Geo-informatics in Agricultural Research and Development: An IASRI Perspective

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1. Introduction

Geo-informatics is integrated technology for collection, transformation and generation of information from integrated spatial and non-spatial data bases. Remote sensing, Geographical Information Sciences (GIS), Global Positioning Systems (GPS), Relational Data Base Management Systems (RDBMS) are some of its important ingredients. It is a powerful tool for assessment, monitoring, planning and management of agricultural research and development. Management of agricultural resources is a myriad activity of conservation practices and land/water resources aimed at increasing the food production. Substantial increase in crop production could be achieved by bringing additional land under cultivation, improved crop management technology through use of high yielding, input responsive and stress tolerant crop varieties, improved pest control as well as by increasing irrigation and fertilizer inputs. These inputs together with reliable information on i) existing land use and acreage under various crops, ii) soil types and extent of problem soils, iii) monitoring of surface water bodies (to determine water availability in irrigation systems) for ground water development and (iv) management of natural calamities etc. will enable formulation of appropriate strategies to sustain the pace of agricultural development. This in turn calls for a holistic approach, which must combine short-term management of agricultural resources at micro-level with long term global perspectives, keeping in view of socio-economic and cultural environment of the people. The role of space geo-informatics in finding new resources for agriculture development for optimally managing the already available resources in order to maximize agriculture production is recognized world wide and is found to be highly potential.

Agricultural remote sensing involving crops and soils are quite complex. These complexities are due to dynamic nature and inherent complexity of biological materials. In order to handle these complex problems, remote sensing technology offers numerous advantages over traditional methods of conducting agricultural and other resource surveys. Advantages include, the potential for accelerated surveys, capability to achieve a synoptic view under relatively uniform lighting conditions, availability of multi-spectral data for providing intense information, capability of repetitive coverage to depict seasonal and long-term changes and availability of imagery with minimum distortion etc. Therefore, it permits direct measurement of important agro-physical parameters. Remote sensing of earth resources utilizes electromagnetic waves, which ranges from short wave length ultra violet through visible near infrared and thermal infrared in the longer wave length, active radar and passive microwave systems. A great advancement in applications of computers to this science is the development of capability of storing vast and varied information, ranging from historical information and aerial photography to spacecraft data, ground reference, and other forms of ancillary data. All these information is stored in the form of highly useful database/information system. Thus remotely sensed data and its derived information have become an integral component of agricultural management system in the country.

Applications of space borne remote sensing data for large area crop survey was explored in USA under Corn Blight Watch Experiment (CBWE) in 1971 which was followed by large number of experiments/large-scale remote sensing program. In a country like India, with vast geographic spread and great diversity in its set up, the need to apply remote sensing technology for national development was recognized during early 70's. The pioneering experiment was of coconut root–wilt disease using colour-infrared aerial photography. Numbers of studies were conducted for methodological development in this area. Remote sensing activities in India received a tremendous boost with the launch of Indian Remote Sensing Satellite-1A (IRS 1A) in March 1988. India is moving fast in development of new satellite systems and recently launched number of satellites dedicated to specific area of applications such as OceanSat, CartoSat, ResourceSat etc. Radar Imaging Satellite (RISAT), a microwave remote sensing mission with Synthetic Aperture Radar (SAR) operating in C-band and having a 6 x 2 meter planar active array antenna based on trans-receiver module architecture has been launched recently. Many technological developments, which occurred in 20th century contributed to the development of the concept of precision farming which includes GPS, GIS and high resolution remote sensing satellite data. In following sections, contributions of this institute are presented in this emerging field.

2. Contributions of IASRI

Indian Agricultural Statistics Research Institute (IASRI) was established on July 02, 1959 as an Institute of Agricultural Research Statistics. The mandate of the Institute is to undertake basic, applied and adaptive research in Agricultural Statistics, to conduct post graduate and in-service training courses in Agricultural Statistics and Computer Applications, to provide consultancy services, to act as a repository of information on Agricultural Statistics for research. Institute has been identified as an Advanced Centre of Excellence in education and training in Agricultural Statistics and Computer Applications. Apart from this institute also liaise with institutions of National Agricultural Research System (NARS), National Agricultural Statistical System (NASS), Department of Space (DOS) etc., to assist in the development and strengthening of quality of agricultural research and agricultural statistics through undertaking research and consultancy projects. Institute is celebrating the Golden Jubilee year (July 03, 2008 – July 02, 2009) of its foundation. This institute also recognized potential of geo-informatics technologies and initiated work in the direction of generation of crop production statistics since early nineties. During these years institute has undertaken number of research projects / studies and made significant contributions broadly in the areas of (i) Crop yield estimation (ii) Spatial stratification techniques (iii) Small area estimation (iii) Spatial sampling (iv) Spatial modeling (v) Classification techniques (vi) Integrated surveys for hilly regions and (vii) Web GIS. Some of important contributions of the institute are briefly described in following sub-sections

2.1 Crop yield estimation

Research on crop yield estimation has been taken up by the institute since beginning of nineties. Goyal (1990) demonstrated that remotely sensed satellite spectral data in the form of vegetation indices has been used to post- stratify the cropped area into area of homogeneous crop vigor and consequently improved estimators are proposed to estimate the crop yield using remote sensing data along with the ground enumerated yield estimation survey data. The usefulness of the suggested procedure has been demonstrated by using the Landsat (TM) satellite data and the crop yield data from yield estimation survey based on crop cutting experiments from Sultanpur district of Uttar Pradesh. Further, it has been observed that Normalized Difference Vegetation Index (NDVI) as compared to Ratio Vegetation Index (RVI) has higher potential to discriminate vegetation vigor and hence has the higher potential to be used in crop yield estimation surveys. An attempt was also made to quantify the effect of misclassification of units on the size of post- strata and the post- stratified estimator of the crop yield. The expressions for the bias and variance of the post-stratified estimator have been derived in terms of the extent of misclassification. Since, spectral reflectance is a manifestation of integrated effects of all inputs like weather, soil and agricultural practices, therefore it is expected that the spectral data can be used with advantage for crop yield forecasting. Therefore, attempt was also made to study the relationship between wheat yield and the spectral parameters obtained through the hand- held spectral radiometers to explore the usefulness of spectral data in crop yield forecasting.

Singh and Goyal (1993), Singh *et al.* (2000) and Singh and Goyal (2000) extended the earlier results for estimation of wheat crop yield for district Rohtak, Haryana using crop cutting experiments data for the year 1995-96 and satellite spectral data from the Indian Remote Sensing Satellite IRS-1B LISS II data for February 17, 1996. Post stratified estimator of crop yield using spectral data in the form of vegetation indices NDVI and RVI for stratification have been obtained for the district. The efficiency of the post stratified estimator based on NDVI and RVI compared to the usual estimator comes to 1.42 and 1.28 respectively. This study thus almost confirm the findings of the earlier study that the district level estimator of crop yield may be obtained by reducing the number of crop cutting experiments to about 2/3rd without loosing the precision thus resulting in great savings of cost. Further, two small area estimators of crop yield, namely the direct estimator and the synthetic estimator have been developed at tehsil level using post stratification based on NDVI. The standard error of both the direct estimator and the synthetic estimator at tehsil level is within 5 per cent and as expected the synthetic estimator is more efficient as compared to the direct estimator.

Ibrahim (1992) investigated the utility of the multi-date spectral data taken at selected intermediate times in the growing season, in a Markov chain model to forecast crop yield. A hand-held spectral radiometer has been used for collecting the spectral responses from the experimental plots of wheat crop at fortnightly intervals during the growth of the crop. The spectral parameters observed at the different growth stages as well as the observed yield have been utilized to simulate a spectral population along with the corresponding yield based on a stochastic model.

Das (2004) proposed alternative approach of crop yield estimation using multi resolution satellite data. The attempts were made to make use of satellite spectral data and spatial sampling technique for crop acreage estimation, crop yield estimation and crop yield forecasting, which involves use of satellite data of coarse spatial resolution, which is cheaper with larger aerial coverage. It was shown that remotely sensed satellite data can be used effectively as area frame for conducting crop yield estimation surveys. Fine resolution data is costly and aerial coverage is less, whereas poor resolution data has larger aerial coverage with lesser cost. Since, spectral reflectance is a manifestation of integrated effects of all inputs like weather, soil and agricultural practices, it is expected to have a very high correlation with crop vigor and hence the crop yield. Since, estimation of yield using different spectral indices provides different estimates attempts were made to combine the estimators from different vegetation indices using multiple frames sampling estimation technique. It has been found that considerable gain in efficiency is obtained in multiple frame sampling estimates as compared to usual estimator using single index. A common approach for classification of satellite data is supervised maximum likelihood classification. In supervised maximum likelihood classification, each pixel is allotted with a particular theme depending on its digital number. The presence of the mixed pixels is a nuisance with performing classification, because in the conventional classification procedures, a pixel is considered as an elementary unit for the analysis. An alternative method of satellite data classification is proposed, which involves the use of spectral signature curve for training the satellite images to estimate the underlying class signatures through the use of fuzzy classification developed by indicator Kriging. Attempt was also made to develop forecasting model based on spectral data and agro-meteorology.

2.2 Spatial sampling

In agricultural surveys often the parameter of interest is geographical in nature i.e. the observations are dependent through space thus classical statistics cannot be applied as such. Dependence implies correlation and spatial dependence implies the presence of spatial autocorrelation. Since, in geographical data 'adjacent units are often more alike than units that are far apart', it is desirable to exploit this information in the sampling designs. In this way duplicate information partly contained in areas already sampled can be avoided. Another advantage is that the sampling cost can be economized without loosing the reliability of the estimates. An attempt by Misra (2001) is being made to improve the conventional survey methodology for agricultural surveys with the help of spatial sampling procedures. The potential of GIS to handle various kinds of information through their geographic coordinates and Remote Sensing with its advantage of wide area coverage, repetitive coverage and synoptic view have been exploited for the study. An improved spatial sampling technique known as *Contiguous Unit Based Spatial Sampling (CUBSS)* Technique is proposed in this study (Sahoo *et al.,* 2006). The technique incorporates size measure along with spatial contiguity of the units in the population. The spatial correlation is estimated for auxiliary character which is used along with size measure in assigning weights for selection of the sampling units. The probability of selection of any unit is governed by these weights. The principle of sample selection is that the probability of selection of any unit increases as the distance from the units (area) already selected increases. The sample selection criterion is based on the weights, accounting for spatial variability and the size measure accounting for areal extent. Further, a suitable unbiased estimator which takes into account the order of the draw is suggested for this situation. The study is carried for regular lattice i.e. assuming the area to consist of regular units. In order to tackle the problem of irregularity of the sampling units, distance based neighbor are suggested. Based on these neighbors the modified formula for spatial correlation is also suggested in this study. For defining these neighbors, the concept of lagged variable and lagged series is being used. A spatial sampling technique termed as *Distance Unit Based Spatial Sampling (DUBSS)* is also proposed in this study and its efficiency is compared with the existing ones and CUBBS technique by carrying out a suitable simulation study. The proposed technique performs considerably better than all the other techniques.

Ranked Set Sampling (RSS) is found to provide better results than Simple Random Sampling (SRS) when ranking is easy and cost effective, especially in ecological and agricultural surveys. After critical review of literature it has been found that there is a hardly any technique of RSS, which takes into account spatial dependence of observation generated by spatial variables. Kankure (2007) made an attempt to develop spatial ranked set sampling methodology for the estimation of finite population mean. Four sampling designs were proposed which takes into account the spatial relationships of the areal sampling units in the population while selecting a sample. The proposed Spatial Ranked Set Sampling (SRSS) procedures involve the selection of ultimate sampling units in two stages. In the first stage Random

Spatial Clusters (RSC) of sampling units in the population are formed and in the second stage ranked set sample of specified size is being selected. Sample selection at the first stage is done by applying Dependent Areal-Unit Sequential Technique (DUST). This technique is based on giving different probabilities of selection to the sampling units in such a way that nearer units, or already selected units in the sample, get lesser probability of selection, while farther units get higher probability of selection. It is one of the desirable characteristics of a sampling design in spatially correlated population. The spatial component of the data is incorporated at this stage by dividing the entire population into Random Spatial Clusters (RSCs) by considering first phase units as the key units. The spatial clusters are formed on the basis of nearest neighborhood approach with respect to randomly selected units. Any particular unit will fall exclusively in a single spatial cluster, which has been formed by the key unit nearest to it on the basis of Cartesian distances calculated using latitudes (La) and longitudes (Lo) of the locations. Having selected the RSC, RSS was carried out using two approaches i.e. (i) the entire ranked set sample was selected independently from each RSC and (ii) different sets of the RSS are selected independently from different RSC. Thus, in this study some new and more efficient sampling techniques have been proposed which take into account the spatial correlation present in the geographical units. The results of the study point out that, in spatial surveys, a considerable gain in efficiency of the estimators could be achieved by using distance based sample selection strategies even when applying these for complex sampling schemes such as RSS. The complex algorithms involved in the selection procedure of distance based sampling strategies could be solved with the use of advanced computing and software.

It is well known fact that there is no objective methodology for estimation of area under different crops in North-Eastern states due to typical problems existing in these regions. The north-eastern states particularly Meghalaya, mainly consists of hilly region with thick forest cover. Besides this, the main problem is its undulating topography and non-accessibility of vast area. Further, the relative percentage area under the crops is very less. Mostly terraced farming and Jhum cultivation is practiced in these regions. Moreover, these areas particularly Meghalaya, are covered by clouds most of the time in a year. Thus it is difficult to get cloud free images of these areas. Therefore, use of remote sensing satellite data alone may not be able to provide reliable information. Further, there are no cadastral maps and village boundary maps existing for these regions. In contrary to other states, in north-eastern regions reliable information regarding total number of villages in each district/block is not available. Further, within a villages total number of farmers, number of fields owned by each farmers, crops grown by the framers etc. are also not available in village records. Thus, the traditional methodology of area estimation is not applicable in these regions. Keeping all this in view, a study (Sahoo *et al.*, 2008) was taken up by Indian Agricultural Statistics Research Institute (IASRI), New Delhi in collaboration with North- Eastern Space Applications Center (NESAC) Shillong and Space Applications Center (SAC) Ahmedabad in which methodology was developed using integrated approach of remote sensing, GIS and ground survey for estimation of area under winter paddy crop in Meghalaya. The satellite data of IRS 1D, LISS III sensor has been used for this study. Under this approach the area under paddy has been obtained by usual classification method. There are two major factors affecting the accuracy of the crop area as obtained from the classified satellite image in the hilly regions: (i) Due to undulating topography of the region, misclassification and topographic geometry, there may be large differences of area under crop in the image and actual area under crop on the ground which may also result in larger extent of misclassification errors (ii) The area under paddy crop falling under hill shades or valleys may not be exposed to the satellite sensor, as satellite sensors are sun-synchronous. Further, small paddy fields are not detectable due to lower spatial resolution of the LISS-III sensors. In order to rectify the area under paddy crop due to undulating topography and misclassification errors, relationship between area under paddy in the classified image and actual area under paddy crop on the ground has been established. The area under paddy which has not been captured by satellite sensor due to hill shades and limitations of spatial resolution of the sensor has been rectified by a suitable sample survey in the buffer created along the National Highway/State roads in GIS environment. Suitable estimators were developed to estimate the area under paddy in this buffer zone. The vector layer of this buffer was overlaid on the satellite-classified image and the corresponding area from the image was extracted. Using these estimates, the area under paddy in the entire district was estimated.

A study was undertaken in Yamunanagar district of Haryana State (Ahmad *et al.*, 2003), to develop a GIS based technique for identification of potential agro-forestry areas. In this study, important factors responsible for growth of agro-forestry were identified, suitability index using Spatial-Analytic Hierarchy Process was constructed and was compared with the Composite development index. A new Objective Analytic Hierarchy Process (OAHP) procedure was used to develop suitability index for agro-forestry of each village. This study strives to find out the potential agro-forestry areas using Geographic Information System (GIS) and proposed OAHP leading to Objective Spatial-AHP to identify and rank areas that are suitable for agro-forestry, using the statistical techniques involved in the proposed OAHP and data contained in GIS maps. This study is useful for the farmers as well as planners. The study is helpful for the social, economic and environmental development of the study area. The study will also be helpful in future research in the area of agro-forestry for other regions.

2.3 Spatial modeling

Agricultural fields are Spatial in nature. If we consider productivity of the field with respect to certain crop provided other factors as constant. It does not change abruptly from one field to another. The change is very gradual and the neighboring fields have more or less same structure. In general crop-cutting experiments (CCE) are carried out for yield estimation in selected villages. It may be noted that from crop cutting experiment the estimation of production at lower level like Tehsil's, villages etc is difficult and prone to large error due to small sample size. The application of spatial statistics in agriculture to improve the prediction and estimation may be a useful attempt for small area levels. Spatial characteristics and CCE will help us in giving the better estimate and at lower level also. With the help of available literature in the field of spatial statistics, it is possible to apply suitable spatial models to predict the production surfaces i.e. values of production at each point of the map, of the target region. Field sizes of our country are fairly small, therefore it is more appropriate to utilize the spectral data as auxiliary information. A study was undertaken by Gupta (2002) to develop an integrated methodology for wheat crop yield estimation using the survey data on wheat crop yield from CCE along with the satellite spectral data in the form of vegetation indices i.e. Normalized Difference Vegetation index (NDVI). The use of remote sensing satellite data along with the crop yield data based on CCE can greatly improve the efficiency of crop yield estimators at small area level.

Spatial statistics is based on the assumptions that nearby units are in some way associated and tend to share similar attribute values. The classical statistical theory is based on the assumption of independence of observations. Thus, classical statistical method when applied to geo-referenced data, fail to capture the spatial dependence of the data. It is unrealistic to assume that the information is location independent while analyzing the data of a character, which is geographical in nature such as productivity of crop, soil parameters and availability of ground water for irrigation. Spatial data is data related to the location of features along with information related to variables of interest. It is always desirable to utilize the knowledge contained in the sample to improve the estimation of spatial statistics. Bayesian approach takes into account any prior knowledge of parameter/variable of interest.

Gupta (2007) made an attempt to develop spatial prediction model under four different situations i.e. (i) using prior information about parameters which is non-informative for known and unknown variance (ii) using prior information about parameters which is informative for known and unknown variance, (iii) using prior information about parameters as natural conjugate prior for known and unknown variance and (iv) using fuzzy approach for linear interval model for vague characters under study. It was shown in this study through simulation that Bayesian regression analysis is always better then simple regression analysis. This may be due to the fact that information contained in the sample as well as about the parameter of the model has been utilized in the estimation procedure. Further, there is significant gain in the precision in case of geographical variables when spatial effects were taken in to account in the estimation procedure under Bayesian framework. It can be seen that variogram models plays significant role in capturing the spatial effect. Spatial Bayesian regression model performs better when spatial effects are incorporated through variogram models. The results obtained through exponential and spherical variogram models were found to be encouraging as compared to other models.

Measurement Errors (ME) in explanatory variables of classical regression model makes the estimators of regression coefficients biased and inconsistent. In case, variable of interest is geographical in nature, regression coefficients do not remain fixed over space and usual regression analysis takes no account of spatial location in its analysis. Therefore, a new technique called Geographically Weighted Regression (GWR) is used in which estimates of regression coefficients are based on local relation instead of global relations among spatial variables of interest. Estimation of regression coefficients when spatial explanatory variables with ME are fixed or random in GWR model is expected to provide efficient estimates as compared to corresponding usual regression model. An attempt has been made in this institute to propose a Functional Spatial Regression (FSR) model under ME and a Structural Spatial Regression (SSR) model under ME for estimation of regression coefficients in case of spatial variables. Explanatory variables under FSR model are assumed to be fixed while it is random in case of SSR model. Modified estimates of spatial regression coefficients were proposed following Ordinary Least Squares (OLS), Generalized Least Squares (GLS), Maximum Likelihood Estimation (MLE) and Method of Moment Estimation (MME) approaches in both model structures. It has been shown through spatial simulation, that proposed estimators are unbiased, consistent and comparatively more efficient than corresponding usual estimators. Four different approaches were followed to incorporate spatial effects in the proposed models (Jha, 2009).

A study was undertaken by Rai *et al.* (2004) in district of Lalitpur in UP due to the fact that this district has been observed to have considerable area under most of the land use classification categories. It has been observed in this study that quality of revenue records in the study area i.e. Lalitpur district is quite reliable for most of the usual nine fold classified land use classes. The statistics of land use classes were restricted to five broader classes, which can be identified by using single time digital data of Remote Sensing out of the above nine-fold classification can be easily obtained using RS. These statistics of land use classes obtained through RS could be used as auxiliary information in spatial /non-spatial models to get reliable statistics of different classes. The above models can be used to predict the statistics related to these classes for non-surveyed area/villages of the districts. Hence, it is possible to develop reliable land use statistics at any smaller level i.e. panchayat/block/tehsils using above models. In order to take into account of spatial dependence of the neighboring units, the classical sampling technique approach is being modified such that the probabilities of selecting neighboring units, once a particular unit is selected in the sample, becomes less as compared to distant areal units. The best fitted spatial model for each class of land use was found to be different, depending on the spatial distribution of the land use class patches of land in the district. The prediction of area under different land use categories covered under nine fold classification based on satellite data using spatial model seems to be quite satisfactory.

Apart from these studies numbers of research papers were published in national and international journals by the researchers of the institute. Some of the important contributions in this regard are Singh *et al.* (1992), Singh and Ibrahim (1996), Singh *et al.* (2002), Sahoo *et al.* (2005), Sahoo *et al.* (2006), Rai *et al.* (2007), Ahmad *et al*. (2007), etc.

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