) provide a framework for integration, management, analysis and finally graphical presentation of a particular phenomena in order to improve the existing decision making process. In the present day context, the decision support system concept has been extended to the spatial dimension by integrating GIS and DSS into spatial decision support systems (SDSS). Due to the lack of computer software to develop user friendly interfaces in the past, GIS have not been used as part of SDSS. Instead GIS have been used to generate and store spatial data which were used that time as inputs for the analytical or manual statistical models. GIS was used independently to display maps by inputting results of the analytical models. With the passing time much of the research has been done on the use of GIS in the visualisation of the results of the analytical models. Developing user friendly graphical interfaces in incorporating analytical models into GIS to arrive at SDSS's is one of the active areas in modern day agricultural management system. Technological or precision farming, a combination of GIS,GPS receivers, continuous yield sensors, geostatistics and variable rate applicators is an innovative approach to practice of sustainable agriculture. The other SDSS applications discussed in this paper are on watershed management, crop productivity management and policy decision analysis.

Keywords: Geographical Information System (GIS), Spatial decision support system, Agriculture, Crop production

1. INTRODUCTION
Raising food demands due to gradually increasing trend of population growth and major changes in political and economic and social systems have created an urgent need to develop a new and more efficient agricultural system to cope up with all difficulties. India is characterized by a high population with a larger growth rate (1.2%/annum). The restless onslaught of demographic pressure (16-17 additional people each year) on India's natural resources and high production gains limited to well endowed irrigated areas, have however put a question mark on the stability and sustainability of Indian agriculture (Katyal *et.al*, 1996). Now, more than ever, decision makers at all levels need an increasing amount of information to help them understand the possible outcomes of their decisions and develop plans and policies for meeting the increasing demand of food requirements without damaging the existing natural resources base.

Decision Support Systems are "interactive computer based systems that help decision makers to utilize data and models to solve unstructured problems" (Turban, 1995). These tools improve the performance of decision makers while reducing the time and human resources required for analyzing complex issues. Spatial Decision Support Systems (SDSS) deals with spatial dimension through digitized geo-referenced spatial databases. Agriculture is essentially a spatial phenomenon which is not independent of location based aspects. GIS is the field that handles various spatial databases, and is a comparatively younger area of information technology. This spatial information technology allows to examine and analyze a wider range of agricultural related resources such as soil, weather, hydrology, various socio-economic variables simultaneously and accurately. Simultaneous examination of all these variables in a GIS environment leads to a better understanding of how agricultural systems function and interact over space and time. This understanding leads to developing stable and sustainable dynamic agricultural technologies.

Decision Support System (DSS) in collaboration with GIS can better organize and analyze spatial data, address the problems related to spatial and temporal variability of various natural resources on which the performance of agricultural systems depends. Spatial databases developed in GIS as input to analytical models such as simulation models and statistical models enables to model agriculture from field to national and global scales accurately. Output on area action plans at different scales can be viewed through maps. Maps provide insight and understanding of spatial and temporal interactions of various agricultural systems and resources over time dimension. The information gallery and accuracy of these maps depends on the scale of spatial data acquisition. Linking of spatial analysis and simulation models to GIS databases is one of the current areas of active research in many parts of the world. These spatial information systems and decision support systems help to manage various agricultural systems efficiently over space to meet the changing food demands in a sustainable manner. In this regard GIS can be looked as an essential and central tool for developing spatial decision support systems. In this paper some applications of SDSS and in agricultural research are discussed.

2. DECISION SUPPORT SYSTEM IN AGRICULTURAL POLICY MAKING

Research publication based on the secondary databases collected from different governmental organization on Spatial and temporal issues in not a new topic. For example studies on agricultural growth and assessing the dynamics of cropping pattern, land use changes and pattern analysis, livestock, population, irrigation, fertiliser use etc., are common. Interestingly, the data are available at micro level but the analysis is being performed on the aggregate data at national or regional or even at state level depending on the study. But analysis of aggregate data does not represent about location specific trends and spatial patterns which are very essential for agricultural policy, planning and management.

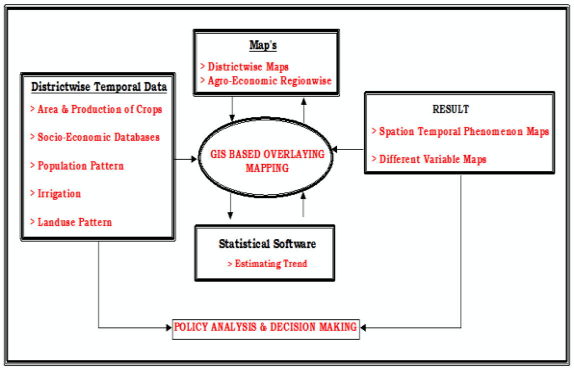

Figure 1: Elements of SDSS for Policy Making

Figure 2: GIS Softwares used in SDSS creation in Agriculture Planning & Management

Anon, (1997) studied the changes in area and productivity of rainfed crops in South India etc. by linking the time series district-wise data to district map of India. Further Agro-eco regions were (Siegal *et al*, 1992) overlaid. These maps reveal the spatial trends in area and productivity of rainfed crops in different Agro-eco regions apart from temporal trends. Their study brings out the need to revitalize the efforts on stabilizing and accelerating the productivity levels even in Agro-eco Region, which is the major sorghum area. Resource characterization is one of the important applications of GIS in agriculture. Overlaying the maps showing the spatial distribution of various crop statistics such as productivity, irrigation, fertilizer etc., against resource characterization maps enables to assess crop performance with respect to resource capabilities. Various components of this SDSS have been shown in Fig.1. These help in developing strategies for optimum resource use in future.

3. CROP PRODUCTIVITY MANAGEMENT

Regional Productivity analysis involves evaluating spatial soil and weather variability, identifying optimum crop management practices, and predicting productivity of the region under different climatic and management scenarios. This analysis can help regional planners and policy makers in delineating acreage and distribution of areas with high productivity and developing management recommendations for different crops. Lal *et. al*, (1993) extended the scope of applicability of site-specific crop simulation models such as "Decision support system for agro-technology transfer" (DSSAT) to regional planning productivity and policy analysis by combining their capabilities with GIS Platform like ARCGIS. In this combined system(Fig. 2), simulation models predict information on yield and other crop related outputs for different homogeneous soil and weather combinations, and GIS aggregates information from individual units, displays maps, and also presents results in tabular format for the study area.

In the case study they used this system of analysis for three sites having considerable soil and weather variability. To generate yield databases, several thousands of simulations are to be made using DSSAT model for a variety of management combinations for different soil and weather conditions in the study areas. The main input layers for this type of study includes soil maps, soil survey reports, daily, precipitation, daily maximum and minimum temperatures, and solar radiation values. The results of the study by Lal *et. al*, indicate considerable variation in optimum planting dates and yield levels under rainfed conditions. Their study successfully demonstrates the scope of applicability of site-specific models to regional planning and productivity analysis by combining their capabilities with GIS software. Singh *et. al*, (1993) demonstrated the use of GIS to investigate nitrogen fertilizer efficiency in several Indian states using sorghum crop simulation model coupled with a GIS. The spatial database contains information on soils, weather and other inputs needed by the sorghum model. The system allows regional analyses and the output will be in thematic maps. Hence these combined tools can be used for classification and evaluation of the region, locating high yielding and problematic areas and estimating their productivity under different management strategies.

4. SDSS & PRODUCTIVITY MANAGEMENT

In generally field experiments are performed in some statistical design, which helps to infer the results based on statistical significance tests. The unaccounted variability called experimental error is attributed to uncontrollable environmental factors. On the other hand computer based decision support systems are developed to understand the interaction between various crop management options and environment. Hoogenboom *et.al.* (1993) used DSSAT models at research farm level by developing a software interface with ARCVIEW. The first objective of their study was to expand the use of crop simulation models through a linkage with GIS and spatial soil databases. The second objective was to apply this system to study the distribution of yield, water use, and other agronomic variables as a function of

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soil spatial variability on a farm level. The strength of a GIS is that we can create various spatial database layers for topology, elevation, soil depth, soil type, weather, land use, and any other related information using GIS. Anybody can for instance, digitize a soil map to provide the basic map layer and develop an attribute database for soil type, soil family texture, soil association, pH, slope and other soil physical and chemical characteristics. Each layer can be overlaid to create homogeneous polygons, each with unique characteristics based on the classification of each layer.

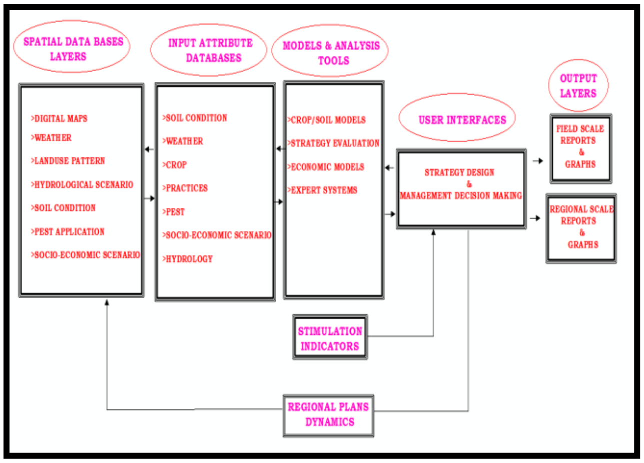

Figure 3: Elements of Spatial Decision Support System in Agricultural System or Productivity

GIS based Crop-model system can then be used to simulate crop growth and development for each polygon or field with different characteristics. The results of the study by Hoogenboom *et.al*. (1993), for the crops grown under rainfed conditions showed a strong spatial variation. Hence, it may be possible to capture the variability in crop yields adequately by overlaying many soil characteristics using GIS and appropriate analytical models. This helps in making decisions on varying input use at field level for sustainable crop productivity management.

5. INTEGRATED WATERSHED MANAGEMENT & SDS

Integrated watershed management & planning is a very integral part of modern day agricultural system, especially it's importance is mostly felt in case of rainfed areas and topographically risky zones located in mountainous or hilly terrain. GIS have been successfully integrated with distributed parameter, single event, water quality models such as Agricultural Non Point Source (AGNPS) and Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS). A brief description on application of GIS technology on the above mentioned parameters have been discussed by Garg (1994). The amount of time, expertise and cost required for acquiring input data for running the models are greatly increased. For example, a simple model like USLE (Universal Soil Loss Equation) requires only six inputs, while a spatially distributed, single - event model like AGNPS requires 22 inputs for each cell or grid analysis within a study area. The need can vary significantly between and within models, depending on the questions to be answered, thereby tremendously increasing the cost, time and complexity of analyzing results. The integration of GIS with distributed parameter models can eliminate many of the limitations associated with the use of these models particularly for input data preparation. Srinivasan and Engel (1991) integrated the AGNPS model to display and facilitate analysis of model output. Rewerts and Engel (1991) integrated the ANSWERES model with the GRASS GIS to build inputs to run the model. Both AGNPS and ANSWERS are single-event-distributed-parameter models that require a watershed to be divided into square grids and resample like a raster-based GIS, where the data are sorted in a grid - like array.

Continuous-time, distributed-parameter models consider the basin or watershed divided into sub-basins based on topography, soil and land use and thus preserve the spatially-distributed parameters and homogeneous characteristics within a sub-basin. Collection of inputs for such models is often difficult due to the level of aggregation and the nature of spatial distribution. To overcome this problem Srinivasan and Arnold (1994) developed a GIS interface to automate inputs to a continuous-time, distributed-parameter model called the Soil and Water Assessment Tool (SWAT). Digital elevation model (DEM) created in GIS is an important input to this model. Given an input surface such as DEM, the hydrologic modelling tools can be used to generate grids that encode the flow direction and flow accumulation for each cell or grid representing local and natural watersheds and drainage network. Fig. 3 shows the GIS layers interface structure for SWAT model.

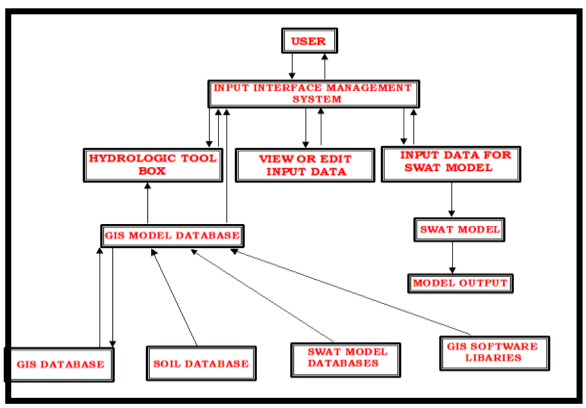

Figure 4: Application of GIS software in Soil and Water parameter analysis

6. GIS FOR FARMRNG PRACTICES

The application of modern Remote sensing technology coupled with GIS has opened the way for significant change in crop production management and agricultural decision making process. This vision is reflected in site specific farming. Site specific farming aims to direct the application of seed, fertilizer, pesticides and water within fields in ways that optimize farm returns and minimize chemical inputs and environmental hazards. These site specific farming systems utilize some combination of GPS receivers, continuous yield sensors, remote sensing, geostatistics and variable rate treatment applicators with GIS (Fig. 4) . Global Positioning System is one of the many new technologies contributing to site specific farming and is the one that really puts the precision into farming for most site specific operations.

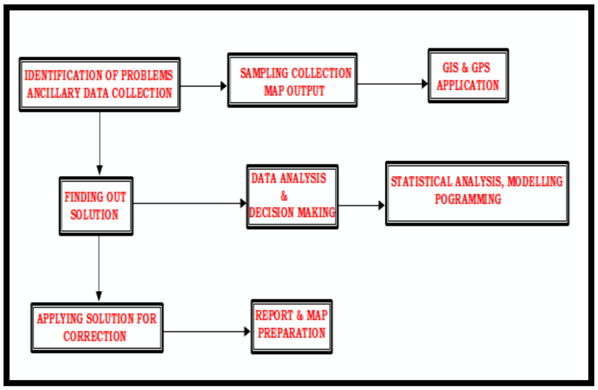

Figure 5: GIS based Site specific farming components

Site specific technology allows farmers to make informed economic decisions about input use, while reducing or avoiding long-term environmental degradation. Adoption of this technology requires accurate geographical maps showing physical and chemical properties and the tools to apply the inputs as per the spatial variability. The concepts embodied in precision agriculture offer the promise of increasing productivity while decreasing production costs and minimizing environmental impacts. Precision agriculture is considered a suite of technologies consisting of crops, weather, pest complexes, and marketing arrangements rather than a single technology. All these components have the common feature of increasing the information intensity of agriculture.

New information technologies will be required to make the more detailed and timely decisions necessary for site specific farming practices. Introduction of new remote sensing techniques will enable in the collection of an unprecedented number of soil, crop, pest and weather observations. Maps created using GIS software can be used during field operations to make more precise and timely application of inputs. Multidisciplinary research will be needed to match measurement methods and analytical techniques with crop production questions of interest to effectively understand and use information about the true variability of measurable parameters within farm fields. Database management and image processing methods are needed to extract useful information from very large data sets. Geo-statistical methods must be advanced both to more effectively sample and to more accurately interpolate sparse data. Spatial analysis methods and spatially explicit components in crop models should be evaluated and calibrated under field conditions, and linked to GIS to facilitate accurate analysis and inference from collected precision agricultural data.

7. CONCLUSION

In the coming years, use of efficient information technologies will play an increasingly important role in crop production and natural resource management. In this context GIS has a significant role to play in the decision making process in agriculture at various levels i.e., field, regional, national and global levels. GIS is one of the important tool of Information Technology (I.T) highly relevant to agriculture. This technology allows to examine and handle a wider range of spatial data bases such as soils, hydrology, weather etc and integrate with socio economic variables. Increased use of fertilizers, pesticides and other chemicals have contributed to the enhancement of agriculture's productivity in recent decades. But currently, agriculture production is facing many challenges such as increased cost of production, shortage of irrigation water, adverse impacts of agriculture on the environment etc. For countries like India it is a challenging task to meet the food demands of the growing population in future. Further, to survive in the highly competitive world market of agricultural commodities in view of globalization, agricultural producers must produce highly quality products at low prices while using environmentally sound practices. Simultaneous examination of these variables leads to a better under standing of various agricultural related process and their interactions over space and time. Interlinking of simulation models such as crop simulation models, hydrologic models, statistical models to GIS databases is one of the current active areas of research. By interfacing these models, GIS is emerging as a powerful spatial decision support system.

Further, GIS is an ideal tool for crop planning on watershed basis since digital elevation models (DEM) created in GIS can be integrated with other spatial information including land use pattern obtained from remote sensing data from time to time. GIS greatly reduce the processing time for data preparation as the amount of input information needed to execute these simulation models is tremendously increased.

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