Scientific endeavours for natural resource management in India

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Natural resource management (NRM) based on scientific principles plays a crucial role for an inclusive and sustainable growth in India. The shrinking per capita natural resources leads to intensive land use and results in further environmental degradation. This calls for developing agroecoregion-specific land-use plans based on homogeneity in soil, water and climatic features in a particular region and managing a particular land unit on watershed basis involving the local community. This article consolidates information on the science-based efforts made by the Government of India through various scientific establishments and science-led development schemes for NRM over time. Despite the existence of a number of institutions for NRM research, there is hardly any coordination across the Departments and Ministries. The missing links in NRM research are discussed in this article keeping in view the emphasis of the government and the importance of natural resources in promoting inclusive and sustainable growth in India.

Keywords: Land degradation, matural resources, soil and water conservation, watershed management.

THE importance of natural resources, comprising land, water and vegetation, is higher than ever before for the need to ensure sustainability in the face of changing climate, increased biotic pressure and declining resource productivity. Economic growth can be inclusive only if the natural resources are sustainably managed. Recognizing the national imperatives for sustainable use of natural resources across varied ecosystems, the Approach Paper to the 12th Five-Year Plan has included a separate chapter on 'Sustainable management of natural resources'. The Approach Paper aptly notes that 'Economic development will be sustainable only if it is pursued in a manner which protects the environment. With acceleration of economic growth, these pressures are expected to intensify, and we therefore, need to pay greater attention to the management of natural resources, viz. water, forests and land.'

With only 2.4% of the world's land area, India is home to 16% of the world human population and contributes immensely to global biodiversity with about 8% of total number of species[1]. India is recognized as a mega biodiverse country and has four identified bio-hotspots, viz. the Himalaya hotspot, the North East of India, the rainforests of the Western Ghats and the Andaman & Nicobar Island chain. According to the livestock census of 2003, the country has about 485 million livestock population and 489 million poultry population, being the first in cattle and buffalo population, second in respect of goat and third in respect of sheep population in the world. India has 57% of the world's buffalo and 16% of the world's cattle population. This means there is not only human population but also livestock population pressure on the shrinking natural resources. Though India is bestowed with 4% of the world's freshwater resources, the distribution is highly skewed across regions. The Ganga–Brahmaputra–Meghna basin with 33% of the land mass has 60% of total water flows, while the western coastline with 3% of the area has another 11%. This leaves just 29% of water resources in the remaining 64% of the area (peninsular India), thus keeping most of peninsular India water-starved compared to other parts of the country[2].

Land degradation continues to be a threat to the food and nutrition security of the country. According to the latest estimate by the Indian Council of Agricultural Research (ICAR), New Delhi and National Academy of Agricultural Sciences (NAAS), out of total geographical area of 328.73 m ha, about 120 m ha (37%) is affected by various kinds of land degradation[3]. This is based on a harmonized database prepared from integration and streamlining of the land-based and remotely-sensed data on the status of degraded and wastelands. A harmonized database was essential in view of the widely differing estimates made earlier by different agencies such as the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP); National Remote Sensing Centre (NRSC), Hyderabad; Ministry of Agriculture (MoA), New Delhi; National Wasteland Development Board, etc. The recent estimate has an edge over the earlier ones in terms of

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usability by the development agencies to decide the reclamation measures on the basis of delineated classes. According to the latest estimate, the primary causal factor of land degradation is water and wind erosion (94.87 m ha), followed by soil acidity (17.93 m ha), sodic soils (3.71 m ha), soil salinity (2.73 m ha), waterlogging (0.91 m ha), and mining and industrial waste (0.26 m ha). The topsoil is most vulnerable to erosion, the loss of which causes depletion in quantity as well as quality of soil. About 1 mm of topsoil is lost every year in the country due to soil (water) erosion at an average rate of 16.4 tonnes/ha/year against the permissible limit of 4.5–11.2 tonnes/ha/year. This results in over 5.3 billion tonnes of soil being lost annually due to soil erosion, causing the loss of around 8 million tonnes (mt) of plant nutrients every year[4,5].

Research infrastructure for NRM

The research network for natural resource management (NRM) is being run primarily by three separate agencies of Government of India, viz. MoA, Ministry of Environment and Forests and Department of Space (DoS).

Research establishments for erosion control and rainfed area management

Soil erosion is primarily caused by water and wind. Soil erosion by water (water erosion) is a three-step natural process involving three basic steps of detachment, transport and deposition. The rainfall and run-off erosivity are the two factors deciding the level of soil erosion by water. Rainfall erosivity is the intrinsic capacity of rain to cause erosion. The major factors deciding the rainfall erosivity are amount, intensity and drop size of rain. The soil loss due to water erosion is measured experimentally through standard size run-off plots and sampling the run-off through different devices such as multi-slot divisors. In watershed scale, run-off is measured through stage-level recorders and measuring the silt content through silt samplers such as Coshocton wheel silt sampler. As run-off measurement is tedious and particularly in large areal scale, estimation of soil loss is usually attempted through empiricial models by combining the processes and factors which contribute to erosion over a catchment scale. The Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith[6,7] is the most popular, easy to use and mostly used for estimation of soil loss by taking into account the rainfall erosivity, soil erodibility, topography and soil cover and management practices. It was developed after decades of soil erosion experiments by university faculty and federal scientists across USA. As a complete technology, it was first published in 1965 in the USDA Agriculture Handbook 282 and later an updated version was published in 1978 in the USDA Agriculture Handbook 537. It estimates the long-term average annual rate of erosion on a field slope and includes the erosion taking place due to sheet and rill erosion. It does not take into account the additional soil loss taking place due to other factors such as gully erosion and tillage erosion. Despite subsequent modifications, the USLE has been the most commonly used empirical model for soil loss estimation globally.

The soil erosion control measures recommended are based on three basic scientific principles: (1) Reducing the hitting action of the raindrop where it falls, through increasing the soil cover. (2) Reducing the run-off velocity through barriers such as contour bunds, graded bunds, stone bunds, vegetative barriers of grasses, establishing hedge row barriers of shrubs such as of *Gliricidia* spp., *Indigofera* spp. The methods depend on the degree of land slope. In higher slopes with land slope varying from 6% to 33%, terracing is recommended where the slope length is broken to a number of terraces. (3) Taking up measures such as increase in soil organic matter content, soil structure improvement, cover and green manure crops, etc., which allow more water to infiltrate down the soil profile rather than generating high run-off volume.

The ICAR under the MoA, New Delhi through its Division of Natural Resource Management has been taking up basic, applied and action-oriented (field-based) research programmes to develop technologies for conservation of natural resources for various ecosystems of the country. For conducting research on conservation of soil and water and particularly to control water erosion, a full-fledged ICAR institute, namely the Central Soil and Water Conservation Research and Training Institute (CSWCRTI) was established on 1 April 1974 with its Headquarter at Dehradun by combining seven Soil and Water Conservation Research, Demonstration and Training Centres of Government of India. These Centres were established in the 1950s at Dehradun (Himalayan region), Kota (ravines of Chambal River), Bellary (deep black soils of low rainfall region), Udhagamandalam (Ooty, for high rainfall southern region and Nilgiri hills), Vasad (ravines of Chambal River), Agra (ravines of Yamuna River) and Chandigarh (Shivalik region), representing different ecosystems prone to different land-degradation processes. These centres were transferred to ICAR on 1 October 1967. Subsequently, two new Research centres were added to CSWCRTI, one at Datia, Madhya Pradesh (1986) to tackle soil and water conservation problems of Bundelkhand region, and another at Koraput, Odisha (1992) to address the problems of areas practicing shifting cultivation. The Institute works on evolving strategies for controlling land degradation following watershed approach, tackling special problems such as ravines, landslides, mine spoils and torrents, demonstration of technologies for popularization and imparting training besides developing technologies for water harvesting and recycling. The first estimate of soil erosion of

India was given[4] by CSWCRTI in 1983 based on the annual soil loss data of 20 land resource regions, sediment loads of some rivers, rainfall erosivity for 36 river basins and 17 catchments of major reservoirs of the country.

The contributions of CSWCRTI are noteworthy in respect of the development of technologies for watershed management and demonstration of successful watershed management programmes. In fact, considering the importance of watershed-based NRM, experimental watersheds were set up for generating watershed-based protection and production technologies way back in 1956. However, the watershed concept was operationalized from 1974 onwards by CSWCRTI through four Operational Research Projects (ORPs) at Sukhomajri (Haryana), Nada (Chandigarh), Fakot (Tehri-Garhwal, Uttarakhand), and G.R. Halli (Chitradurga, Karnataka). After realizing tremendous tangible and intangible benefits from these watersheds, ICAR developed 47 model watersheds in 16 states in collaboration with State Agricultural Universities and State Departments[8]. Encouraged by the success of the model watersheds in 1991, the MoA conceived a massive National Watershed Development Programme for Rainfed Areas (NWDPRA) for conservation and sustainable development in 29 states.

In view of the fact that the arid zone covers about 12% of the country's geographical area and occupies over 31.7 m ha of hot desert and about 7.0 m ha under cold desert, in 1959 ICAR established the Central Arid Zone Research Institute (CAZRI) at Jodhpur to conduct research and development technologies for wind erosion control and arresting desertification processes, and to develop arid land-management technologies and sustainable farming system models for the arid ecosystemss[9]. At present, about 12.4 m ha area suffers from wind erosion problems[3]. CAZRI originated as a Desert Afforestation Station in 1952, later upgraded to Desert Afforestation and Soil Conservation Station in 1957 followed by upgradation to an ICAR Institute in 1959. Currently, the Institute also has five regional research stations at Bhuj, Pali, Jaisalmer, Bikaner and Leh.

In India, about 57% of net cropped area is rainfed, contributing only about 44% to the total foodgrain production because of a series of socio-economic problems such as low cropping intensity, intra- and inter-seasonal variability in rainfall, poor adoption of modern technology, low crop yield, inadequate public investment, and incidence of rural poverty. However, rainfed regions contribute more than 90% of pulses and about 80% of oilseeds production in the country. It is said that the possibility of a second green revolution can be better explored from the rainfed areas. Also, development of rainfed areas contributes to balanced regional development with minimal inter-regional imbalances. Realizing the importance of rainfed regions, the Central Research Institute for Dryland Agriculture (CRIDA) under ICAR was established in Hyderabad during 1985, to work on development and popularization of suitable location-specific rainfed technologies for productivity enhancement in rainfed areas. CRIDA works along with 25 coordinated project centres located in different parts of the country.

Research establishments for soil fertility and soil salinity studies

Excessive use of chemical fertilizers, combined with low use of organic inputs and irrational irrigation management have affected the productive soil adversely. This has caused a reduction in soil productivity, decrease in partial factor productivity of major plant nutrients (nitrogen, phosphorus and potassium) and reports of deficiency of several plant micronutrients, apart from being the leading cause for land and environmental degradation such as eutrophication and groundwater pollution. Therefore, the future gains of enhancing food production in a sustainable manner can essentially be realized through the generation and adoption of more appropriate nutrient and water management technologies that are based on basic and sound strategic research information. In view of the growing importance of enhancing and sustaining productivity of soil resources, in 1988 ICAR established the Indian Institute of Soil Science at Bhopal to conduct basic and strategic research with a mandate to 'provide scientific basis for enhancing and sustaining productivity of soil resource with minimal environmental degradation'[10].

Similarly, to cater to the problems of soil salinity and to suitably manage saline and alkali soils, and develop technologies for using poor-quality irrigation water in different agroecological zones of the country, the Central Soil Salinity Research Institute (CSSRI) is working at Karnal since 1969. The Institute was established as a follow-up to the Government of India appointed Indo-American Committee constituted to assist ICAR to develop a comprehensive water management programme for the country. The Institute has also three regional research centres at Canning town, West Bengal to look into the problems of coastal salinity; Lucknow, Uttar Pradesh (for salinity arising from surface drainage congestion, high water table and indurated pans in the central and eastern Gangetic plains), and Bharuch, Gujarat (to cater to the problem of inland salinity in heavy soils in the western parts of the country). The Institute has developed technologies for the reclamation of alkali soils with the addition of chemical amendments, reclamation of saline soils through subsurface drainage, development and release of salt-tolerant crop varieties of rice, wheat and mustard and the reclamation of salt-affected soils through salt-tolerant trees. The basic principle behind reclamation of alkali or sodic soils is through leaching the sodium (Na) salts as Na_2SO_4. This is done by adding gypsum ($CaSO_4 \cdot 2H_2O$) to the sodic soil so that Na_2SO_4 is formed, which is soluble and thus leached down from the root zone profile.

As such, nearly 1.5 m ha salt-affected land has been reclaimed and put to productive use. It has been estimated that reclaimed area is contributing more than 15 mt foodgrains to the national pool. For waterlogged saline soils, subsurface drainage technology developed by the Institute initially for Haryana has been widely adopted and replicated in Rajasthan, Gujarat, Andhra Pradesh, Maharashtra and Karnataka. About 60,000 ha waterlogged saline areas have been reclaimed using this technology[11].

Research establishments for water management

The Central Water Commission (CWC) and the Central Ground Water Board (CGWB) are the two key agencies of the Ministry of Water Resources, Government of India. The CWC coordinates schemes for control, conservation and utilization of water resources throughout the country for flood control, irrigation, hydropower generation, etc. The CGWB provides scientific inputs for management, exploration, monitoring, assessment, augmentation and regulation of groundwater resources of the country. Major activities being taken up by CGWB include macro/micro-level groundwater management studies, exploratory drilling programmes, monitoring of groundwater levels and water quality through a network of groundwater observation wells comprising both large diameter open wells and purpose-built bore/tube wells (piezometers), implementation of demonstration schemes for artificial recharge and rainwater harvesting for recharge augmentation. Periodic assessment of replenishable groundwater resources of the country is also carried out by the Board jointly with the concerned State Government agencies. The Board also takes up special studies on various aspects of groundwater sector such as groundwater depletion, sea water ingress, groundwater contamination, conjunctive use of surface and groundwater, water balance, etc. It also organizes various capacity-building activities for its own personnel and those of Central/State Government organizations engaged in various activities in groundwater sector as well as mass awareness campaigns on the importance of water conservation and judicious groundwater management. The data generated from various studies taken up by the CGWB provide a scientific base for water resource planning by stakeholders. Besides advising states and other user agencies on planning and management of groundwater resources, the CGWB also provides technical know-how for scientific groundwater exploration, development and management to various stakeholders[12].

Irrigation accounts for 80% of India's total water usage. Further, 60% of irrigation water and 80% of rural drinking water come from groundwater. Thus, water management in agriculture to a large extent can solve the freshwater crisis in India. To develop water-use efficiency in different agricultural production systems, the Directorate of Water Management, Bhubaneswar (under ICAR) was established in 1988. Abiotic stress coupled with changing climate adversely affects agriculture production across the country. To take up high-end research programmes employing latest technologies such as biotechnology, nanotechnology, remote sensing, information technology and polymer sciences, in 2008 the National Institute on Abiotic Stress Management was established at Baramati, Pune.

Research establishment for forest and vegetation

Forests are considered a national wealth and have a pervasive impact on micro-climate regulation and maintaining soil, water and environmental quality. In India, the Forest Research Institute (FRI), Dehradun is the premier institution with thrust areas on biodiversity conservation, social forestry and agroforestry, stock improvement of different tree species, restoration of ecologically fragile and risk-prone areas and developing technologies for mine-spoil areas and wastelands.

Use of space science in NRM

Space science, particularly remote sensing technology, has been effectively used in India for natural resources appraisal, survey, monitoring and management. Towards this end, the Indian Space Research Organization (ISRO), Bengaluru has established a network of centres with specific mandates. ISRO-based National Remote Sensing Centre (NRSC) located at Hyderabad has the primary responsibility of providing earth observation (EO) data from space and aerial platforms to users and capacity building of the users for utilization of the EO data. The Indian Institute of Remote Sensing, Dehradun has the mandate for capacity building and development of trained professionals in the field of remote sensing (RS), geoinformatics and global positioning system (GPS) technologies for NRMs. The Space Applications Centre (SAC), Ahmedabad also works on applications of space technology for societal benefits, including disaster monitoring, environment monitoring and natural resources survey. There are also Regional Remote Sensing Centres under ISRO such as Northeastern Space Application Centre (NESAC), Shillong and under some state governments for applications of space science in NRM activities in their respective regions.

To make use of the high-end geospatial information and technology such as RS, GPS and geographical information system (GIS) in conjunction with conventional methods for NRM, environmental monitoring and disaster management on a larger (regional) scale, in 1983 the Planning Commission, Government of India established the National Natural Resource Management System

(NNRMS). DoS is the nodal agency for NNRMS. There are ten focus areas of NNRMS, including agriculture and soils, bio-resources and environment, geology and mineral resources, ocean resources, rural development, urban areas and meteorology.

Government programmes for NRM

Watershed-based planning for NRM has been the major focus in the recent past because of the scientific basis underlying in the 'watershed' concept. Hydrologically, watershed refers to a land area having a single drainage outlet. However, it is also a social and biological entity having similar land, climate and water resource conditions. Thus watersheds are an integral unit for development and environmental planning purposes. Depending upon the areal scale, it can be called as milli-watershed, micro-watershed, catchment or basin, though for effective rural development programmes, micro-watersheds are considered as a single unit consisting of one or more village habitations. The integrated watershed management approaches consider the participation of the stakeholders for optimum development of land, water and biological resources to meet the basic needs of human and animals in a sustainable manner. Depending upon the land situation, the three basic principles of soil erosion control, viz. reducing the hitting action of raindrops, reducing the velocity and volume of run-off, are employed through location-specific suitable measures so as to achieve optimum productivity without much degradation to soil, water body and environment.

For effective planning and management of natural resources, Government of India launched several programmes to be implemented on watershed basis during various plan periods, through two nodal Ministries, MoA and the Ministry of Rural Development – the Department of Land Resources (DoLR). The first such scheme was the 'River Valley Projects (RVP)', launched in 1962–63 by the MoA, followed by the 'Flood Prone Rivers (FPR)' scheme in 1980–81 for integrated watershed management in the catchments of flood-prone rivers. Also during the period, success stories of integrated watershed management were demonstrated by ICAR-based CSWCRTI at Sukhomajri (pioneered by P. R. Mishra) and Ralegaon Siddhi (pioneered by Anna Hazare). The launch of the National Watershed Development Programme for Rainfed Areas (NWDPRA) in 1990, covering 99 districts in 16 states was a major milestone achieved by the MoA. Simultaneously, the MoA implemented the Watershed Development Programme for Shifting Cultivation Areas (WDPSCA) scheme in the states affected by shifting cultivation. However, to make the watershed management schemes participatory and ensure sustainability and equity, the NWDPRA guidelines were revised to WARASA-JAN SAHABHAGITA Guidelines. Since April 2013, all the watershed management programmes of the MoA, i.e. RVP, FPR, NWDPRA, WDPSCA and other schemes have been included under one umbrella called Macro Management of Agriculture (MMA).

The other nodal department, i.e. DoLR has implemented three major programmes of watershed management, viz. Drought Prone Areas Programme (DPAP), Desert Development Programme (DDP), and Integrated Wasteland Development Programme (IWDP). The DPAP was launched during 1972–73. The DDP was started in 1977–78 as a special programme for hot desert areas of Rajasthan, Gujarat and Haryana and cold desert areas of Jammu & Kashmir and Himachal Pradesh. However, all the three have been merged to a single programme called Integrated Watershed Management Programme (IWMP) since 2009–10. The main objectives of IWMP are to restore the ecological balance by harnessing, conserving and developing degraded natural resources such as soil, vegetation cover and water. This enables multi-cropping and the introduction of diverse agro-based activities, which help provide sustainable livelihoods to the people residing in the watershed areas.

Need for agroecoregion-specific NRM

Being a vast country, India has a wide range of climate, soil and vegetation and thus the importance of regional development based on uniformity in natural resource endowments. A sustained regional development is possible only if the land use and regional development plans are based on relatively homogenous edaphic (soil) and bio-climatic conditions. In this context, NBSS&LUP, Nagpur has divided the whole country into 20 agro-ecological regions (AERs) and 60 agro-ecological subregions (AESRs)[13,14] based on uniformity in soil, bio-climate, physiography and length of conducive moisture availability periods (length of crop growth period). The AESRs have further been divided into agro-eco units at the district level for developing long-term land-use strategies. The AER and AESR-based classification permits land use based on land capability and thus arrests soil and environmental degradation.

A recent publication of ICAR[3] has identified the different categories of degraded lands in the 20 AERs of the country. This is a major gain for the development agencies and policy makers to select most efficient reclamation technologies for restoration of degraded lands in a particular AER.

Missing links

The research establishments for NRM research in the country spread across different Departments and Ministries of Government of India have developed a number of useful technologies and generated sufficient database over time. However, few missing links need to be considered.

1. Weak network: NRM research is essentially multidisciplinary in nature. Hence there should be an established network and coordination among the public-funded research organizations cutting across the various Departments and Ministries engaged in NRM research. The network should be mandatory for the research organizations so that mutual data transfer and multidisciplinary investigations can be possible without unnecessary repetition.

2. Need for scientific database: The generated scientific data from public-funded research needs to be archived by each organization and the archive should be accessible to all the public-funded research organizations engaged in NRM research. This will help the researchers in strengthening the research objectives and also in preparing collaborative studies without much procedural obstacles in getting generated data.

3. Regular monitoring and appraisal of natural resources is essential to develop appropriate planning. The land degradation statistics is reported by various agencies with different figures by adopting different methodologies and monitoring is not done at regular periodicity. It is essential to develop a sound methodology using the conventional and the remotely sensed data by involving NRSC, ICAR, Wasteland Development Board and the other user agencies, in a common platform and develop a framework for monitoring at a fixed time interval, say 10 years.

4. Soil quality monitoring: Though most of the estimates on land degradation report the degraded and wasteland statistics, no report is available on the status of soil quality, at least for crop production. The depletion in soil quality is a type of hidden hunger to agricultural growth and may not be visible to be classified as a degraded land till the soil becomes fully exhausted. The efforts required to bring back a depleted soil is much higher than those for a depleting soil. Thus there should be an effort to develop soil quality indices and monitor the soil quality at regular time intervals so as to plan appropriate land-use measures that ensure maintaining soil productivity and allow the soil to perform optimum soil functions and provide ecosystem services.

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