Application of Geographical Information System (GIS) tools in Plant Genetic Resources Management

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Abstract

India has a rich and varied heritage of plant biodiversity, encompassing a wide spectrum of habitats. The Indian sub-continent is one of the eight centres of origin and is one of the 12 mega diversity centres of the world. India confirmed its commitment towards sustainable PGR management for global food and fodder security by becoming a party/ signatory to global conventions/ treaties. Geographical Information system can play an important role in the management of large and complex PGR datasets. The major areas in which uses of GIS described are inventorisation/mapping, exploration/collection, conservation and crop expansion strategies. GIS technology can be effectively used in planning field explorations for collecting agro-biodiversity, design and management of *in-situ* conservation sites, identify ecogeographical gaps in existing *ex-situ* germplasm collections, site identification for germplasm evaluation and regeneration; identifying geographic regions which are likely to contain specific desired traits, taxa or habitats of interest. Potential uses of Geographical Information system (GIS) tools for managing Plant Genetic Resources have been reviewed and discussed. GIS has been successfully used for diversity analysis to locate rich diversity, yield and oil quality attributes, in several annual oilseed crops in India, which are briefly discussed. Future strategies and priority areas where GIS could be integrated to enhance crop production through effective management of plant genetic resources are also discussed.

Key words: Plant genetic resources, germplasm, conservation, GIS

Plant genetic resources (PGR) are vital for crop improvement ensuring food security. They comprise the diversity of genetic material contained in traditional cultivars, modern varieties as well as crop wild relatives and other economically important plant species that can be used as food, feed, fibre, clothing, shelter, wood, timber, energy etc. These natural resources represent both the raw material used in the production of new cultivars either through classical plant breeding or through biotechnology - and are a reservoir of genetic adaptability which acts as a buffer against potentially harmful environmental and economic change. Plant genetic resources are most important for the continued existence and interests of humanity. There are currently several underutilized plant species and varieties displaying traits of interest to meet present and future needs, while the value of many other plant species is yet to be discovered.

India has a rich and varied heritage of plant biodiversity, encompassing a wide spectrum of habitats ranging from tropical rain forests to alpine vegetation and from temperate forests to coastal wetlands (Gautam 2004). The Indian sub-continent is one of the eight centres of origin (Vavilov 1950), and is one of the 12 mega diversity centres of the world with 11.9% of the world flora. India is endowed with rich PGR wealth of 49, 219 higher plant species including 5, 725 endemic species belonging to 141 genera under 47 families (Nayar 1980). Of these endemic species, 3500 are found in the Himalayan region and 1600 in the Western Ghats (Arora, 1991). The Indian region is an important centre of origin and diversity of nearly 160 domesticated plant species of economic importance, more than 350 species of their wild relatives and over 9,500 species of ethnobotanical interest. It has about 30,000-50,000 landraces of rice, pigeonpea, mango, turmeric, ginger, sugarcane, etc. and ranks seventh in terms of contribution to world agriculture. An estimated 1000 wild edible plant species are exploited by native

tribal communities. These include 145 species of roots and tubers, 521 of leafy vegetables/greens, 101 of buds and flowers, 647 of fruits and 118 of seeds and nuts (Arora and Pandey 1996). Plant genetic resources of potential value are being lost at an alarming rate due to habitat destruction, land degradation, over exploitation of water resources, forestry practices, urban expansion, changing patterns of diversity, changing social and cultural norms, and adoption of improved varieties and technologies of intensive agriculture by the farmers (Gautam 2004). A total of 3.95 lakhs of germplasm accessions are conserved in the seed bank *ex-situ*, located in National Gene Bank, New Delhi.

In view of the Convention on Biological Diversity (CBD), established in 1992, biodiversity in general including the wealth of plant genetic a resource occurring within a country has become the property with sovereign rights established to the nation concerned changing the scenario of biodiversity as human heritage. Consequently, PGR conservation, sustainable use and equitable sharing of benefits arising out of such use have become the responsibility of sovereign nations. India is a signatory to CBD and International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)(FAO, 2009). Consequently India confirmed its commitment towards sustainable PGR management for global food and fodder security. Thus India has become a partner of the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture (GPA).
A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts (*www.esri.com*). Thus, GIS is a database management system that can simultaneously handle data representing spatial objects and their attribute data. GIS can be effectively used in PGR management particularly in the areas namely a) inventorisation/ mapping, b) collection strategies, c) conservation strategies d) crop expansion strategies and e) Plant quarantine.

Inventorisation/ Mapping Strategies

Priority Action 1 of Global Plan of Action (GPA) calls for increased surveying and inventorying of plant genetic resources for food and agriculture. Datasets of PGR with attributes, identity and geo-reference data of relevant point locations are prerequisites for GIS mapping. Some of the GIS Software used for mapping is provided below.

Some GIS Software used for plant genetic resources management

Name of GIS software	Function
ArcGIS	Tools for building applications (including genetic resources management)
Biomapper	GIS tool kit to model ecological niche and habitat suitability
CLIMEX	Assess the risk of pest establishing in a new location
Degree	Spatial data infrastructures
GARP*	Predict and analyse species distribution
DIVA-GIS*	Maps of species distribution and analysis
DSSAT	Software that combines crop, soil and weather data bases into standard formats for access by crop models and application programs.
EcoSim	Null model software for ecologists
EstimateS	Statistical estimation of species richness and shared species from samples
FloraMap	Likely distribution of wild species in nature
GBIF MAPA	Species Richness Assessment (SRA)

Geo Da	Spatial data analysis
GPSphotolinker	Save location and GPS position data to a photo
gvSIG	Manage geographic information
HyperNiche	Multiplicative habitat modelling
Maxent*	Species and habitat modeling
Quantum GIS*	Spatial data analysis
S-Distance	Spatial decision support system
SAM – Spatial Analysis Macroecology	Statistical tools for spatial analysis
SPADE (Species prediction And Diversity)	Spatial data analysis

**Open source software*

GIS mapping has been successfully used in assessing biodiversity and in identifying areas of high diversity in *Phaseolus* bean (Jones et al. 1997); coconut (Bourdeix et al. 2005); wild potatoes (Hijmans and Spooner 2001); wild arachis (Jarvis et al. 2003); horsegram (Sunil et al. 2008); *Jatropha curcas* (Sunil et al. 2009); linseed (Sivaraj et al. 2009; 2012); sesame (Spandana et al. 2012), blackgram (Babu Abraham *et al*., 2010); piper (Parthasarathy et al. 2008); *Canavalia* fatty acids (Sivaraj et al. 2010); medicinal plants (Varaprasad et al. 2007); *Spondias* (Miller et al., 2006), common bean(Sheikh Sultan et al., 2014) and agrobiodiversity in general for South East coastal India (Varaprasad et al. 2008).

Collection Strategies

Germplasm exploration and collections are planned generally based on available databases of passport information. Passport information includes an identity to the collection, specific location of collection, details of habit/ habitat and other reference data. GIS can be effectively used in preparing distribution maps of species, probable location of the collection sites, gap analysis, analyzing diversity rich pockets etc. GIS can be used to link the passport database with district and state map layers to analyse what has been explored and collected and from where and what are the gaps in terms of areas to be explored and germplasm need to be collected. Thus, to plan future exploration programmes which are trait specific/region specific GIS can be used effectively (Jones et al., 1997; Greene et al., 1999). Mapping the spatial distribution of target species along with the prevailing knowledge systems of communities can be effectively carried out using GIS. Traditionally tribals/farmers have been the custodians of plant genetic resources and developed huge knowledge systems over years. These traditional knowledge systems form an integral part of the all the communities and more specifically tribal communities. Indigenous traditional knowledge associated with the plant genetic resources, their time of cultivation, system of cultivation, its relation to the environment form a vital part of the tribal system. Such systems which co-evolved with the nature provide the food and nutritional security of the tribal communities. Documentation followed by validation of such crop genetic resources related ITK would make available such secure sources of ethnic systems to be harnessed for benefit of all. GIS and other specialized computer program (e.g. FloraMap) along with associated data can be used to map the predicted distribution of plant species or areas of possible climatic adaptation of organisms in the wild (Jones et al., 2002). Also, GIS can play an important role in the management of large and complex PGR datasets (Guarino et al., 2001). Guarino (1995) discusses the use of GIS to develop strategies for collecting germplasm. For example, collection regions can be mapped to identify areas with desired ecogeographic attributes such as acid soils or climate extremes (Hart et al. 1996).

Conservation Strategies

Complementary conservation strategies include the protection of wild species, plant populations and traditional crop varieties where they have evolved (*in situ* conservation), with the collection and preservation of inter- and intraspecific diversity in gene banks and botanical gardens (*ex situ* conservation). *Ex situ* genetic resource collections maintain germplasm in the form of seed or live plants, representing current, obsolete and primitive crop varieties, wild and weedy relatives of crop species, and wild species collected or augmented from around the world. GIS can be effectively used for genetic resources conservation in the following areas:

- Identifying gaps for conservation in both *ex-situ* and *in-situ*
- Design and management of *on-farm in-situ* conservation sites

Geographical information systems (GIS), climate change models and geographical distribution data of crop plants and their wild relatives may be used to predict the impact of a changing climate on plant genetic resources (PGR), conservation and use, in various agri-horticultural crops important in Indian crop improvement programmes.

Crop Expansion Strategies

GIS can play a crucial role by way of managing large data sets, identifying suitable locations for multiplication and evaluation of germplasm introduced from other countries. Morphological descriptors/genetic variations may be linked with environmental attributes using GIS for selecting potentially useful germplasm accessions for crop expansion (Pederson *et al*., 1996). Ecological niche modelling studies on horticultural crops (Ceylon spinach, sorrel, roselle) using GIS had been worked out by Reddy et al., (2015a,b,c). Exotic germplasm of several agri-horticulutral crops (Tef, Kiwi, Olive etc.) can be introduced into suitable agro-climatic regions of our country after assessment using GIS.

Plant Quarantine Strategies

Pest monitoring and detection

- Data visualization and query
- Survey data collection, management, and analysis
- Risk and pathway analysis
    - What area has highest risk for a pest introduction?
    - Prediction models can be generated
- Change detection in case of Invasive Alien Species and others

Why should we use GIS in PQ?

- Economic benefit
- Proactive approach in safeguarding Indian Agriculture
- Quality control assistance
- Decision support system

Some Examples

- Adult grasshopper hazard analysis (in USA) – Identify patterns in grasshopper survey that may predict future population increases – Understand patterns in grasshopper survey as related to environmental conditions (i.e. climate, soil, vegetation)
- Sugarcane woolly aphid spread in south India.

- Asian Gypsy moth trapping model (in USA) - GIS to identify those areas most likely to have AGM activity – to improve and/or validate existing AGM trapping locations
- Mapping of pest distribution data (from pest interceptions of import quarantine)
- To quantify area change in Invasive Alien Species spread

GIS and Genetic Resources Management of Oilseed crops in India

Oilseed crops have been the backbone of agricultural economy of India., and important ones with major area and production are soybean, rapeseed-mustard, and groundnut. Sesame is grown throughout India across the seasons and has rich linkages with tradition, religion, culture and health of communities. The Indian oilseed scientists, sustaining the highest average productivity in the world till today, have developed castor as a cash crop. Linseed and safflower have specific niches where they are being grown for the specific value attached to the quality of oil. Niger is being grown in high altitude tribal zones. Sunflower, though an exotic crop introduced in to India, excellent hybrids developed and the crop occupied an area over 2.5 million ha till a decade back. Among the non-traditional sources of oil, rice bran and cottonseed oil share a significant portion. Pongamia and Jatropha are potential biofuel sources in India. India is one of the leading oilseeds producing countries in the world and it is a rich centre of diversity for rapeseed-mustard, sesame, safflower and niger. In the production of oils and fats, it has unique opportunities as the wide range of agro-climatic and soil types are available for cultivation of oilseed crops (Ranbir Singh, 1994). India ranks first in the world in area and production for groundnut, castor, sesame and niger; second in safflower and third in rapeseed mustard and linseed. In spite of large possibilities for cultivation, vast area and different agro-climatic conditions, we import about 50% of annual edible oils and having low productivity as compared to world average. A total of 58,574 accessions of oilseed germplasm consisting of groundnut (13,819), Brassica (11,311), Safflower (7,364), Sesame (10,148), Soybean (4,042), Sunflower (1,382) and others (10,508) are conserved in the National Gene Bank (NGB), New Delhi (www.nbpgr.ernet.in). A large number of germplasm collections have been made during the past three decades in various oilseed crops from India. Several promising accessions for various traits have been identified after characterization and evaluation. In addition to oilseed crops germplasm maintained by NBPGR, several crop specific institutes and coordinated research projects under ICAR on oilseed crops, SAUs also hold germplasm of different oilseeds. The availability of diverse agro-ecological situations and crop diversity for oil that include annual edible (soybean, rapeseed mustard, groundnut, sesame, sunflower, safflower), non-edible (castor, linseed, niger) oilseed crops and other perennial, non-traditional, minor edible, biofuel, minor perennial non-edible crops. GIS has been successfully used for diversity analysis to locate rich diversity, yield and oil quality attributes, in several annual oilseed crops (sesame, safflower, linseed, mustard) and biofuel crops (pongamia and jatropha) in India, which are briefly described below.

Sesame (*Sesamum indicum* L.) is one of the oldest oil crops and is widely cultivated in Asia and Africa. Characterization and quantification of genetic diversity has long been a major goal in evolutionary biology. Information on the genetic diversity within and among closely related crop varieties is essential for a rational use of genetic resources. Spandana et al., (2012) studied distribution and diversity of sesame (viz., plant height, inter-node length, leaves per plant, number of flowers per plant, number of capsules per plant, number of seeds per capsule, seed weight and seed yield) using GIS. The outcome of the study indicated that diverse accessions for all these traits can be sourced from Maharashtra, Gujarat and Madhya Pradesh (partly covering Chattisgarh) states and these states are diversity rich pockets for sesame germplasm in India.

Diversity analysis of 102 accessions of safflower collected from India (Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu, Bihar, Himachal Pradesh, Uttar Pradesh and West Bengal states) using DIVA-GIS was carried out by Sivaraj et al. (2012). Grid map generated using DIVA-GIS analysis of number capitula per plant indicated that a high diversity index value (2.7-3.4) for the safflower germplasm

accessions from the North-East region of Maharashtra state in India. Targeting this region for the recollection of germplasm for number of capitula per plant would be beneficial in safflower crop improvement programme.

DIVA-GIS techniques for assessing the variability in fatty acid composition of linseed germplasm for identification of potential areas and germplasm accessions rich in quality omega-3 fatty acids for conservation have been studied by Sivaraj et al., (2012). Based on DIVA-GIS diversity analysis on eighty-four accessions of linseed (*Linum usitatissimum* L.) collected from Andhra Pradesh and Maharashtra, the study indicated Kohir, Jarasangham, Nayalkal, Shankarampet and Zaheerabad which are sub-units (mandals) of Medak district and Jainoor, Koutala and Bhimni mandals of Adilabad district are potential areas for collection of diverse accessions for omega-3 content and test weight of seed.

Semwal et al., (2012) analysed 5,358 accessions of rapeseed-mustard germplasm collected during 1976–2011 through crop-specific and multi-crop explorations in collaboration with Indian Council of Agricultural Research (ICAR) crop-based institutes and State Agricultural Universities (SAUs) from different diversity rich areas of the country. The geo-referenced map of collected diversity also indicated that parts of north-western plains (mainly western Uttar Pradesh), Himachal Pradesh and Uttarakhand have been extensively surveyed for collections of *Brassica* germplasm. In addition, grid mapping technique (GIS based) was also used to know the diversity rich areas and occurrence of trait-specific germplasm of rapeseed-mustard in different parts of the country. The distribution and diversity analyses on biofuel crops viz. *Jatropha curcas* and *Pongamia pinnata* using DIVA-GIS were undertaken by Sunil et al., 2009, 2012 respectively. GIS study enabled the researchers in identifying gaps in collection and diversity richness from South East Coastal Zone of India.

The analysis of genetic variation within and among elite breeding materials is of fundamental interest to plant breeders. It contributes to monitoring of germplasm and can also be used to predict potential genetic gains. Thus, GIS play a role in assessing diversity exists among various oilseed crops. Some of the research oilseed crops where GIS could be successfully incorporated are Castor for gap analysis, collection and exploitation of wild perennial castor for the farming and non-farming communities as a source of income. High omega-3 richness and quality fibre traits of linseed need to be mapped improving and expanding area under linseed in identified areas. High oleic oil, early and high yielding traits need to be mapped in Safflower and area expansion based on length of growing period based on soil moisture and fertility mapping would be a priority area. Highest productivity in sesame is being recorded in Eastern India particularly in summer crop, hence GIS approach need to be exploited for non-traditional areas focussing on export oriented white seeded types. GIS can be effectively used in several areas of PGR management including managing oilseed genetic resources. *In-situ* on-farm and field conservation of sesame, safflower, niger, castor, linseed and other minor oil bearing tree species could be effectively handled using GIS approaches. Attempts are being made to introduce exotic species of Olive and other crops into various agro-climatic regions India after thorough analysis using GIS for crop suitability. The crop improvement programmes in oilseeds would be benefitted immensely if we successfully integrate GIS component in the research programmes.

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