ROLE OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM IN SUSTAINABLE DEVELOPMENT

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ABSTRACT

Over exploitation of available natural resources for meeting the growing demand for food, fuel and fibre of an ever-increasing population has led to serious environmental degradation. Globally, $1964.4x10^6$ ha land are affected by human-induced degradation. Of this, $1,903x10^6$ha are subject to soil erosion by water, $548.3x10^6$ ha to wind erosion, $239.1x10^6$ha to chemical deterioration, $68.2x10^6$ha to compaction and 10.5 x 10^6ha to waterlogging (UNEP, 1993). Furthermore, rapid industrialization coupled with the deforestation has led to building up of green house gases in thee atmosphere resulting in global warming. Thus, it is obvious that the environmental degradation process unless detected early and action taken to arrest or mitigate may lead to further deterioration and may affect sustainable development efforts which is key concern in Agenda 21. Sustainable development of natural resources refers to maintaining a fragile balance between productivity functions and conservation practices through identification and monitoring of problem areas and calls for optimal utilization of available natural resources based on their potentials and limitations while maintaining a good harmony with the environment.

Information on the nature, extent, spatial distribution along with the potentials and limitations of natural resources is a pre-requisite to achieve the goals of sustainable development. By virtue of providing synoptic view of fairly large area at a regular interval spaceborne multispectral measurements hold great promise in generating reliable, information on various natural resources, namely soils, mineral, surface and ground water, forest cover, marine resources, in a timely and cost-effective manner. Geographic Information System (GIS) offers an ideal environment for integrating spatial and attribute data on natural resources and environment, and for subsequent generation of optimal land use plan on a micro-watershed basis. Furthermore, Global Positioning System (GPS) enables making precise *in situ* measurements on various terrain parameters which are used for both generating baseline as well as derivative information on natural resources for various developmental activities. Advancements in weather forecasting and tele-communication further help in effective implementation of

optimal land use plans/action plans. An attempt has been made in this article to provide an overview of the magnitude of the land degradation problem, concepts of sustainable development based on conservation of land and water resources and to identify sustainability indicators and to illustrate the role of remote sensing, GIS, GPS and digital photogrammetry. A few case studies are cited on the success stories on sustainable development of land and water resources. Furthermore, the article also identifies gap areas, and projects future scenario vis-à-vis likely developments in sensor technology, data processing and interpretation/analysis and integration.

1. INTRODUCTION

Due to ever increasing pressure of population on land, the per capita arable land has been dwindling. In the year 1986, the worldwide cropped area was 1.5billion ha which was supporting the total world population of about 5 billion. The per capita arable land in 1986, thus works out to be 0.3 ha. With the increasing population pressure it has been progressively declining. By the year 2000, the per capita arable land area will decline to 0.23ha, and to 0.15ha by 2050 (Lal and Pierce, 1991).?? The problem of low land-to-people ratio is further compounded by land degradation by way of accelerated soil erosion by water and wind, salinization and / alkalization, waterlogging, compaction ; mining and depletion of organic matter. With only 55 per cent of the geographical area of the world, the developing countries carry 75 per cent of the world population which leads to over-exploitation of natural resources.

Globally, 1964.4×10^6 ha land are affected by human-induced degradation(UNEP, 1993). Of this, $1{,}903 \times 10^6$ha are subject to soil erosion by water, 548.3×10^6 ha to wind erosion, 239.1×10^6ha to chemical deterioration, 68.2×10^6ha to compaction and 10.5×10^6ha to waterlogging In addition, an estimated 3,600 million ha of global area comprising of hilly regions of the humid tropics of India , Manchurea, Korea, south-west China and Africa are under shifting cultivation (Schlippe, 1956; Conklin, 1957). In India alone, out of a 329 million ha geographical area, 150 million ha of land are affected by wind and water erosion (Anonymous, 1976). Annually, an estimated 6000 million tonnes of soil in lost through soil erosion by water (Das, 1985). Apart from this, shifting cultivation, waterlogging, and salinization and / or alkalization have affected an estimated 4.36million ha, 6million ha and 7.16million ha of land respectively (Anonymous, 1976). Frequent floods and drought further compound the problem. Degradation of by way of deforestation for timber and fuel wood, shifting cultivation and occasionally forest fire is a very serious environmental problem. Besides, another equally important aspect of the sustainability of vegetation is the bio-diversity that need to be preserved.

Exploitation, mis-management and neglect can ruin the fragile natural resources and become threat to human survival. Archaeological evidences, in fact, have revealed that land degradation was responsible for extinction of the Harappan civilization in Western India, Mesopotamia in Western Asia and the Mayan culture in Central America (Olson, 1981). In India, the deterioration of erstwhile forest ecosystem of Cherapunji, Meghalaya state of North-eastern India is an example of the devastating effects of overexploitation of natural resources. Meeting food and fibre demands in the next century will require higher productivity levels for land now in production, the addition of new land not currently in production and the restoration of degraded lands to reasonable of productivity (Pierce and Lal, 1991).

Water resources, both surface as well as ground water is very crucial for sustaining flora and fauna. Over exploitation of ground water and wastage of precipitation water as run-off are the major issues which are to be addressed in the context of sustainable development. In addition, pollution of water by mining waste, solid wastes and sewage need to be checked. Anthropogenic activities along the coast may further deteriorate the delicate coastal ecosystem. In the event of major climatic change, coastal areas are going to be affected more. In addition, exploitation of marine resources especially off-shore oil drilling and ocean water pollution due to effluents from industries, solid wastes and oil-spilled over from ships may affect the ocean environment.

World soils contain about three times more reserves of organic carbon than world vegetation -1500 billion versus 560billion metric tons, respectively (Parr et al., 1989). Soil degradation contributes to an increase in atmospheric carbon dioxide through rapid decomposition of organic matter. In addition, rapid industrialization and deforestation have led to building up of greenhouse gases in the atmosphere resulting in global warming. Carbon dioxide concentration has increased from 280ppm during 1850 to 350ppm at present. Similarly, the concentration of methane (CH_4) has increased from 0.85ppm during 1850 to 1.7ppm at present. Furthermore, chlorofluorocarbons (CFCs) with very long residence time (over 100 years) and nitrous oxide (N_2O) have further added to environmental problem. The increase in the concentration of green house gases has resulted in the average increase in the global mean temperature of 0.5K. Even with the adoption of revised Montreal Protocol regulation, the global mean temperature rise is likely to reach 3K which can result in the rise of sea level by 18-20cm, leading to recession of shoreline by 27-30m, change in rainfall pattern particularly in the tropical regions, fall in food production by about 15.0 per cent and 10.0per cent depletion of ozone (Rao, 1991). The process of this degradation, unless detected early and action taken to arrest or mitigate may lead to further environmental deterioration.

2.0 SUSTAINABLE DEVELOPMENT

Sustainable development of natural resources refers to maintaining a fragile balance between productivity functions and conservation practice through identification and monitoring of problem areas, and calls for application of alternate agriculture practices, crop rotation, use of bio-fertilizers, energy - efficient farming methods and reclamation of unutilized and under-utilized lands. Although the importance of the role of holistic and systemic approaches to solutions for large scale and complex socio-economic problems has been emphasized for many years, it does not appear to have been seriously advocated or experimented for management of natural resources. The sustainable development paradigm is built on the premise that neither of the two objectives- economic development and environmental protection - can be ignored and that an acceptable balance must be achieved between the two (Haimes, 1992). The World Commission on Environment and Development (WCED, 1987) defined sustainable development as that which meets the needs of the present without compromising the ability of future generations to meet their own needs. The Food and Agriculture Organization (1989) defined it as 'sustainable development is the management and conservation of natural resources base and the orientation of technological and institutional changes in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable'.

Since the unsustainable patterns of production and consumption in the industrialized society and developing countries have led to environmental degradation, the Governments of the different countries made a commitment to foster sustainable development at the Earth Summit of 1992 in Reo de Janeiro. Agenda 21 of the summit addresses these issues in detail and identifies the action items for sustainable development. One of the issues which is addressed in the Agenda is the conservation and management of natural resources for development. It could be achieved by planning and management of land resources, combating deforestation and conservation of biodiversity, combating desertification and drought, protection of the quality and supply of fresh water, protection of the oceans and coastal areas, rational use and development of their living resources, and protection of the atmosphere from pollution.

For sustainable development of natural resources Hurni (1997) has advocated an approach viz. sustainable land management (SLM) and is of the view that the natural resources can potentially be used in a sustainable way if appropriate land management technology, regional planning and the policy framework complement a purposeful way in accordance with the principles and concepts of each other in SLM. Sustainable land management (SLM) has been defined as "a system of technologies and/planning that aims to integrate ecological with socioeconomic and political principles in the management of land for agricultural and other purposes to achieve intra- and intergenerational equity (Dumanski, 1994; Hurni, 1996). SLM is thus, comprises of three development components, namely technology, policyt and land use planning. Following the sustainability paradigm, 'appropriate' would require that a technology follow five pillars of sustainability, namely be (i) ecologically protective (ii) socially acceptable (iii) economically productive (iv) economically viable, and (v) reduce the risk.

3.0 SUSTAINABNILITY

Sustainability refers to qualitative and quantitative continuity in the use of a resource. It implies a state of equilibrium between human activities as influenced by social behavior, acquired knowledge and applied technology, on one hand, and the food production on the other (Farshad and Zinck, 1993). Sustainability could be defined in elementary terms by (Gallopin, 1996) :

$$\nu(O_{t+1}) \geq \nu\,(O_t)$$

Where ν is a value function of the outputs of the system. There are several perspectives of sustainability, namely economic, ecological, social and an optimum mix of ecological and economic perspective Sustainability attempts not only to address global issues, such as resource degradation, deforestation and ozone layer depletion, but also local issues, such as maintenance of eco- and socio-eco-systems or a combination of these. Sustainability of natural resources depends on their resilience and carrying capacity. Resilience refers to how easily a soil can recover lost functions or restore the balance among functions (Warkentin, 1995). Further, resilience of land when under stress due to inadequate management is, in fact, central to sustainability. In agro-ecosystems resilience has been defined as "The ability of a disturbed system to return after new disturbance to a new equilibrium (Blum and Santelises, 1994). Central to the concept of resilience in agricultural system is the soil architecture and its recovery after damage. Carrying capacity refers to the maximum number of a population that can continue to live at a pre-defined level of well-being and in a limited area without causing irreversible changes in the environment, so that its living conditions deteriorates and its growth declines (Farshad and Zinck, 1993).

There are several perspectives of sustainability, namely economic, ecological, social and an optimum mix of ecological and economic perspective. From ecological view point, sustainability may be defined as "an increasing trend in production over time per unit consumption of the non-renewable or limiting resources or per unit degradation of soil and environmental characteristic. The dominantly economically oriented perspective puts more emphasis on economic aspects. Natural resources are either disregarded or only marginally taken into account (Ikerd, 1990). The role of such factors of production as the availability of natural resources and environmental services, but also that of environmental impacts as products of economic activity are neglected. In the eco-friendly economic development perspective, the ecological equilibrium is taken as norm and the focus is mainly on building up a pattern and a rate of resource use which the environment can sustain indefinitely (Wilkinson, 1973). Lastly, the social perspective lays more emphasis on continued welfare of the society. The role of economic - demographic interrelationship is either explicitly or implicitly referred to.

4.0 SUSTAINABILITY INDICATORS

Quantification of sustainability is essential to objectively assess the impact of management systems of actual and potential productivity, and environment. However, sustainability is a concept and can not be measured directly. Appropriate indicators must, therefore, be selected, tested, and validated to determine levels and duration of sustainable land management. Sustainability indicators are needed to monitor progress and to assess the effectiveness and impact of policies on natural resources development. An ideal indicator should be unbiased, sensitive to changes, predictive, referenced to threshold values, data transformable, integrative and easy to collect and communicate (Liverman et al.,1988). One such indicator is land quality indicator which includes nutrient balance, yield trend and yield gaps, land use (agrodiversity) and land cover (Dumanski,1997).

Sustainability can be assessed one or several indices. Although, general principles may be the same, these indices must be fine-tuned and adapted under local environments. Some of the indices of sustainability are as follows:

(i) Productivity (p) - Production per unit resource used can be assessed by(Lal,1994).

$$P=p/R$$

Where P is productivity, p is total production, and R is resource used.

(ii) Total Factor of Productivity (TFP) - It is defined as productivity per unit cost of all factors involved (Herdt,1993) and could be expressed as

$$TFP = \frac{p}{\Sigma^n (Ri \times Ci)}$$

where p is total production, R is resources used, and C is cost of the resources and n is the number of resources used in achieving total production.

(iii) Sustainability coefficient (Cs) which is dynamic and is problem or mission-oriented is another indicator of sustainability. There are three basic systems, natural human-made and interface. One such proposed coefficient for a human-made system may be as follows(Lal,1991) .

Cs = f(Oi,Od, Om)t

where Oi =Output per that unit input that maximizes the per capita productivity or profit
Od = Output per unit decline in the most limiting or non-renewable resource
Om = Minimum assured output
t = time

The exact nature of the function may be site-specific and will need input from local empirical research data. For a natural system the sustainability coefficient (Cs), mentioned above, could be modified to account for the role of human being and could be written as (Rao and Chandrashekhar,1996).

Cs = f (Oi,Od,Om,HDI)t

where HDI=Human Development Index.

Further, in case of a interface system also the HDI becomes very important modulating factor for deriving sustainability indices. Conceptually, it can be formulated as (Rao and Chandrashekhar,1996).

Cs = f (Oi,Od,Om)t. HDI

[Human Development Index (HDI) is a composite index of achievements in basic human capabilities in three fundamental dimensions - a long and healthy life; knowledge and decent standard of living (UNDP,1996)· Three variables have been chosen to represent these three dimensions - life expectancy, educational attainment and income. The longevity is measured by life expectancy at birth, educational attainment is measured by a combination of adult literacy (two-third weights) and combined primary, secondary and tertiary enrolment ratios (one-third weight); and weight of living as measured by real GDP per capita (PPP$).

For computation of index fixed minimum and maximum values have been established for each of these indicators.

Life expectancy at birth	:	25 years and 85 years
Adult litracy	:	0 per cent and 100 per cent.
Combined enrolment ratio	:	0 per cent and 100 per cent
Real GDP per capita (PPP$)	:	PPP$ 100 and PPP$ 40,000

For any component of the HDI, individual indices can be computed using the following formula:

$$\text{Index} = \frac{\text{Actual xi value - minimum xi value}}{\text{Maximum xi value - minimum xi value}}$$

The HDI is a simple average of life expectancy index, educational attainment index and the adjusted real GDP per capita (PPP$) index. It is calculated by dividing the sum of these three indices by three.]

For human-made system dominated by agricultural farming, the model conceptualizes a positive feed back mechanism between Q_1 and Q_2 which could be expressed in a simple form as (Rao et al.,1995).

Q_1-Q_2 > 0 Unsustainable development

Q_1- Q_2 = 0 Sustainable development

Q_1- Q_2 < 0 Virgin eco-systems (Protected bio-reserves)

Where Q_1 = Production in energy units and includes the emission of CO_2, transport of moisture through evapo-transpiration and transport of nutrients
Q_2 = Consumption in terms of energy units CO_2, H_2O and nutrients from the atmosphere or external sources.

A fragile balance between production processes (Q_1 energy units) and consumption practices (Q_2 energy units) ensures compatibility between supportive and assimilative capacity of a region.

5.0 ACHIEVING SUSTAINABILITY

Over exploitation of natural resources, as pointed out earlier, has led to land degradation of varying degrees. In order to achieve sustainability of our natural resources, efforts need to made to prevent further deterioration of degraded lands, therefore, to employ appropriate soil and water conservation measures to arrest soil loss and conserve soil moisture for vegetation growth, to restore and improve soil fertility, followed by adoption of suitable soil and water management practices to maintain soil fertility in the long run.

For preventing soil degradation alley cropping – raising fast growing trees between broad beds of field crops to develop conditions similar to the recycling system of the original forest ecosystem need to be practiced. Arresting soil loss from severely eroded lands under cultivation, on the other hand, could be achieved by switching over to fallowing for at least 10 years period from existing annually tilled crops. Such a practice allows regeneration of the resource base. In developing countries, the major constraints ton achieve sustainability include lack of required agricultural inputs owing to poor economic conditions, fragmentation of holdings, population pressure preventing long fallowing (10 years or more) of cultivated marginal lands undergoing degradation.

Managing the non-crop period especially before onset of monsoon where soil erosion is very severe, is a key to sustainable development. Such a practice aims at minimizing undesirable material flows from agro-ecosystems. The noncrop period is to be used to increase the diversity and complexity of agroecosystems . Cover crops could be seeded during the life cycle of existing crop to serve ecologically important functions including erosion control, suppression of pests, alteration of pest cycle, and fixation and bio-cycling of nutrients.

There are, however, several constraints, namely agroecologic, agronomic, technologic, social, economic, institutional and political on achieving sustainable development. Constraints occur mostly at two levels i.e. the farm level, where application takes place, and the policy-making level, where many of the application conditions are set in. At the farm level for example, sustainability is controlled not only by the limited resources of the production unit but also by national and international policies (e.g. the General Agreement on Tariff and Trade). Policy making, in turn, is conditioned by global programmes (e.g. Agenda 21 and birth control programmes).

6. INTEGRATED ASSESSMENT

Hitherto, the natural resources, namely minerals, groundwater, soils, vegetation/ forest cover and surface water have been assessed and treated individually for their optimal utilization. Since most of these resources are interdependent and co-exist in nature, they need to be considered collectively for their optimal utilization. This fact has led to the development of the concept of integrated assessment of natural resources. Integrated assessment can be defined as an interdisciplinary and participatory process of combining, interpreting and communicating knowledge from diverse scientific disciplines to allow a better understanding of complex phenomena. The aim is to describe the entire cause-effect chain of a problem so that it can be evaluated from a synoptic perspective. Integrated assessment has two characteristics: (i) it should provide added value compared to single disciplinary assessment; and (ii) it should offer decision-makers useful information (Rotmans and Dowlatabadi ,1996).

Attempts have been made in India, for the first time, to integrate the information on various natural resources, namely soils, ground water, surface water, land use/land cover and forest cover derived from remote sensing data, with the socio-economic and other ancillary data in a GIS environment to generate locale-specific action plan on a watershed basis for sustainable development under a unique remote sensing application project, 'Integrated Mission for Sustainable Development (IMSD)' covering about 84.00million ha and spread over in 175 districts. The project aims at generating thematic maps on various natural resources like soils, groundwater, surface water, land use / land cover / forest cover at 1:50,000 scale from the Indian Remote Sensing Satellite (IRS-1) Linear Imaging Self-scanning Sensor (LISS-II) data and integrating them in a GIS environment to generate locale-specific action plan on a watershed basis for sustainable development. The locale -specific action plan recommended under this project is based on certain assumptions. In case these assumptions do not hold good due to unforeseen changes in the climatic conditions, lack of expected cooperation from the people, the anticipated results may not be achieved.

7.0 ROLE OF REMOTE SENSING AND GIS

As mentioned earlier, information on the nature, extent, spatial distribution, and potential and limitations of natural resources is a pre-requisite for planning the strategy for sustainable development. In addition, socio-economic and meteorological, and other related ancillary information is also required while recommending locale-specific prescriptions for taking up curative or preventive measures. By virtue of providing synoptic view of a fairly large area at a regular interval, spaceborne multispectral data have been used at operational level for generating base line information on mineral resources, soils, ground water and surface water, land use/land cover, forests, etc. at scales ranging from regional to micro level i.e. 1:250,000 to 1:12,500 scale and monitoring the changes, if any, over a period of time. Beginning with the Landsat-MSS data with a 60X80m spatial resolution and four spectral bands spanning from green to near infrared in early seventies, the natural resources scientists had access to Landsat-TM data with a 30m spatial resolution and seven spectral bands spread over between blue and thermal infrared region of the electromagnetic spectrum in early eighties which helped further refinement and generation of thematic information at a larger scale. Further, high spatial resolution HRV-MLA and PLA data with 20m and 10m spatial resolution, respectively from SPOT series of satellite in later half of eighties have supplemented the effort of generating information on natural resources.

The indigenous effort on design and development of satellites and sensors led initially to the launch of Indian Remote Sensing Satellite (IRS-1A and B), carrying Linear Imaging Self-scanning Sensors (LISS-I and II) with the spatial resolution comparable with those of Landsat MSS and TM, respectively in late eighties and early nineties. Further development in the sensor technology had resulted in the launch of the state-of-the-art satellite (IRS-IC) in December, 1995 with an unique combination of the following three sensors:

Wide Field sensor (WiFS) with 188m spatial, two spectral bands - red and near infrared, 810km swath and a repetivity of 5 days.

Linear Imaging Self-scanning Sensor (LISS-III) with 23.5m spatial resolution in the green red and near infrared region, and 70.5 m in the middle infrared region, and 140 km swath,

Panchromatic (PAN) camera with 5.8m spatial resolution, 70km swath and stereo capability.

While WiFS with 5-day repetivity and large swath provides a regional level monitoring of crop condition assessment, LISS-III multispectral sensor with 140 km. swath provides detailed level crop acreage estimation and crop condition assessment. PAN data with 5.8m spatial resolution and stereo capability enables appreciation of terrain's relief. Merging LISS-III data with PAN offers additional advantage of exploiting both spectral information from LISS-III and high spatial resolution from PAN for such applications as geomorphological mapping, soil resources mapping and terrain analyses. The uniqueness of these sensors lies in the fact that all the sensors with regional and local level coverage are mounted on the same platform and collect data under similar illumination conditions thereby avoiding the need for radiometric normalization. The IRS-1D with the similar payload as of IRS-1C was launched in March,1997 as a back-up of latter.

Further, the development of launch vehicles especially Polar Satellite Launch Vehicle (PSLV) has enabled India, launching three experimental satellites, namely IRS-1E in September, 1993, IRS-P2 in October 1994 and IRS-P3 in March, 1996. The IRS-P3 has two payloads namely Wide Field Sensors (WiFS) same as the one aboard IRS-1C/1D, and Modular Electro-optical Scanner (MOS) with 13 channels spanning from blue to middle infrared region of the electromagnetic spectrum.

For visual interpretation, the standard false colour composite (FCC) prints generated from green, red and near infra-red bands have been used. However, special products with varying combination of spectral bands have also been tried out for certain specific applications. For instance, red, near infrared and shortwave infrared combination has been found to help improved delineation of lithological boundaries - an important element in soil resources mapping.

Apart from supervised classification of digital multispectral data, new classification algorithms like fuzzy logic, artificial neural network, etc have been developed which help refining the information generated on natural resources using Gaussiun maximum likelihood per-pixel classifier. Further, using advanced image fusion techniques like Intensity, Hue and Saturation (IHS) transformation, further refinement in the information on natural resources could be made. Similarly, for monitoring changes that have taken place either due to developmental programmes or land degradation, image differencing and principal component analysis provide more objective assessment of such changes.

Hitherto, only optical sensor data with a few broad spectral bands have been used to generate base line information on natural resources. The hyperspectral remote sensing with a potential to provide diagnostic capability of some natural features like minerals, vegetation, etc will help refining the information generated on natural resources.

Imaging the terrain in the presence of smoke, haze and cloud cover has been the major limitation of the optical sensor data. Microwave data with day-and-night observation; and cloud/haze/smoke penetration capability hold very good promise for generating information on crop coverage, floods, etc. during monsoon season. The polarimetric images generated from microwave energy with different polarization provide further insight into structure and flouristics of vegetation, soil properties and parent material (Skidmore et al.,1997). Further, radar interferometry is yet another tool that enables generating DEM which allows monitoring glaciers, volcanic eruption, mine subsidence, mudslips, etc.

Integration of information on natural resources, socio-economic and climatic conditions and other related ancillary information in a holistic manner for prescribing locale-specific intervention for a given area is very crucial. Geographic Information System (GIS) offers the capability of integrating such spatial and attribute data and subsequent generation of action plan/developmental plan for sustainable development. The GIS has been used in a variety of applications, namely database development and changes in the aquatic environment (Remilard and Welch, 1993), modeling of non- point source pollution (Welch et al, 1993), database design for a multiscale spatial information system (Jones et al.1996), assessment of surface and zonal models of population (Martin,1996), military housing management (Forgionne et al. 1996), multiple criteria group decision making (Malczewski,1996),etc. Further, remote sensing and GIS have been used conjunctively in several studies for addressing issues related to developmental planning(Trotter,1991; Smith and Blackwell,1980; Welsh et al.,1992; Hellden et al.,1982).

8.0 INDIAN EXPERIENCE

Having realised the importance of integrated approach for sustainable development, the Department of Space, Government of India in collaboration with the State Governments had initiated pilot studies in 21 districts covering 203,000 sq. km. and representing diverse terrain, agro-climatic conditions and social and cultural practices apart from very often affected by drought, in the year 1987, to find scientific and lasting solution to mitigate drought following the unprecedented drought in many parts of the country during the period 1985-87. Based on encouraging results of the pilot projects, such study was extended to another 153 districts covering 549,496 sq. km. spread over in 25 states at the instance of Planning Commission, Govt. of India - the highest policy decision making body, under a national project titled "Integrated Mission for Sustainable Development (IMSD)". A conceptual framework of IMSD is given in Fig.-1. For ease of implementation of the action plan in phased manner in these selected districts, initially it was decided to identify a priority block in each district for the study. (A block is an administrative unit covering an area ranging from 1000-1500 sq. Km.). Subsequently, 80 blocks spread over in 80 districts and covering 85,339 sq. km. have been selected on a priority basis for taking up such study.

8.1 DATABASE

For generating information on land and water resources, the Linear Imaging Self-scanning (LISS-II) data from Indian Remote Sensing Satellite (IRS-1A/1B) in the form of False Colour Composite (FCC) prints at 1:50,000 scale and digital data in the form of Computer Compatible Tape (CCT) were used in conjunction with the ancillary information, namely published reports, thematic maps, etc. and adequate field check. Information on slope has been derived from 1:50,000 scale Survey of India topographical maps. For appreciation of climate of the area, meteorological data available with the India Meteorological Department/respective district or *taluk* (an administrative unit) headquarters were made use of. Besides, information on demographic and socio-economic conditions were taken from the published records by the concerned departments.

8.2 APPROACH

A holistic approach involving generation of thematic maps on land and water resources and their integration with the socio-economic and other ancillary information was employed to arrive at locale-specific prescription for sustainable development land and water resources. Various steps involved are described hereunder :

8.2.1 Generation of Thematic Maps

To begin with, the watershed boundaries were taken from the published Watershed Atlas (All India Soil and Land Use Survey,1990). Further divisions within each watershed in terms of sub-watershed, mini- watershed, and micro-watershed were made following the guidelines laid down by the All India Soil and Land Use Survey (1991). Thematic maps on hydrogeomorphological condition, soil resources and present land use/land cover have been generated through systematic visual interpretation and/digital analysis of IRS-IA/B LISS-II multispectral data with 36.25m resolution in conjunction with the collateral information supported by adequate ground truth. The information, thus derived, on lithology of the area and geomorphic features therein was used to infer ground water potential of each lithological unit based on geomorphic features and recharge conditions. Soil resources map of the area was prepared by delineating sub-divisions within each geo-morphic units based on erosion status, land use/land cover and image elements, namely colour, texture, shape, pattern, association, etc. Soil composition of each geomorphic unit was defined by studying the typical soil profiles in the field and classifying them upto series level according to Soil Taxonomy (U.S. Department of Agriculture, 1998) based on morphological characteristics and chemical analyses data. In addition, derivative maps, namely land capability and land irrigability were generated from the information on soils and terrain conditions based on criteria laid down by All India Soil and Land Use Survey (1970). Besides, land use/land cover maps were prepared using monsoon (*kharif*) and winter (*rabi*) crop growing seasons and summer period satellite data, and single-cropped and double-cropped areas apart from other land use/land cover categories were delineated. Furthermore, micro watersheds and water bodies were delineated and the drainage network have also been mapped.

Slope maps showing various slope categories were prepared based on contour information (20m contour interval) available at 1:50,000 scale Survey of India topographical maps. Road network and the location and extent of settlements were also taken from topographical sheets. Demographic and socio-economic data were analysed to generate information on population density, tribal population, literacy status, economic backwardness and the availability of basic amenities.

8.2.2 Generation of Action Plan

Generation of action plan involves a careful study of thematic maps on land and water resources both individually as well as in combination to identify various land and water resources regions termed as Composite Land Development Units (CLDU), and their spatial distribution, potential and limitations for sustained agriculture and other uses; and development of an integration key. The first step was accomplished by superimposing individual thematic map over each other manually and identifying CLDUs. This could also be done by digitizing/ scanning all the thematic maps and studying them subsequently in a GIS environment. Each CLDU was then studied carefully with respect to potentials / limitations of various natural resources and socio-economic and climatic conditions and a specific land use and/soil and water conservation practice are suggested. Subsequently, taking landform as a base an integration key in terms of potential/limitations of soils, present land use/land cover, and ground water potential; and suggested alternate land use/action plan was developed.

8.2.3 Implementation of Action Plan

The action plan and/alternate land use practices emerging from aforesaid approach are implemented in part of the watershed by the implementing agencies in the district depending on availability of funds. The state-of-the-art technology available for each action item i.e. activity to develop land and water resources of an area, is used in order to fully exploit the contemporary research and developments in the field of agriculture, science and technology. While implementing the action plan, the aspiration of the local people obtained through a process called Participatory Rural Appraisal (PRA) is given utmost importance. Initially, a micro watershed of 500 – 1,000ha is identified by the district/block authorities based on developmental priority and the operational aspects of each activity under action plan is studied carefully. Since most of the land except for common land/government land, belongs to cultivators/individuals, for implementation of action plan information on each land holding which is available in cadastral maps (large scale village maps) is required. For this purpose, cadastral map boundaries were digitized/scanned and overlaid onto satellite data. The individual field where a specific action plan is recommended could be identified by superimposing action plan map over digitized/scanned cadastral maps. The progress of the implementation is monitored by an expert committee constituted by the state government for each state/district.

8.3 IMPACT ASSESSMENT

After implementation of suggested action plan for land and water resources development, the area undergoes transformation which could be monitored regularly using satellite data and in situ observations. Such an exercise not only helps studying the impact of the programme but also enables resorting to midcourse correction, if required. Parameters included under monitoring activities are land use/land cover, extent of irrigated area, vegetation density and condition; fluctuation of ground water table, well density and yield, cropping pattern and crop yield, occurrence of hazards and socio-economic conditions. Included under land use/land cover parameters are: changes in the number and areal extent of surface water bodies, spatial extent of forest and other plantations, wastelands and cropped area. The vegetation density and vigor have been assessed using vegetation index (VI) generated from IRS -1A/-1B LISS-II or IRS-1C/-1D LISS-III data.

9. A CASE STUDY

In order to demonstrate the approach, an example of such an approach used in a watershed in the semi-arid region of southern India is presented here. The Pitlam watershed was selected for the study owing to its low (897mm) and erratic rainfall, recurring drought, land degradation, poor irrigation facility and poor literacy). Covering an area of 17,218ha, the test site lies between $18^0 10'$ to $18^0 17'$ N and $77^0 35'$ to $77^0 45'$ E and forms parts of Pitlam block (an administrative unit) of Nizamabad district of Andhra Pradesh, Nanded district of Maharastra. Lithologically, the are comprises of granite-gneissic complex and basalt. Most of the area comprises of denudation slope and lower plateau which is interspersed with burried pediplain, mesa inselberg and pediment. The area is drained by the river Nallavagu and its tributaries.

9.1 Land and Water Resources

For generating information on land and water resources IRS-1B LISS-II data in the form of False Colour Composite (FCC) prints at 1:50,000 scale acquired during October, 1992, and February and May, 1993 was were used following the approach described in the Section 8.2. Denudation slope, plateau, pediplain, buried pediplain-shallow and medium, pediment, mesa and inselberg , as mentioned earlier, comprise the geomorphic units (Fig.- 2). While inselberg, mesa, pediments favour more run-off, the buried pediplain and plateau with considerable thickness of weathered material are favourable for groundwater development. Denudation slopes, inselbergs and mesas have, however, poor to nil ground water potential. Coarse loamy Lithic Ustorthents and Loamy-skeletal Typic Ustochrepts; Fine Vertic Ustochrepts and Fine loamy Typic Ustochrepts, and Fine Udertic Ustochrepts and Fine loamy Udic Ustochrepts comprise the major soil categories of the watershed (Fig.-3). Owing to rugged and slopy nature terrain, shallow and gravelly soils, fairly large area of the watershed is not supporting crops.The *kharif* is the major crop and covers an estimated 7,289ha comprising 42.33% of the watershed (Fig.-4). The *rabi* crop is, however, taken wherever assured irrigation through ground water /tank is available and covers1049ha(Fig.-4). The area under double crop is only 308ha or 1.79% of the total area. Further, an equally large area (8,250ha) comprising

48.38% of the watershed is essentially lying barren except for some scrubs at places.

9.2 Collateral Information

The collateral information includes the information on slope, aspect, altitude and socio-economic conditions. As mentioned earlier, the information on slope was generated from topographical sheets by taking 20m contour interval as a base. Most of the area except for mesa, inselberg and pediment is very gently to gently sloping whereas a few pockets of nearly level lands occur in the buried pediplain (Fig.-5).

9.3 Action Plan

The information on land and water resources of the watershed, thus generated, enables the policy makers and administrators having an overview of the potentials and limitations of the natural resources of entire watershed and eventually helps identifying potential and critical areas requiring detailed investigation. Based on information on land and water resources, terrain attributes like slope, aspect, altitude, quantum and distribution of rainfall, an integration key was developed after scanning the spatial data on land and water resources on a CONTEX FSS 800 black and white and white scanner, and studying them in a GIS environment using ARC/INFO software, along with collateral information, for generation of optimal land use plan for sustainable development of the watershed.

For optimal utilization of available land and water resources, intensive agriculture has been recommended in the buried pediplain with fine–textured moderately deep to deep soils with good to moderate ground water potential. Whereas fuelwood and fodder plantation has been recommended in 3,198ha of land comprising 18.57% of the watershed for providing protective cover to denudational slope with coarse-textured, shallow and gravelly soils; agro-forestry/rain-fed agro-horticulture/horticulture has been proposed in 9,299ha of land covering28.38% of the test site following soil conservation measures in the lower plateau with moderately deep to deep black soils (Fig.-6).

Soil erosion by water is one of the major problems. In order to arrest soil loss and run-off check dams with suitable soil conservation measures like vegetative bunding, construction of check walls across gullies have been advocated (Fig.-7). Such check dams not only help arresting soil loss but contribute significantly to groundwater recharge. In addition, the construction of percolation tanks has also been recommended at suitable locations which are exclusively meant for groundwater recharge.

10. CONCLUSIONS

Sustainable development aims at maintaining the balance between often conflicting ideals of economic growth and nurturing environmental quality and viability. Remote sensing provides a sound data base for generating baseline information on natural resources, a pre-requisite for planning and implementation , and monitoring of any developmental programme. GIS offers an ideal environment for integration of spatial and attribute data on natural resources for formulating the developmental plan of an area taking into account social, cultural and economic needs of the people. The digital elevation model(DEM) generated from the measurements made by Global Positioning System(GIS) through digital photogrammetric approach enable further refining the developmental plans.Creation of digital database on natural resources for Indian sub-continent under a national project titled "National(Natural) Resources Information System(NRIS)" is, in fact, a major step forward in this direction. The developmental plans, thus formulated, could be implemented through participatory Rural Appraisal(PRA) programme.

Despite tremendous development in sensor technology, data processing and analysis/interpretation techniques, certain specific inputs such as, development of GIS-based land evaluation models for land capability, land irrigability, suitability of land for a specific usage, development of cadastral - level action plan, risk analysis in the event of certain assumptions are not satisfied, objective impact assessment using space technology, development of ecological models to project future developmental scenario, etc. could not be addressed. Hyperspectral data from MODIS aboard EOS mission, high spatial resolution data from recently launched IKONOS-II and future earth observation missions, namely Cartosat-1, Resourcesat, Cartosat-2, Quickbird, Eyeglass, EROS-A and B, and Orbview, etc. may enable generating cadastral-level optimal land use plan or action plan for sustainable development of land and water resources. Such a database would also enable objective monitoring of the developments resulting from implementation of the action plan.

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