Ganga River Basin Management Plan - 2015

Mission 4: Sustainable Agriculture

January 2015

by

Consortium of 7 "Indian Institute of Technology"s (IITs)

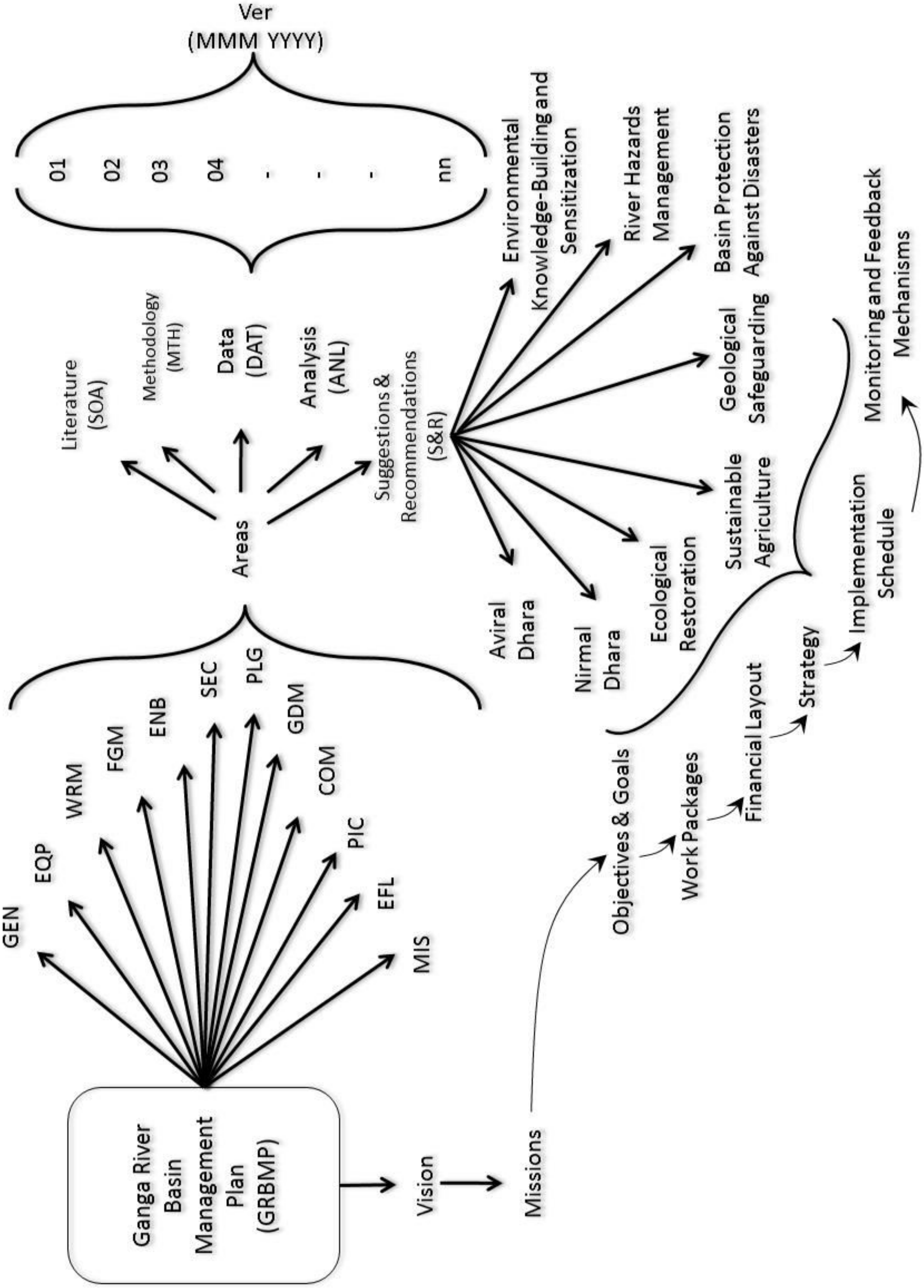
IIT Bombay | IIT Delhi | IIT Guwahati | IIT Kanpur | IIT Kharagpur | IIT Madras | IIT Roorkee

In Collaboration with

IIT BHU | IIT Gandhinagar | CIFRI | NEERI | JNU | PU | NIT-K | DU

NIH Roorkee | ISI Kolkata | Allahabad University | WWF India

GRBMP Work Structure



Preface

In exercise of the powers conferred by sub-sections (1) and (3) of Section 3 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government constituted the National Ganga River Basin Authority (NGRBA) as a planning, financing, monitoring and coordinating authority for strengthening the collective efforts of the Central and State Government for effective abatement of pollution and conservation of River Ganga. One of the important functions of the NGRBA is to prepare and implement a Ganga River Basin Management Plan (GRBMP). A Consortium of seven "Indian Institute of Technology"s (IITs) was given the responsibility of preparing the GRBMP by the Ministry of Environment and Forests (MoEF), GOI, New Delhi. A Memorandum of Agreement (MoA) was therefore signed between the 7 IITs (IITs Bombay, Delhi, Guwahati, Kanpur, Kharagpur, Madras and Roorkee) and MoEF for this purpose on July 6, 2010.

The GRBMP is presented as a 3-tier set of documents. The three tiers comprise of: (i) Thematic Reports (TRs) providing inputs for different Missions, (ii) Mission Reports (MRs) documenting the requirements and actions for specific missions, and (iii) the Main Plan Document (MPD) synthesizing background information with the main conclusions and recommendations emanating from the Thematic and Mission Reports. It is hoped that this modular structure will make the Plan easier to comprehend and implement in a systematic manner.

There are two aspects to the development of GRBMP that deserve special mention. Firstly, the GRBMP is based mostly on secondary information obtained from governmental and other sources rather than on primary data collected by IIT Consortium. Likewise, most ideas and concepts used are not original but based on literature and other sources. Thus, on the whole, the GRBMP and its reports are an attempt to dig into the world's collective wisdom and distil relevant truths about the complex problem of Ganga River Basin Management and solutions thereof.

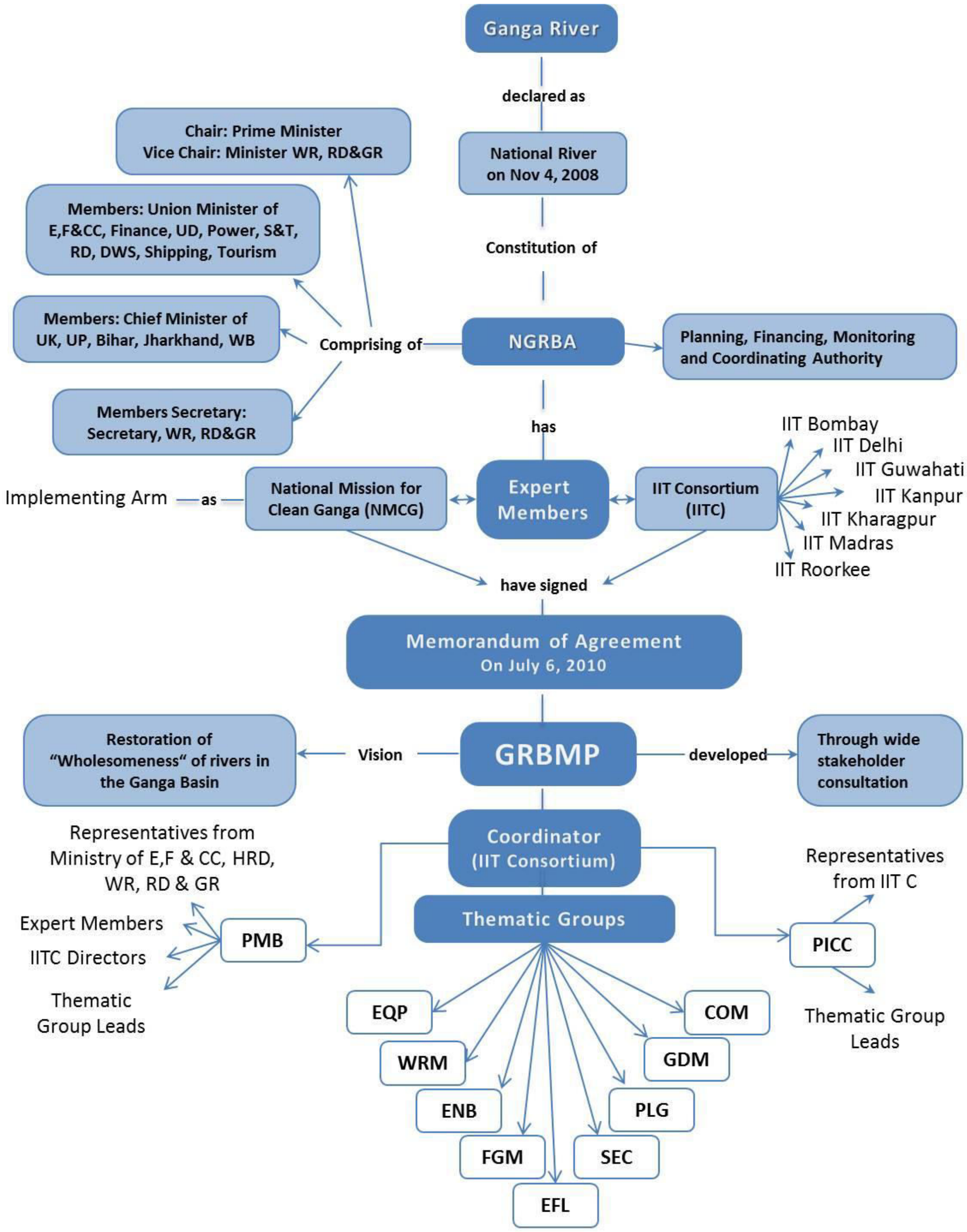
Secondly, many dedicated people spent hours discussing major concerns, issues and solutions to the problems addressed in GRBMP. Their dedication led to the preparation of a comprehensive GRBMP that hopes to articulate the outcome of the dialog in a meaningful way. Thus, directly or indirectly, many people contributed significantly to the preparation of GRBMP. The GRBMP therefore truly is an outcome of collective effort that reflects the cooperation of many, particularly those who are members of the IIT Team and of the associate organizations as well as many government departments and individuals.

Dr Vinod Tare
Professor and Coordinator
Development of GRBMP
IIT Kanpur

Authors

Vinod Tare (vinod@iitk.ac.in), Gautam Roy (gautamwho@gmail.com) and
S P Singh (singhfhs@iitr.ac.in)

Organizational Structure for Preparing GRBMP



NGRBA: National Ganga River Basin Authority
NMCG: National Mission for Clean Ganga
MoEF: Ministry of Environment and Forests
MHRD: Ministry of Human Resource Development
MoWR, RD&GR: Ministry of Water Resources, River Development and Ganga Rejuvenation
GRBMP: Ganga River Basin Management Plan
IITC: IIT Consortium
PMB: Project Management Board
PICC: Project Implementation and Coordination Committee

EQP: Environmental Quality and Pollution
WRM: Water Resources Management
ENB: Ecology and Biodiversity
FGM: Fluvial Geomorphology
EFL: Environmental Flows
SEC: Socio Economic and Cultural
PLG: Policy Law and Governance
GDM: Geospatial Database Management
COM: Communication

Project Management Board [PMB]

Expert Members:

- Sri Swami Avimukteshwaranand Saraswati
- Dr Madhav A Chitale
- Dr Bharat Jhunjhunwala

Project Implementation and Coordination Committee [PICC]

Representatives from IIT Consortium:

- Dr Shyam Asolekar, IIT Bombay
- Dr A K Mittal, IIT Delhi
- Dr Mohammad Jawed, IIT Guwahati
- Dr Vinod Tare, IIT Kanpur
- Dr D J Sen, IIT Kharagpur
- Dr Ligy Philip, IIT Madras
- Dr I M Mishra, IIT Roorkee

Thematic Group Leads:

- Dr Purnendu Bose, Environmental Quality and Pollution (EQP)
- Dr A K Gosain, Water Resources Management (WRM)
- Dr R P Mathur, Ecology and Biodiversity (ENB)
- Dr Rajiv Sinha, Fluvial Geomorphology (FGM)
- Dr Vinod Tare, Environmental Flows (EFL)
- Dr S P Singh, Socio Economic and Cultural (SEC)
- Dr N C Narayanan and Dr Indrajit Dube, Policy Law and Governance (PLG)
- Dr Harish Karnick, Geospatial Database Management (GDM)
- Dr T V Prabhakar, Communication (COM)

Composition of Thematic Groups

1. Environmental Quality and Pollution (EQP)

Lead: Purnendu Bose, IIT Kanpur

Members: Shyam R Asolekar, Suparna Mukherjee (IIT Bombay); A K Mittal, A K Nema, Arun Kumar, T R Sreekrishanan (IIT Delhi); Ajay Kalmhad (IIT Guwahati); Saumyen Guha, Vinod Tare (IIT Kanpur); A K Gupta, M M Ghangrekar, Sudha Goel (IIT Kharagpur); Ligy Philip, Mukesh Doble, R Ravi Krishna, S M Shivnagendra (IIT Madras); A AKazmi, B R Gurjar, Himanshu Joshi, Indu Mehrotra, I M Mishra, Vivek Kumar (IIT Roorkee); Anirban Gupta (BESU Shibpur); P K Singh (IIT BHU); Rakesh Kumar (NEERI Nagpur); S K Patidar (NIT Kurukshetra); Sanmit Ahuja (ETI Dynamics, New Delhi)

2. Water Resources Management (WRM)

Lead: A K Gosain, IIT Delhi

Members: Rakesh Khosa, R Maheswaran, B R Chahar, C T Dhanya, D R Kaushal (IIT Delhi); Subashisa Dutta, Suresh Kartha (IIT Guwahati); Shivam Tripathi, Gautam Rai, Vinod Tare (IIT Kanpur); Anirban Dhar, D J Sen (IIT Kharagpur); B S Murty, BalajiNarasimhan (IIT Mdras); C S P Ojha, P Perumal (IIT Roorkee); S K Jain (NIH, Roorkee); Pranab Mohapatra (IIT Gandhi Nagar); Sandhya Rao (INRM, New Delhi)

3. Fluvial Geomorphology (FGM)

Lead: Rajiv Sinha, IIT Kanpur

Members: Vinod Tare (IIT Kanpur); Vikrant Jain (IIT Gandhi Nagar); J K Pati (Allahabad University); Kirteshwar Prasad, Ramesh Shukla (Patna University); Parthasarthi Ghosh, Soumendra Nath Sarkar, Tapan Chakarborty (ISI Kolkata); KalyanRudra (WBPCB); S K Tandon, Shashank Shekhar (University of Delhi); Saumitra Mukherjee (JNU Delhi)

4. Ecology and Biodiversity (ENB)

Lead: R P Mathur, IIT Kanpur

Members: A K Thakur, Vinod Tare (IIT Kanpur); Utpal Bora (IIT Guwahati); M D Behera (IIT Kharagpur); Naveen Navania, Partha Roy, PruthiVikas, R P Singh, Ramasre Prasad, Ranjana Pathania (IIT Roorkee); Sandeep Behera (WWF-India)

5. Socio Economic and Cultural (SEC)

Lead: S P Singh, IIT Roorkee

Members: Pushpa L Trivedi (IIT Bombay); Seema Sharma, V B Upadhyay (IIT Delhi); P M Prasad, Vinod Tare (IIT Kanpur); Bhagirath Behera, N C Nayak, Pulak Mishra, T N Mazumder (IIT Kharagpur); C Kumar, D K Nauriyal, Rajat Agrawal, Vinay Sharma (IIT Roorkee)

6. Policy Law and Governance (PLG)

Lead: N C Narayanan, IIT Bombay and IndrajitDube, IIT Kharagpur

Members: Shyam Asolekar, Subodh Wagle (IIT Bombay); Mukesh Khare (IIT Delhi); Vinod Tare (IIT Kanpur); Deepa Dube, Uday Shankar (IIT Kharagpur); G N Kathpalia, ParitoshTyagi (IDC, New Delhi)

7. Geo-Spatial Database Management (GDM)

Lead: Harish Karnick, IIT Kanpur

Members: N L Sharda, Smriti Sengupta (IIT Bombay); A K Gosain (IIT Delhi); Arnab Bhattacharya, Kritika Venkatramani, Rajiv Sinha, T V Prabhakar, Vinod Tare (IIT Kanpur)

8. Communication (COM)

Lead: T V Prabhakar, IIT Kanpur

Members: Purnendu Bose, Rajiv Sinha, Vinod Tare (IIT Kanpur)

9. Environmental Flows (EFL)

Lead: Vinod Tare, IIT Kanpur

Members: Shyam Asolekar (IIT Bombay); A K Gosain (IIT Delhi); P M Prasad, R P Mathur, Rajiv Sinha, Shivam Tripathi (IIT Kanpur); M D Behara (IIT Kharagpur); B S Murthy, N Balaji (IIT Madras); Pranab Mohaparta, Vikrant Jain (IIT Gandhinagar); S K Jain (NIH Roorkee); Nitin Kaushal (WWF-India, New Delhi); Sandeep Behera (NMCG, MoWR, RD & GR, New Delhi); A P Sharma K D Joshi (CIFRI, Barrackpore); Ravindra Kumar (SWaRA-UP); Ravi Chopra (PSI, Dehradoon); Paritosh Tyagi, (IDC, New Delhi)

Abbreviations and Acronyms

1.	FAO	:	Food and Agricultural Organisation.
2.	GRBMP	:	Ganga River Basin Management Plan.
3.	IFDC	:	International Fertilizer Development Center.
4.	IITC	:	IIT Consortium.
5.	MOA	:	Ministry of Agriculture.
6.	MoEF	:	Ministry of Environment and Forests.
7.	MoEFCC	:	Ministry of Environment, Forests & Climate Change
8.	MoWR	:	Ministry of Water Resources (Govt. of India).
9.	MoWRRDGR	:	Ministry of Water Resources, River Development & Ganga Rejuvenation
10.	NGRBA	:	National Ganga River Basin Authority.
11.	NMCG	:	National Mission for Clean Ganga.
12.	NPK	:	Nitrogen, Phosphorous, Potassium.
13.	NRGB	:	National River Ganga Basin.
14.	NRGBMC	:	National River Ganga Basin Management Commission.
15.	SOM	:	Soil Organic Matter.
16.	SRI	:	System of Rice Intensification.
17.	UNEP	:	United Nations Environment Programme.

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Summary

The Ganga River Network was adopted as the primary indicator of health of the National River Ganga Basin (NRGB) in GRBMP, and human-technology-environment aspects were factored in to assess the basin's resource dynamics. Modern agricultural practices have been major causes of soil degradation and fertility loss, pollution of water bodies and natural resource depletion in NRGB. Hence transition to sustainable agriculture is urgently needed to maintain NRGB's ecosystem services. Though arable land is a limiting constraint in NRGB, NRGB's agricultural growth almost quadrupled in forty years since the 1960s by adopting high-yield crops with high fertilizer and water inputs. But extensive use of water, chemical fertilizers and pesticides, soil tillage, and mono-cropping have increased soil erosion and degradation, depleted soil nutrients and biodiversity, dwindled the basin's waters, and polluted its ecosystems. The main agricultural reforms recommended in NRGB are therefore identified as follows: (1) Adoption of Conservation Agriculture (involving no tillage, crop diversification, and permanent organic soil cover) to enhance long-term soil fertility and agricultural output, especially in degrading lands. (2) Adoption of Organic Farming where economically feasible. (3) Improved water and nutrient management techniques in rice cultivation. (4) Promoting other resource conservation technologies wherever possible. (5) Resource use optimization by extensive soil testing for balanced management of nutrients and soil amendments. (6) Promoting regional (landscape-scale) resource conservation measures to mollify agroecosystem impacts. (7) Infusing experimentation, adaptability and flexibility in NRGB's agricultural practices. (8) Devising appropriate policy measures to achieve the above goals within the existing socio-cultural, economic and institutional framework.

1. Introduction

Indian civilization grew up under the care of River Ganga, nourished by her bounties for thousands of years. The Ganga river – along with her many tributaries and distributaries – provided material, spiritual and cultural sustenance to millions of people who lived in her basin or partook of her beneficence from time to time. To the traditional Indian mind, therefore, River Ganga is not only the holiest of rivers and savior of mortal beings, she is also a living Goddess. Very aptly is she personified in Indian consciousness as "MOTHER GANGA". This psychic pre-eminence of River Ganga in the Indian ethos testifies to her centrality in Indian civilization and her supreme importance in Indian life.

The Ganga river basin is the largest river basin of India that covers a diverse landscape, reflecting the cultural and geographical diversity of the India. It is also a fertile and relatively water-rich alluvial basin that hosts about 43% of India's population [*MoWR, 2014*]. It is fitting, therefore, that the Indian government declared River Ganga as India's **National River** in the year 2008. But the declaration was none too early. River Ganga had been degrading rapidly for a long time, and national concern about her state had already become serious in the twentieth century. It was against this backdrop that the Ministry of Environment and Forests (Govt. of India) assigned the task of preparing a Ganga River Basin Management Plan (GRBMP) to restore and preserve National River Ganga to a "Consortium of Seven IITs". The outcome of this effort – the GRBMP – evolved an eight-pronged action plan, with each prong envisaged to be taken up for execution in mission mode.

A river basin is the area of land from which the river provides the only exit route for surface water flows. For understanding its dynamics, a basin may be viewed as a closely-connected hydrological-ecological system. Hydrological connections include groundwater flow, surface runoff, local/ regional evapotranspiration-precipitation cycles and areal flooding, while ecological links are many and varied (such as the food web and transport by biological agents). These linkages provide for extensive material transfer and communication between the river and her basin, which constitute the functional unity of a river basin. Directly and indirectly, therefore, National

River Ganga (along with her tributaries and distributaries), is a definitive indication of the health of the basin as a whole. Hence, GRBMP adopted the Ganga River Network as the primary environmental indicator of the National River Ganga Basin (NRGB).

River basin management needs to ensure that a basin's natural resources (biotic and abiotic) are adequately preserved over time. The main abiotic (or physical) resources of a river basin are *soil* and *water*, along with a multitude of minerals and compounds bound up with them. Now, water is a highly variable resource. Barring variations from year to year, the water in a basin follows an annual cycle of replenishment (primarily through atmospheric precipitation and groundwater inflows) and losses (primarily through river and groundwater outflows, evaporation, transpiration, and biological consumption). In contrast to water, formation of mature soils – from the weathering of parent material (rocks) to chemical decomposition and transformation – is a drawn-out process that may take hundreds or thousands of years [*Jenny, 1994; Wikipedia, 2014*]; but, once formed, soils can be fairly durable. Thus, changes in a basin's water resource status tend to be relatively faster and easily detected, while those of soils are slow and often go unnoticed for long periods. However, soil and water are affected by each other through many biotic and abiotic processes. Being thus interrelated, degradation of either soil or water has a concurrent effect on the other, hence neither can be considered in isolation.

It is not only soil and water that are mutually interactive, living organisms also interact with them and help shape the basin's environment. The biotic resources of a basin consist of plants, animals and micro-organisms. Since biota evolve over time to achieve a stable balance in a given environment, the biotic resources depend on the constituent ecosystems of the basin – rivers, wetlands, forests, grasslands, etc. However, with significant human activity in many ecosystems (as, for example, in agro-ecosystems and urban ecosystems), the complexity of human-technology-environment systems has increased manifold in recent times [*Pahl-Wostl, 2006*]. Nonetheless, GRBMP attempts to incorporate the interactive resource dynamics and human-technology-environment considerations in the Basin Plan. For, with human activities multiplying and diversifying in the basin, the resulting environmental consequences have also been pronounced in recent times. In sum, GRBMP focuses on the basin's overall resource environment and the major factors affecting it (especially diverse anthropogenic activities), and seeks ways and means to protect the basin and its resources against identifiable adverse impacts. For, only thus can we secure the environmental foundation of NRGB for the good of one and all.

2. Objective

The objective of Mission "Sustainable Agriculture" is to ensure that agriculture remains environmentally sustainable in NRGB, i.e. agricultural productivity can remain sufficiently high and enduring without fouling or depleting the natural resources of the basin.

3. Why Sustainable Agriculture is Important for Ganga River Basin Management

Soil and water are the main physical resources of a river basin that support all life in the basin. Over the last several millennia, human civilization has been increasingly using these resources in agriculture to sustain and expand human communities. Thus, if shifting cultivation needed 2–10 ha of land to feed a person and early floodplain-based agricultural societies used 0.5–1.5 ha, modern agriculture needs only about 0.25 ha to feed each person, with the world's most intensively farmed regions using just 0.1–0.2 ha to support a person [*Montgomery, 2007*]. India is among such "most intensively farmed" regions in the world. The total area under cropland in India was nearly 190 million ha in 2000 [*MOA, undated*], indicating a per capita cropland of only about 0.18 ha. If one considers only the sown area, the area would be even less – about 0.14 ha per capita. More significantly, India accounts for only about 2.4% of the world's geographical area and 4 % of the world's water resources, but supports about 17% of the world's human population [*MOA, undated; MoWR, 2008*]. Thus, with respect to world averages, India's per capita water availability is only about 23% and per capita land availability is just 14%. In NRGB (*which occupies about 26% of India's land area, hosts about 43% of her population, and has about 28% of her water resources, vide GRBMP – Main Plan Document*) the corresponding figures are more telling – only about 16% for water and 8-9% for land. Thus, in terms of global averages, not only is water a meagre resource, but land – and hence soil – is an even more critical resource. This double constraint underlies the overwhelming difficulty in sustaining agricultural productivity in NRGB.

Sustainable agriculture integrates environmental viability, economic profitability and social equity [*IITC, 2014*]. But, among these three aspects, environmental sustainability is the most important, since the latter two goals are contingent upon it. Now, as noted by Montgomery [*2007*], "*conventional agriculture has dramatically increased soil erosion around the world. … With global agricultural soil erosion outpacing soil production by a wide margin, modern conventional agriculture is literally mining soil to produce food. ... (Moreover) soil productivity involves nutrient budgets, not just soil loss. Ecologically productive soils, those with more soil microorganisms and organic matter, can support greater plant growth.*" Thus, apart from soil erosion, regular tillage and the extensive use of chemical fertilizers and pesticides have affected soil fertility by debilitating soil's nutrient cycles and leading to progressive soil degradation. In water-constrained areas, increased crop water use has also led to water crises in many parts of the region. While these issues are global, the extreme land and water constraints of NRGB's agriculture have speeded up the degradation of its agricultural lands, with eroded soils and nutrients running into the Ganga river network and seriously affecting the rivers and other ecosystems. Thus, there is an urgent need to devise and promote appropriate sustainable agricultural practices to protect the basin and its agricultural lands from any further damage.

4. Status of NRGB's Agro-ecosystems

An agroecosystem is an interactive group of biotic and abiotic components, only some of which are under human control. Agroecosystems are intentionally disturbed ecosystems that, through human influences, are forced into states different than the natural systems from which they are derived [*Elliot and Cole, 1989*]. The change in the state of an agroecosystem is essentially due to change in the state of its soils. The effect of modern agricultural on soils has been negative in many ways, with alarming soil erosion and land degradation in many parts of the world. Globally, the rate of soil erosion from conventional agricultural lands is estimated to average 1.54

(±0.32) mm/year whereas the rate of soil formation is only about 0.075 (±0.05) mm/year [*Parikh, 2011*]. Additionally, deterioration of soil properties has led to many types of soil degradation.

In India, a large area of about 120.40 million ha (out of India's total geographical area of 328.73 million ha) is reportedly affected by land degradation, with annual soil loss of about 5.3 billion tonnes through erosion [*MOA, undated*]. In economic terms India's soil degradation ranged from 11 to 26 percent of her Gross Domestic Product during the 1980s and 1990s [*IITC, 2014*]. The general picture is probably the same for NRGB, given its intensively cultivated farmlands. In addition to general soil degradation in terms of edaphic parameters is the depletion of soil nutrients and biota, information on which is limited. Such depletions have necessitated increased inputs of chemical fertilizers and pesticides to compensate for the loss of soil fertility and pest resistance, whose consequences on NRGB's agroecosystems are obvious. As noted in the IITC [2014] "*the high input-intensive farm practices followed by farmers in the basin have caused depletion in the groundwater table, deterioration in the quality of soil and water…* ." The direct adverse effects of these "high input" and "intensive" farm practices are on the agricultural land itself – loss of valuable topsoil, depletion of nutrients, decimation of soil biota, and degeneration of soil structure. These effects, in turn, affect the entire ecozone.

Agriculture is the main source of livelihood of about half of the population of NRGB and the majority of its rural population [*IITC, 2014*]. Considering the trend, pattern, influence, ascendancy, problems, and prospects etc., the significant agricultural areas of NRGB were assessed to comprise the states of Uttarakhand, Uttar Pradesh, Bihar and West Bengal, vide FIgure 1 [*IITC, 2011*]. There has been significant agricultural growth in the above regions of NRGB over the last 4–5 decades. But, on the whole, the growth has been limited by land constraints rather than of water or other natural resources. Most of the arable land has already been brought under cultivation, while the land demand for non-agricultural uses has increased. In contrast, irrigation water supplies have been increasing rapidly through groundwater usage.

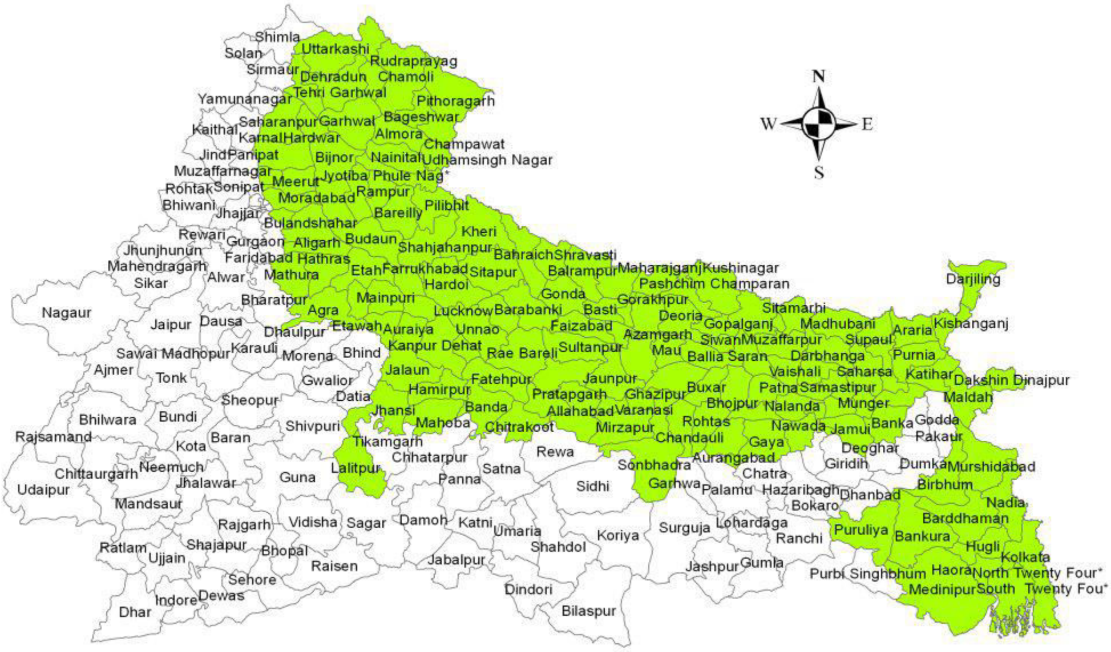

Figure 1: Geographical Delineation of Significant Agricultural Area of NRGB [*IITC, 2011*]

The Borlaug seed-fertilizer technology ushered into India in the 1960s raised crop outputs rapidly in India (including the NRGB). The average value of crop output in the delineated NRGB area grew almost four-fold from Rs. 1.97 billion during 1962-65 to Rs. 5.24 billion during 2003-06 (at 1990-93 prices), vide Figure 2 [*IITC, 2011*]. The growth was enabled by crop yields more than doubling from Rs. 4,300 to Rs.9,900 per hectare of gross cropped area from 1962-65 to 2003-06 (at 1990-93 prices), vide figure 3 [*IITC, 2011*]. The Green Revolution's impact on agricultural yields were evidently limited in the first couple of decades, but accelerated since the 1980s. The gross cropped area during the four decades from the mid 1960s grew by about 20% from 502 to 599 thousand hectares per district (vide Figure 4), but the gross irrigated area more than tripled from about 134 to 411 thousand hectares per district (vide Figure 5), while average fertilizer consumption grew many-fold from 1,700 to 76,300 tonnes per district (vide Figure 6) [*IITC, 2011*], with consistently increasing trends of fertilizer usage in different regions of NRGB (see Figure 7) [IITC, 2014]. Thus, it is obvious that the remarkable agricultural growth in NRGB was sustained by rapidly increasing agricultural inputs rather than significant increase in cropping area.

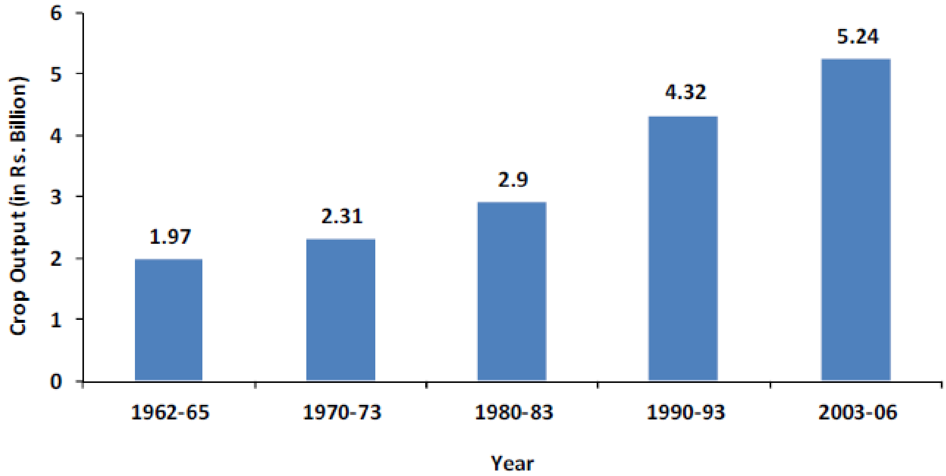

Figure 2: **Average Crop Output Value per District in NRGB between 1962-65 to 2003-06 [*IITC, 2011*]**

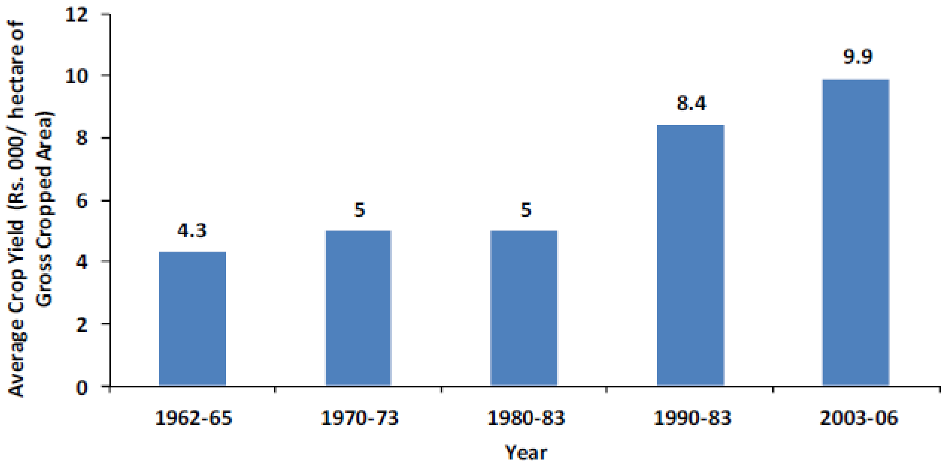

Figure 3: **Average Crop Yield (Rs.1000/ hectare of Gross Cropped Area) per district in NRGB, 1962-65 to 2003-06 [*IITC, 2011*]**

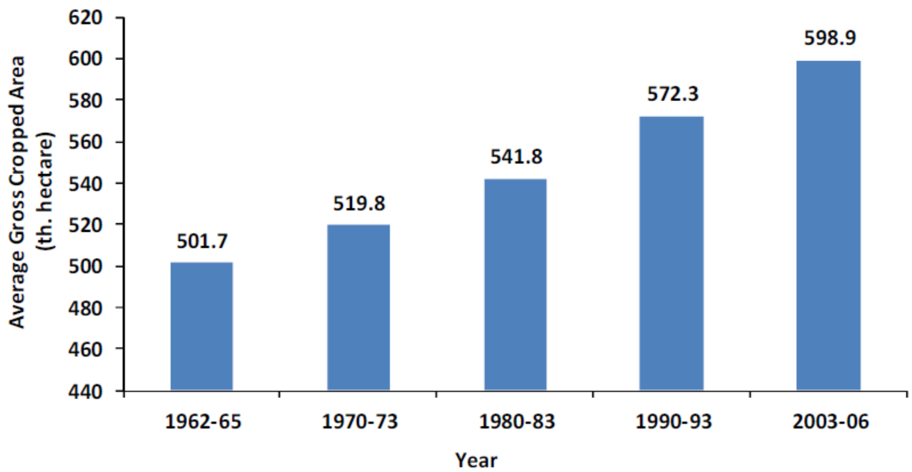

Figure 4: **Average Gross Cropped Area (thousand hectares) per District in NRGB between 1962-65 to 2003-06 [*IITC, 2011*]**

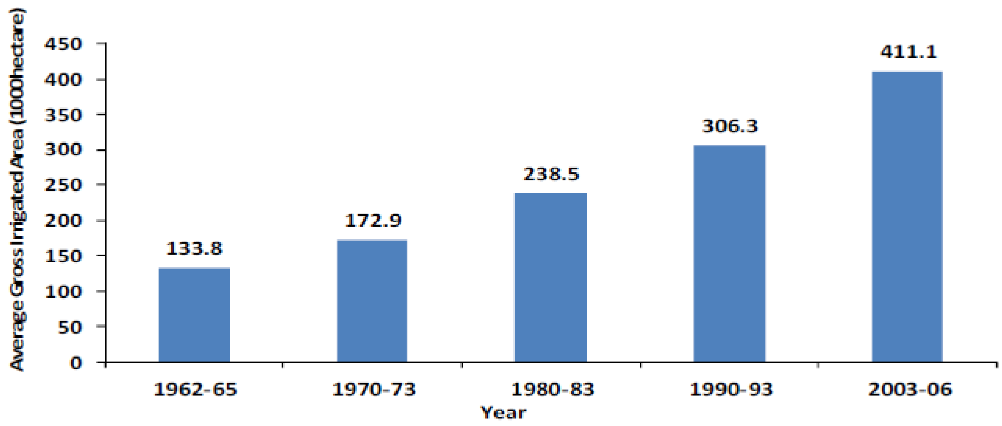

Figure 5: Average Gross Irrigated Area (1000 hectares) per District in NRGB between 1962-65 to 2003-06 [*IITC, 2011*]

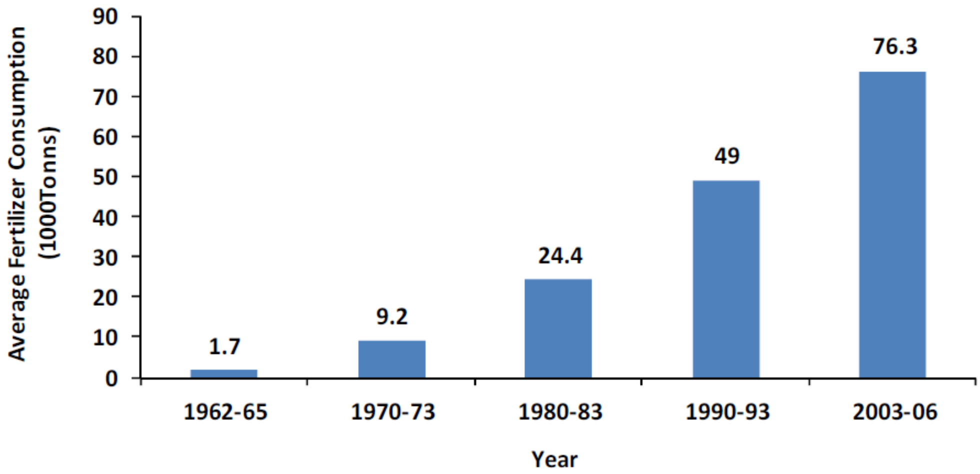

Figure 6: Average Fertilizer Consumption (1000 tonnes) per District in NRGB between 1962-65 to 2003-06 [*IITC, 2011*]

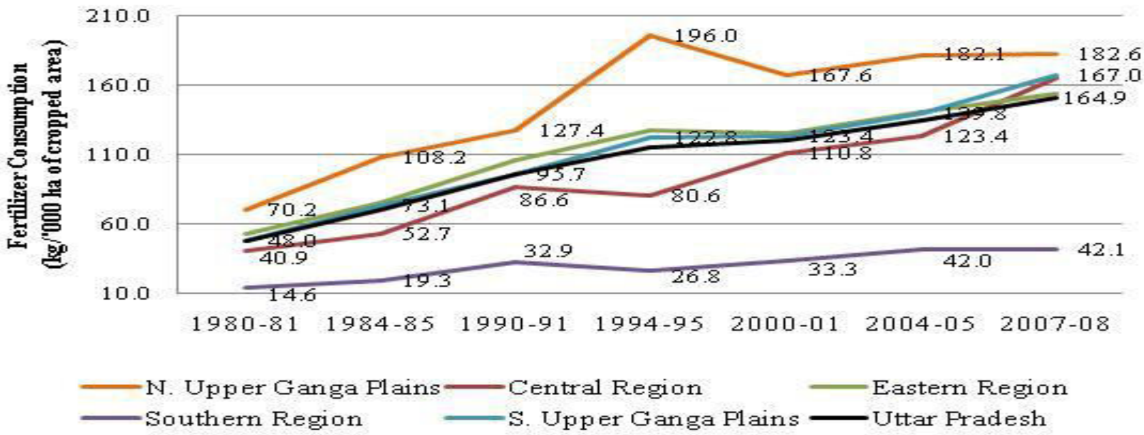

Figure 7: Region-wise Trends in use of Chemical Fertilizers per Hectare [*IITC, 2014*]

The above data indicate the extent of growth of agricultural inputs and outputs in NRGB. It may be also noted here that rice, wheat and sugarcane constitute the bulk of agricultural crops in the basin. Out of these, rice and sugarcane are high water-consuming crops, whose growth depended not only on mineral fertilizer inputs, but also on escalating groundwater irrigation (*e.g. groundwater irrigation covered about 80% of the gross irrigated area in the Middle Ganga Basin in 2007-08, vide IITC, 2014*). A second point of note is that fertilizer usage is far from balanced, with Nitrogen fertilizers comprising about 75% of the total fertilizer usage [*IITC, 2014*]. Farm mechanization also grew rapidly over the decades. The consequence of the composite agricultural developments in NRGB's agroecosystems can easily be surmised to have increased soil erosion and reduced soil fertility, besides dispatching eroded soils and much of the nutrients beyond the croplands and adversely affecting the basin's ecosystems (including the Ganga river network).

5. Agro-ecosystem Concerns in NRGB

As evident from the preceding section, current agricultural practices in NRGB have had diverse negative impacts on the region's ecosystems that make it nearly impossible to maintain agriculture growth (and perhaps even the present agricultural output) in the long run. Urgent reforms are needed to prevent (or at least minimize) soil erosion and maintain soil fertility (soil structure, nutrient base and biodiversity), besides also protecting the region's various other natural resources (including water, nutrients, biodiversity and forests) from agriculture's adverse effects. These goals together comprise the parameters defining the need for sustainable agriculture in NRGB. They are in fact universally acknowledged in today's world. As summed up by Brodt *et al*. [*2011*], "a sustainable agriculture approach seeks to utilize natural resources in such a way that they can regenerate their productive capacity, and also minimize harmful impacts on ecosystems beyond a field's edge." The main concerns about NRGB's evolving agroecosystems are outlined below in further detail.

5.1. Soil Erosion

Among the major types of land degradation in India, soil erosion is reported to be the most important, causing nearly 4/5th of the degradation, vide Figure 8 [*MOA, undated*]. Much of this erosion is from agricultural lands, with agricultural soil erosion being largely related to soil tillage (besides topography, soil texture, soil composition, etc.). Minimizing soil tillage is, therefore, a key step in erosion control.

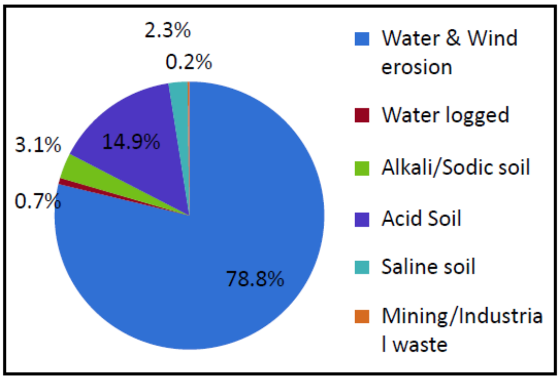

Figure 8: Share of Different Types of Land Degradation in India [*MOA, undated*]

5.2 Soil Nutrients

Plant nutrient requirements include many chemical elements needed by plants in varying quantities. There are at least 17 essential elements required for plant growth as listed in Table 1. The lack of any of these essential nutrients can result in a severe limitation of crop yield. Of the 17 or more essential elements, the non-mineral elements C, H and O are obtained from air and water, but the mineral elements must be available in the soil as water-soluble compounds suitable for plant uptake. Among the 14 mineral elements, N, P and K are primary macronutrients that are needed in the greatest quantities. Secondary macronutrients (Ca, Mg and S) needed in smaller quantities, are typically sufficiently present in soil, and hence are seldom limiting for crop growth. The remaining 8 elements – Fe, Mn, Zn, Cu, B, Mo, Cl and Ni – are micronutrients (or trace nutrients), that are needed in very small amounts, and can be toxic to plants if in excess. Besides these 17 elements, Silicon (Si) and sodium (Na) are also essential elements, but due to their ubiquitous presence in soils they are never in short supply [*Epstein, 1994; Parikh et al., 2012*]. In addition to the above micronutrients, cobalt (Co) is also an essential micro-element required by nitrogen-fixing plants [*Graham, 2008*].

It should be noted here that the above 17 or 18 elements are the ones known to be essential for plants in general, but there are likely to be more essential elements that are still unknown or those that are required by specific plant species. The possible additions include at least 8 more elements known to be essential for animals (including humans), viz. selenium (Se), iodine (I), chromium (Cr), tin (Sn), fluorine (F), lithium (Li), silicon (Si), arsenic (As) and vanadium (V) [*Graham, 2008*]. Since these additional microelements are sourced by humans and animals mainly through plants (directly or indirectly through the food chain) and since billions of people worldwide are estimated to have been already affected by their deficiency – especially of Se and I [*Graham, 2008*], the availability of these elements in soil should also be considered essential for human and ecosystem health.

Table 1: Essential plant nutrient elements and their primary form utilized by plants [*Parikh et al., 2012*]

Essential plant element		**Symbol**	**Primary form**
Non-Mineral Elements:			
	Carbon	C	CO_2 (g)
	Hydrogen	H	H_2O (l), H^+
	Oxygen	O	H_2O (l), O_2(g)
Mineral Elements:			
Primary Macronutrients	Nitrogen	N	NH_4^+, NO_3^-
	Phosphorus	P	HPO_4^{2-}, $H_2PO_4^-$
	Potassium	K	K^+
Secondary Macronutrients	Calcium	Ca	Ca^{2+}
	Magnesium	Mg	Mg^{2+}
	Sulfur	S	SO_4^{2-}
Micronutrients	Iron	Fe	Fe^{3+}, Fe^{2+}
	Manganese	Mn	Mn^{2+}
	Zinc	Zn	Zn^{2+}
	Copper	Cu	Cu^{2+}
	Boron	B	$B(OH)_3$
	Molybdenum	Mo	MoO_4^{2-}
	Chlorine	Cl	Cl^-
	Nickel	Ni	Ni^{2+}

The mere presence of nutrient elements in soil does not assure their adequate supply to plants. Some nutrients, such as N and P, are often present in the soil in large amounts but are made available to plants only very slowly. Others, such as K, are readily available for plant uptake. An important parameter of nutrient availability in soil is its relative mobility, which is high for N, S and B but low for P and most micronutrients. In general, as nutrient mobility increases, its location in the soil becomes less important for plant uptake, but the potential for nutrient loss increases. Thus, the potential for N loss from the soil is generally high, and little available N accumulates in the soil. Conversely, P availability near plant roots is critical for its uptake, and the loss of P from soils usually requires erosion of the soil itself. However, recent evidence indicates that significant amounts of soluble P can also be lost in runoff from fields when the soil becomes saturated with excessive soil test phosphorus levels [*PSU, 2013*].

In recent times, the two major fertilizer inputs N and P have been a cause for soil degradation and environmental pollution in many parts of the world. On the one hand, overuse of N fertilizers can lead to acidification of croplands[1], which has already happened significantly in China [*Guo et al., 2010*]. On the other hand, N and P fertilizers tend to damage neighbouring ecosystems. For instance, many forests have been severely affected by the excessive use of N fertilizers in modern agriculture [*Nosengo, 2003*]. As noted by Goulding *et al*. [*2008*], "*N is a particular problem. Its importance as a growth- and yield-determining nutrient has led to large and rapid increases in application rates, but with often very poor efficiencies. … (And) the view that P is strongly held in soils and so applying more than enough P is 'money in the bank' has resulted in the build-up of excessive P levels in some soils, resulting in enhanced leaching … (and) loss by erosion*." Globally, only 30–50% of applied nitrogen fertilizer and about 45% of phosphorus fertilizer is taken up by crops. A significant amount of the applied N (and a smaller portion of the applied P) is lost from agricultural fields. These nutrient losses as well as gaseous nitrogen oxides (NO_X) emitted from fertilized soils harm off-site ecosystems, water quality and

[1] Note**:** As seen from Figure 4.8, nearly 15% of the 21% non-eroded degraded land in India is acidic; hence possible acidification of more agricultural lands due to N fertilizers is of concern in India.

aquatic ecosystems, and increase atmospheric ozone to damaging levels [*Tilman et al., 2002*]. The increasing amounts of reactive nitrogen in the environment due to N fertilizers have in fact become a global issue [*UNEP-WHRC, 2007; Bodirsky et al., 2014*].

It is also worth noting that, while N fertilizers are manufactured from petroleum, P and K fertilizers are produced from ores, whose reserves have been steadily declining worldwide. P fertilizers, in particular, are a matter of concern due to globally limited P reserves [*Elser and Bennett, 2011; Vacari, 2009*]. P ores are available at only a few places on earth, and 85% of the known reserves are concentrated in just 3 countries, with the bulk of the reserves being in Morocco and its disputed territory of Western Sahara (*Elser and Bennett, 2011*), vide Figure 9. For India, which is almost entirely dependent on imports for P fertilizers, the limited and skewed global P reserves are a matter of special concern, and this is an additional reason for restrained and efficient use of P fertilizers.

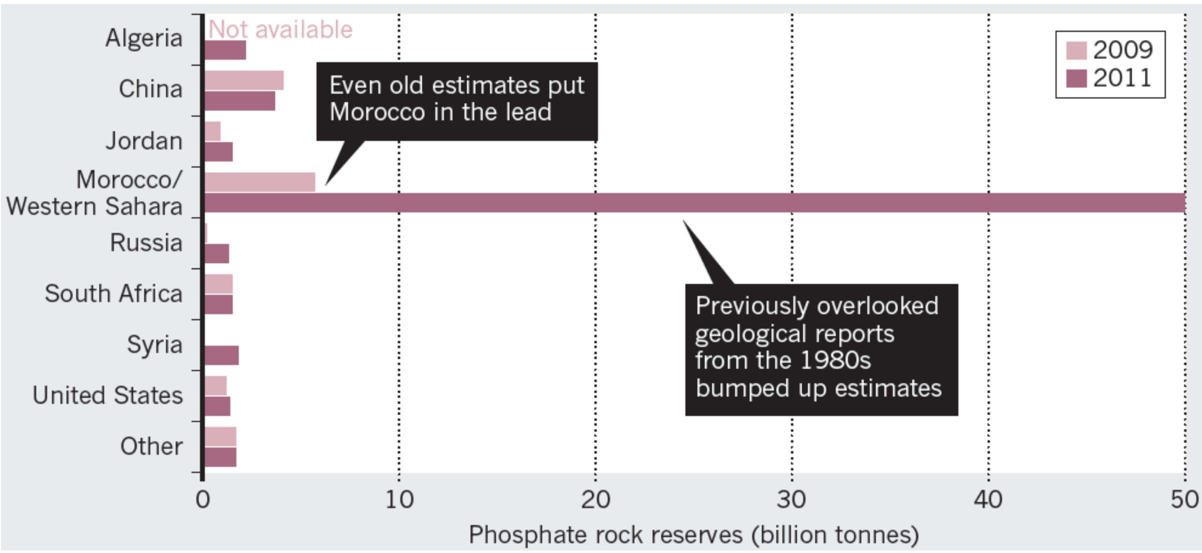

Figure 9: Global Phosphate Reserves: 2009 and 2011 estimates [*Elser & Bennett, 2011*] (*Note: India's phosphate reserves being negligible, phosphate fertilizers are almost entirely import-dependent in India.*)

In terms of the primary macronutrients (N, P and K), India's overall soil fertility status is probably satisfactory, but there are significant variations across different states (including in NRGB) [*Pathak, 2010*]. And there are likely to be even more significant variations between different parts of each state. Hence, a uniform recommendation of fertilizer application of 120:60:30 NPK kg/ha dose (in 4:2:1 ratio) for wheat/rice crop [*vide IITC, 2014*] could be damaging for some of NRGB's agroecosystems.

A further cause for concern is the growing deficiencies of micronutrients in Indian soils, especially since the onset of Green Revolution. The increasing deficiencies are largely due to excessive mining of soil micronutrients by agricultural crops, whose output increases aided by NPK fertilizer inputs are not complemented with corresponding micronutrient inputs. Figure 10 depicts the extent of deficiencies of some micronutrients in India [*Singh, 2004*]. Among the micronutrients shown, zinc is the most common deficiency in India's and NRGB's soils. But there are deficiencies of other micronutrients (like boron and sulphur) also in NRGB's soils, plus those of macronutrients like calcium [*Singh, 2009*]. Where micronutrients are not actually deficient in soil, their availability may still be limited by soil acidity or alkalinity [*FAO, 2000*]. Comprehensive measures to ensure balanced nutrient fertility in NRGB's soils are, therefore, essential.

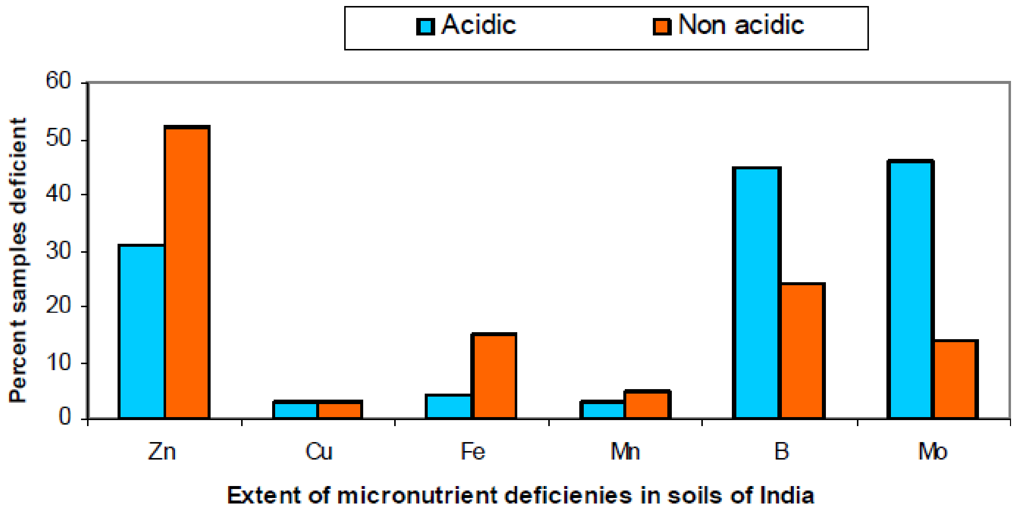

Figure 10: Micronutrient Deficiencies in Indian Soils [*Singh, 2004*]

5.3 Soil Biodiversity

Soil biodiversity plays a key role in soil fertility, vide Figure 11 (although the figure depicts the role of soil biota in nutrient movements of C and N only). As noted by Scholes and Scholes [2013], "*the key to understanding the behaviour of life-supporting elements in soils lies not in the absolute amounts present, but* *in the fluxes between their various forms, modulated by biology. ... The variety of ways in which soil constituents can be processed and transformed by a diverse soil microbial community provides an energy-efficient, nonleaky, self-regulating system that can adapt to changing environments."* But not only soil micro-organisms, invertebrates (such as earthworms and macro-arthropods) present in the soil are extremely useful for robust soil structure and nutrient recycling – by building large and stable organo-mineral structures, and by breaking up large organic litter. Soils rich in organic matter contain many thousands (or even millions) of species of micro-flora such as bacteria (including actinomycetes), fungi and algae plus micro-fauna such as protozoa and nematodes. The microbes decompose the active component of soil organic matter (or SOM) composed of fresh plant or animal material, thereby releasing nutrients for plant uptake [*Giller et al., 1997; Hoorman & Islam, 2010*]. Without adequate microbial activity, the nutrients would remain inaccessible to plants. For a typical case of soils containing 1% SOM, the macronutrients in the topsoil have been valued at about US $ 680, vide Table 2. The table illustrates the economic importance of soil biodiversity for maintaining soil fertility.

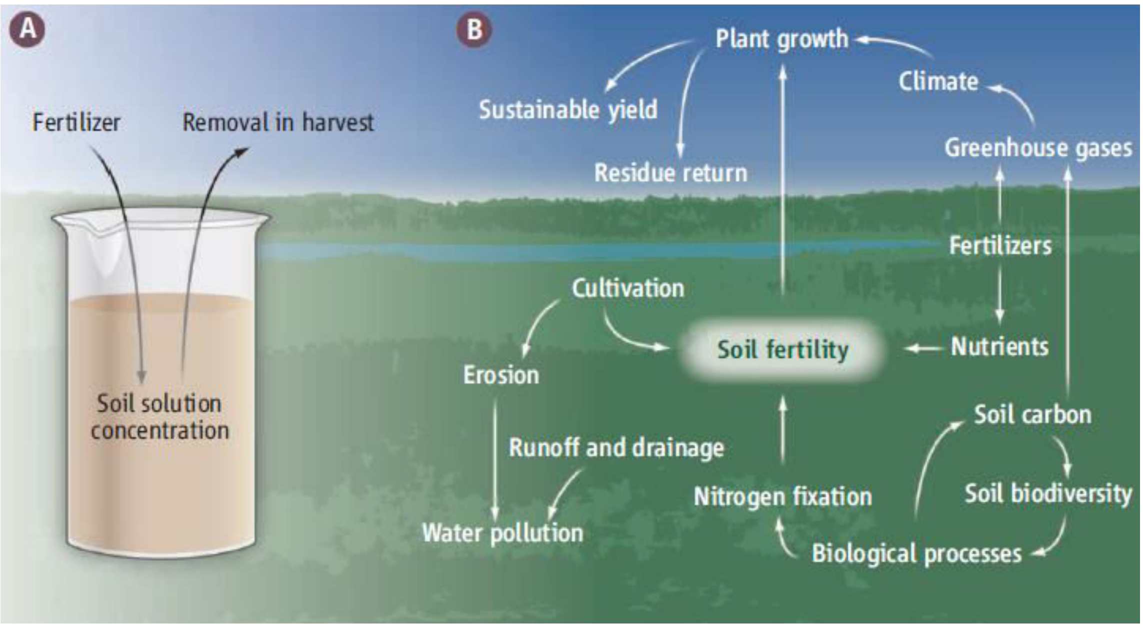

Figure 11: Soil Fertility Management Models – (A) Conventional Simplistic Model. (B) Realistic Model based on Soil Biodiversity [*Scholes and Scholes, 2013*]

Table 2: Typical Nutrient Value of Soil Organic Matter [*Hoorman & Islam., 2010*]

Assumptions: 2,000,000 pounds soil in top 6 inches	
Nutrients	1% organic matter = 20,000 # 50% Carbon, C:N ratio = 10:1
Nitrogen	1000 # * $0.50/#N = $500
Phosphorus	100# * $0.70/#P = $70
Potassium	100# * $0.40/#K = $40
Sulfur	100# * $0.50/#S = $50
Carbon	10,000# or 5 ton * $4/Ton = $20
Value of 1% SOM Nutrients/Acre	= $680
Relative Ratio of Nutrients	100 Carbon/ 10 Nitrogen/ 1 Phosphorus/ 1 Sulfur

A brief overview of soil microbial activity is presented here based on Giller et al. [*1997*] and Hoorman & Islam [*2010*]. Protozoa and nematodes (soil micro-fauna) consume microflora and release N as ammonia, which becomes available to other microorganisms or is absorbed by plant roots. Between bacteria and fungi, bacteria are generally quick to digest labile organics (fresh plant and animal residues), while fungi are slower but more efficient decomposers. Notable among fungi are the mycorrhizal fungi that live on the surface of or within plant roots (usually in symbiotic association) that aid the transport of mineral nutrients and water to plants. But fungi are not as hardy as bacteria in surviving starvation conditions, and their population tends to decline with tillage. In general, organic residues with a low carbon to nitrogen ratio (C:N < 20) are easily decomposed and nutrients are quickly released (4 to 8 weeks), while organic residues with high C:N ratio (> 20) decompose slowly, with microbes using up soil nitrogen in the process. This broad picture of soil microbial activity takes various complex forms in different conditions. Even in similar and nearby areas, the soil biodiversity can be vastly different depending on plant communities and human interventions. For instance, American prairie soils abound in a sturdy variety of bacteria (Verrucomicrobia) that are specialized for low-nutrient conditions, but these bacteria do not exist in fertilized agricultural soils of the region [*Scholes & Scholes, 2013*]. The key biological functions in tropical agricultural soils, the principal groups of organisms responsible for them, and the agricultural management practices that impact them the most were succinctly summarized by Giller *et al.* [*1997*] as reproduced in Table 3.

Table 3: Key biological functions, the groups of soil biota principally responsible for them, and management practices that most affect them [*Giller et al., 1997*]

Biological function	Biological/ functional group	Management practices
Residue comminution/ decomposition	Residue-borne microorganisms, meso/macrofauna	Burning, soil tillage, pesticide applications.
Carbon sequestration	Microbial biomass (especially fungi), macrofauna building compact structures	Burning, shortening of fallow in slash-and-burn, soil tillage
Nitrogen fixation	Free and symbiotic nitrogen-fixers	Reduction in crop diversity, fertilization
Organic matter/nutrient redistribution	Roots, Mycorrhizas, soil macrofauna	Reduction in crop diversity, soil tillage, fertilization
Nutrient Cycling, Mineralization immobilization	Soil microorganisms, soil microfauna	Soil tillage, irrigation, fertilization, pesticide applications, burning
Bioturbation	Roots, soil macrofauna	Soil tillage, irrigation, pesticides applications
Soil aggregation	Roots, soil fungal hyphae, soil macrofauna, soil mesofauna	Soil tillage, burning, reduction in crop diversity, irrigation
Population control	Predators/grazers, parasites, pathogens	Fertilization, pesticide application, reduction in crop diversity, soil tillage.

It is evident from the above discussions, that building up soil organic matter to restore soil biodiversity is the key to achieving lasting food and environmental security [*Scholes & Scholes, 2013*]. This fundamental principle underlies agricultural sustainability in NRGB.

5.4 Water Usage

High water usage in agriculture in NRGB is a matter of concern because, on the one hand it tends to deplete limited water resources; on the other hand, it enhances soil erosion, loss of soil nutrients and wastewater generation through leaching and runoff. These issues are well-known and have been discussed under Missions Aviral Dhara and Nirmal Dhara of GRBMP. But a few points deserve mention regarding groundwater irrigation. Large-scale groundwater usage for irrigation has been occurring in India (and elsewhere in the world) only in the last 5-6 decades. The enhanced groundwater extraction rates have caused land subsidence in some places, and is also considered a potential cause for earthquakes (vide Mission Report on Geological Safeguarding). Secondly groundwater irrigation can sometimes be a cause for mineral toxicity in plants and animals. For instance, high arsenic levels in groundwater have been widely reported in many parts of West Bengal and contiguous regions, which entail a distinct possibility of arsenic entering the food chain in NRGB if groundwater irrigation continues unabated. Likewise, toxic fluoride levels in groundwater exist in many areas. The spurt in groundwater irrigation in NRGB over the past few decades therefore needs to be monitored, and deep groundwater usage certainly needs to be restrained.

6. Measures to Implement Sustainable Agriculture in NRGB

The preceding discussions underscore the basic requirements to be fulfilled to achieve agricultural sustainability in NRGB, viz., conservation of soil resources (primary soil particles, nutrients and biodiversity) and water resources of the region. Fulfilling these goals require minimization of tillage and of agricultural inputs (mainly chemical fertilizers and pesticides), which, together with economic water use, can protect neighbouring ecosystems from the ill-effects of present agricultural practices. Based on the issues covered and recommendations of in GRBMP Thematic Reports [*IITC, 2011; IITC, 2014*] and other sources [e.g. *FAO, 2014; MOA, 2010; MOA, undated; Planning Commission, 2007; Tilman et al., 2002; Wilkins, 2008*], the desired changes in agricultural practices that can economically meet the sustainable agriculture goals in NRGB are outlined below.

6.1 Conservation Agriculture

Conservation agriculture, aimed at preventing soil erosion and maintaining soil fertility, is defined by FAO as combining three working principles, namely**:** (i) minimum mechanical soil disturbance ("no till" or "minimum tillage"), (ii) permanent organic soil cover, and (iii) crop diversification. All the three components of conservation agriculture – crop diversification (crop rotation, intercropping), organic soil cover (cover crops and mulching) and "no till" or "zero tillage" farming – are essentially part of traditional agriculture [*Derpsch, 2004; Roland, 2012*]; but these were actively revived in the mid-twentieth century, especially in North and South America, before gaining worldwide ascendancy. By the year 2000, about 45–60% of cropland areas of Paraguay, Brazil and Argentina and about 17% of croplands in USA had converted to no-tillage [*Derpsch, 2004*]. However, no-tillage farming has been slow to pick up in Asia and Europe, vide Table 4, and in India it was limited to only about 5 million ha in 2007-08 [*Huggins & Reganold, 2008; Friedrich et al., 2012; UNEP, 2013*]. In brief, "no till" farming implies no soil erosion caused by tillage. Together with the other two principles of conservation agriculture, it ensures high soil fertility and, hence, reduced agriculture inputs and higher agricultural productivity. Conservation agriculture is, therefore, an economically advantageous reform needed in NRGB (especially in degrading soils), and no-till farming has been recommended by the Indian government [*MOA, undated*]. However, the adoption of conservation agriculture has inherent difficulties that need to be addressed.

Table 4: Global Extent of No Tillage Cultivation in 2007-08 [*UNEP, 2013*]

Country	Climate Zone	Base Year	Area under no-tillage in 2007/08	Best estimate cumulative avoided greenhouse gas emissions by replacing till-with no-till cultivation (between indicated base year and 2007/08)
Unit			*(million hectares)*	*($MtCO_2e$)*
Notes	*(a)*	*(b)*	*(c)*	*(d)*
Australia *(e)*	warm-dry	1976	17	95.2
Argentina	warm-moist	1993	19.7	109.4
Bolivia	warm-moist	1996	0.7	3.1
Brazil	warm-moist	1992	25.5	145.7
Canada	cool-moist	1985	13.5	82.3
China*(f)*	cool-dry	2000	2	1.6
Kazakhstan	cool-dry	2006	1.2	0.2
New Zealand	cool-moist	1993	0.16	0.7
Uruguay	warm-moist	1999	0.66	2.0
USA	cool-moist	1974	26.5	241.3

Notes:

- *(a)* Considering the lack of information on where no-till cultivation is being practiced, we assume one climate zone throughout the country, considering, where possible, the regional distribution of no-till agriculture.
- *(b)* The base year is the estimated year in which the area of no-till cultivation began significantly expanding from a small baseline value in the country. The base year was estimated by linearly extending adoption rates from Derpsch *et al.* (2010), unless otherwise stated.
- *(c)* From Derpsch *et al.* (2010) unless otherwise stated.
- *(d)* Mitigation here refers mostly to avoided carbon dioxide emissions, with a small amount of avoided nitrous oxide emissions. Mitigation estimates on a per hectare basis are from Smith *et al.* (2008). There were multiplied by the area covered by no-till cultivation to obtain a value for total avoided emissions were summed for each year from 2007/08 back to the base year (in column 3). To compute the area covered by no-till cultivation in each year, it was assumed that the area covered decreased linearly from 2007/08 back to the base year (in column 3). In countries with long histories of no-till agriculture this probably led to an underestimate of the mitigation that was achieved. However, if the use of no-till cultivation began very slowly, then it is also possible that cumulative avoided emissions were overestimated.
- *(e)* The 2007/08 estimate is derived from Derpsch *et al*. (2010) whereas the base year was established from Llewellyn and D'Emden (2010).
- *(f)* The area stated for China is derived from Liu and Qingdong (2007) and Ministry of Agriculture (2009).

No-till farming and conservation agriculture have been reviewed extensively in literature [e.g. *Huggins & Reganold, 2008; Hobbes, 2008; Hoorman et al., 2009; UNEP, 2013*], and based on these reviews and FAO [*2014*], it needs to be emphasized that transition from conventional farming to no-till may take several years during which agricultural output could be considerably reduced. Thus adequate support (including supply of increased N fertilizers and suitable herbicides) may be needed by farmers to tide over the transition period. Secondly, selection of cover crops and crop rotations should be suited to the specific agro-zone, for which farmers may need advice. Thirdly, specialized (and expensive) seeding equipment are needed in no-till farming. Fourthly, the availability of crop residues for fuel and fodder may be significantly reduced due to the green cover needed on croplands. Finally, the adoption of no-till for wetland rice and root crops (like potatoes) is problematic. Nonetheless, as observed by Huggins & Reganold [*2008*], "*ultimately all farmers should integrate conservation tillage, and no-till if feasible, on their farms*." Overall, financial support/ incentives and timely technical help/ advice are essential for speedy and successful transition to conservation agriculture in NRGB.

6.2. Organic Farming

Like no-till farming, organic farming is also a relatively recent agricultural revival of earlier practices, having gained ascendancy towards the end of the twentieth century. However, unlike conservation agriculture which focuses on natural resource conservation, organic farming grew out of human health concerns due to extensive chemical inputs in modern agriculture, and hence its main focus is on human health. Thus, several agroecosystem problems (like soil erosion, nutrient balance, soil biodiversity, and effects on nearby ecosystems) may not be adequately met by organic farming. Moreover, the agricultural productivity of organic farming can be significantly lower (and hence costlier) by about 13–34% than that of conventional agriculture [*Seufert et al., 2012*]. Connor [*2008*] pointed out the limited spread of organic farming in world agriculture (only 0.3%) and showed that the additional land needed in organic farming to generate organic fertilizers and grow legume crops implies significantly reduced productivity of organic agriculture as compared to conventional agriculture. In an earlier critique of organic farming, Trewavas

[*2001*] had pointed out some other shortcomings of organic farming including the harmfulness of certain bio-pesticides for human and animal health, extensive labour inputs needed for weed and pest control, and inefficient nutrient utilization. Despite these drawbacks, however, organic farming can result in significant improvement of agroecosystem health, protect surrounding ecosystems from damaging spillovers of chemical nutrients and pesticides, and reduce irrigation water requirement. Hence, organic farming methods should be promoted wherever feasible (e.g. for horticulture and high-value crops) with adequate support for the transition period of a few years.

6.3. Water and Nutrient Management Techniques in Rice Cultivation

Two key methods for improved resource conservation for paddy cultivation are**:** (a) Alternate Wetting and Drying irrigation cycles (including the System of Rice Intensification or SRI), which can result in up to 40% water saving, and (b) Urea Deep Placement to drastically improve efficiency of N uptake and thereby reduce N fertilizer use [*Adhya et al., 2014; Thyiagarajan & Gujja, 2013; UNEP, 2013*]. While SRI has been adopted in parts of India since 2000, its spread in the NRGB – along with Urea Deep Placement – needs to be hastened since rice is a major crop grown in NRGB.

6.4. Additional Resource Conservation Techniques

Several resource conservation technologies need to be promoted in NRGB keeping their cost-effectiveness in view. These include Laser Land Leveling, Raised Bed Planting, and Micro-Irrigation Systems (sprinkler and drip irrigation), besides Urea Deep Placement (or Fertilizer Deep Placement, vide *IFDC, 2013*) technology mentioned in the previous section.

6.5. Resource Optimization Measures

As discussed in Section 5.2, NRGB's soils have been found to have varying degrees of nutrient deficiencies (such as of calcium, zinc, boron, sulphur, etc.) in different places. But soil nutrient balance is essential for optimizing agricultural productivity. In case of selective nutrient deficiencies, the output is limited by the deficient elements, while other soil nutrients being in relative excess may be wasted. Thus extensive soil testing is necessary in NRGB's agriculture, along with the availability of needed nutrients (through organic or chemical fertilizers of sufficiently high purity) and other soil amendments (especially for acidic, alkaline and saline soils). Improved seed quality (with bio-fortification where needed) and fertilizer quality can also improve nutrient uptakes and reduce resource wastage.

6.6. Regional (Landscape-scale) Resource Conservation Measures

While the above measures are implementable at the level of small farms, large farms and communities of farms spread over large areas should be coordinated for controlling region-scale agroecosystem impacts. This measure also includes other agricultural activities than crops – such as fisheries and animal husbandry. The main approach is to promote mixed farming systems combining various types of plants (such as agro-forestry, crop-horticulture) as well as crops, freshwater fisheries and livestock (with grazing pasture lands interspersed between croplands). Rejuvenation or creation of water bodies and harvesting of rainfall and irrigation runoffs are also needed to enhance local irrigation water availability and reduced dependence on groundwater. Curbs on cultivation of non-essential water-guzzling crops (such as sugarcane) are also desirable, particularly in water-constrained regions. Finally, adequate buffer regions of natural vegetation (trees, shrubs and grasslands) between farmlands and rivers, lakes, etc. are often useful in minimizing polluted runoff from agricultural fields directly reaching nearby water bodies.

6.7. Scoping Future Advancements

Globally, the shift from intensive mechanized agriculture to ecologically sustainable agriculture started some decades ago but gained momentum only in recent times as tradeoffs between agricultural outputs and other ecosystem services and between quantity and quality of agricultural outputs raised new concerns. This new impetus has propelled radically new thinking and experimentation covering the whole gamut of agricultural techniques from land and water management to crop breeding and biotechnological applications. The attempt must, therefore, be to keep ground-level options open to experiment with, adopt and adapt radically new technologies and practices developed within NRGB and outside. An example of such radically new quests is the attempt to develop perennial deep-rooted crops in place of seasonal shallow-rooted ones [*Glover et al., 2007*]. As observed by Tilman et al. [*2002*], "*sustainable agriculture … will require increased crop yields, increased efficiency of nitrogen, phosphorus and water use, ecologically based management practices, judicious use of pesticides and antibiotics, and major changes in some livestock production practices. Advances in the fundamental understanding of agroecology, biogeochemistry and biotechnology that are linked directly to breeding programmes can contribute greatly to sustainability*." The agricultural future of NRGB will depend considerably on openness and adaptability to promising developments worldwide on agroecosystem management as also on re-evaluation of traditional practices.

6.8. Policy Issues

The means to speedily achieve the above reforms in NRGB depend upon a variety of social, institutional and economic factors relating to the large number of small and fragmented landholdings in the basin, the extent of poverty and limited educational levels prevalent in the farming community, social fissures, institutional constraints, etc. Various measures have been suggested [*IITC, 2014; MOA, 2010; MOA, undated; Planning Commission, 2007*] to help the transition to sustainable agriculture overcome these constraints through financial support (credits, incentives, disincentives, subsidies, etc.), knowledge support (knowledge dissemination, training, demonstration, etc.), extension services in implementing new technologies, allocation of water rights and credits, improved availability of farm equipment and agricultural inputs, improved market access, organizing individual farmers through farmers' collectives and contract farming, etc. These and other appropriate policy measures need to be finalized depending on basin-wide assessment of the implementation bottlenecks in NRGB.

7. Summary of Recommended Actions

The main recommendations for speedy transition to sustainable agriculture in NRGB are summarized below:

i) Promotion of conservation agriculture practices, aimed at preventing soil erosion and maintaining soil fertility, by means of "no till" or "minimum tillage" of soils, permanent organic soil cover, and crop diversification, especially in degrading agricultural lands.

ii) Promotion of organic farming where feasible to reduce damage to soil health and human health by chemical inputs.

iii) Adoption of resource conservation practices in rice cultivation including System of Rice Intensification and Urea Deep Placement techniques.

iv) Promotion of resource conservation technologies like Laser Land Levelling, Micro-irrigation Systems, Raised Bed Planting, UreaDeep Placement, Bio-fortified seeds, etc.

v) Extensive soil testing facilities with easy availability of micronutrients and soil amendments.

vi) Regional (landscape) level resource management through agro-forestry, crop-livestock-fishery-grassland combinations, water harvesting, and buffering of water courses and water bodies by forests and natural vegetation.

vii) Building adaptability and flexibility in agricultural practices of NRGB through assimilation of new sciences, knowledge exchanges with the outer world, field-level experimentation, and regeneration of traditional knowledge systems.

viii) Selection of appropriate policy measures to implement the above goals, keeping in view the existing social, cultural, economic and institutional strengths and constraints.

References

1. Adhya, T.K. et al. [2014], *"Wetting and Drying: Reducing Greenhouse Gas Emissions and Saving Water from Rice Production,"* Working Paper, Installment 8 of *Creating a Sustainable Food Future*. World Resources Institute, Washington, DC. [*Accessed October 12, 2014 from:* www.wri.org/publication/wetting-and-drying-reducing-greenhouse-gas-emissions-and-saving-water-rice-production.]
2. Bodirsky, L.B. et al. [2014], "*Reactive nitrogen requirements to feed the world in 2050 and potential to mitigate nitrogen pollution*," Nature Communications 5, Article Number: 3858, doi:10.1038/ncomms4858 [*Accessed May 05, 2014 from:* http://www.nature.com/ncomms/2014/140513/ncomms4858/full/ncomms4858.html]
3. Brodt, S.J. Six, G. Feenstra, C. Ingels and D. Campbell [2011], "Sustainable Agriculture," Nature Education Knowledge 3(10):1. [*Accessed on April 02, 2014 from:* http://www.nature.com/scitable/knowledge/library/sustainable-agriculture-23562787]
4. Bunch, Roland [2012], "*Restoring the soil: a guide for using green manure/cover crops to improve the food security for smallholder farmers*," Canadian Foodgrains Bank, Winnipeg, Canada.
5. Connor, D.J. [*2008*], "*Organic agriculture cannot feed the world*," Field Crops Research, 106, pp 187–190.
6. Derpsch, R. [2004], "*History of Crop Production With and Without Tillage*," Leading Edge, March 2004, Vol. 3, No. 1, pp 150–154. [*Accessed September 27, 2014 from: http://notill.org/sites/default/files/history-of-crop-production-with-without-tillage-derpsch.pdf*]
7. Elliott, E.T. & C.V. Cole [1989], "*A Perspective on Agroecosystem Science*," Ecology, Vol. 70, No. 6, pp. 1597-1602 [*Accessed on April 03, 2014 from:* http://www.jstor.org/stable/1938092]
8. Elser, J. & E. Bennett [2011], "*A Broken Geochemical Cycle*," Nature, Vol.478, pp. 29–31.
9. Epstein, E. [1994], "*The Anomaly of Silicon in Plant Biology*," Proc. Natl. Acad. Sci. USA, Vol. 91, pp 11-17.
10. FAO (Food and Agricultural Organization) [2000], "*Fertilizers and Their Use: A Pocket Guide for Extension Workers* ," 4^{th} Edition, FAO, Rome.

11. FAO (Food and Agricultural Organization) [2014], "*What is Conservation Agriculture*." [*Accessed on September 18, 2014 from*: http://www.fao.org/ag/ca/1a.html]
12. Friedrich, T., R. Derpsch & A. Kassam [2012], "*Overview of the Global Spread of Conservation Agriculture*," Field Actions Science Reports [Online], Special Issue 6, 2012. [*Accessed September 26, 2014 from*: http://www.rolf-derpsch.com/fileadmin/templates/main/downloads/factsreports-1941-special-issue-6-document-sans-titre.pdf]
13. Giller, K.E. et al. [1997], "*Agricultural intensification, soil biodiversity and agroecosystem function*," Applied Soil Ecology, 6, pp 3–16.
14. Glover, J.D., C.M. Cox & J.P. Reganold [2007], "*Future Farming: A Return to Roots*," Scientific American, August 2007, pp 82–89.
15. Goulding, K., S. Jarvis & A. Whitmore [2008], "*Optimizing Nutrient Management for Farm Systems*", Phil. Transactions of the Royal Society B, Vol. 363, pp 667–680.
16. Graham, R.D. [2008], "*Micronutrient Deficiencies in Crops and Their Global Significance*", in "*Micronutrient Deficiencies in Global Crop Production*", by B.J. Alloway (editor), Springer Science Business Media PV.
17. Guo, J.H. et al. [2010], "*Significant Acidification of Major Chinese Croplands*", Science, Vol 327, pp 1008–1010.
18. Hobbes, P.R., K. Sayre & R. Gupta [2008], "*The Role of Conservation Agriculture in Sustainable Agriculture*," Phil. Transactions of the Royal Society B, Vol. 363, pp 543–555.
19. Hoorman, J.J. et al. [2009], "*Using Cover Crops to Convert to No-till*," Sustainable Agriculture Factsheet SAG-11-09, Ohio State University. [*Accessed April 03, 2014 from:* http://ohioline.osu.edu/sag-fact/pdf/0011.pdf.]
20. Hoorman, J.J. & R. Islam [2010], "*Understanding Soil Microbes and Nutrient Recycling*," Sustainable Agriculture Factsheet SAG-16-10, Ohio State University. [*Accessed April 03, 2014 from:* http://ohioline.osu.edu/sag-fact/pdf/0016.pdf.]
21. Huggins, D.R. & J.P. Reganold [2008] "*No-Till: the Quiet Revolution*," Scientific American, July 2008, pp 70–77.
22. IFDC (International Fertilizer Development Center) [2014], "*Fertlizer Deep Placement*," IFDC, Alabama, USA, 8 pages. [*Accessed April 03, 2014 from:* http://www.ifdc.org/getattachment/1c7e9b2e-37b3-4ea4-93c1-318013dc3ce9/FDP.pdf/]

23. IITC [2011]: "A*griculture in the Ganga River Basin: An Overview*", GRBMP Thematic Report – Report Code: 015_GBP_IIT_SEC_ANL_01_Ver 1_Dec 2011.
24. IITC [2014]:"Reform Imperatives for Agricultural Sustainability in Ganga Basin", GRBMP Thematic Report – Report Code: 052_GBP_IIT_ SEC_ANL_15_Ver 1_May 2014.
25. Jenny, H. [1994], "*Factors of soil formation: a system of quantitative pedology*", Dover Publication. [*Accessed May 28, 2014 from:* http://www.soilandhealth.org/01aglibrary/010159.Jenny.pdf.]
26. Montgomery, D.R. [*2009*], "*Is agriculture eroding civilization's foundation?*" *GSA Today*: Vol. 17, No. 10, pp 4–9, 2007.
27. MOA (Min. of Agriculture, Govt. of India) [2010], "*National Mission for Sustainable Agriculture,*" New Delhi.
28. MOA (Min. of Agriculture, Govt. of India) [undated], "*State of Indian Agriculture 2012-13*," New Delhi [*Accessed June 07, 2014 from*: http://164.100.47.132/paperlaidfiles/AGRICULTURE/State%20of%20Indian%20Agriculture%202012-13%20%28English%29%20with%20cover.pdf]
29. MoWR (Min. of Water Resources, Govt. of India) [2008], "*Integrated Water Resources Development and Management,*" Theme Paper Water Resources Day–2008, New Delhi.
30. MoWR (Min. of Water Resources, Govt. of India) [2014], "*Ganga Basin – Version 2.0*".
31. Nosengo, N. [2003], "*Fertilized to Death (News Feature*)," Nature, Vol. 425, pp 894-895.
32. Pahl-Wostl, C. [2007], "*The implications of complexity for integrated resources management*", Environmental Modelling & Software, Vol. 22, pp 561-569.
33. Parikh, S.J. & B.R. James [2012], "*Soil: The Foundation of Agriculture*," Nature Education Knowledge 3(10):2 [*Accessed April 02, 2014 from:* http://www.nature.com/scitable/knowledge/library/soil-the-foundation-of-agriculture-84224268]
34. Pathak, H. [2010], "*Trend of Fertility Status of Indian Soils*", Current Advances in Agricultural Sciences, Vol.2(1), June 2010, pp 10-12.
35. Planning Commission (Govt. of India) [2007], "*Report of the Working Group on Natural Resource Management*," Vol.1.
36. PSU (Penn State University) [2013], "*Plant Nutrients, Additional Considerations.*" [*Accessed November 11, 2013 from:* http://extension.psu.edu/agronomy-guide/cm/sec2/sec23a]

37. Scholes, C. & Scholes R.J. [2013], *"Dust unto Dust,"* Science, Vol. 342, pp 565–566.
38. Seufert, V., N. Ramankutty & J.A. Foley [2012], "*Comparing the yields of organic and conventional agriculture*," Nature, Vol. 485, pp 229–232.
39. Singh, M.V. (2004), "*Micronutrient deficiencies in Indian soils and field usable practices for their correction*." IFA Intl. Conference on Micronutrients, New Delhi.
40. Thyiagarajan, T.M. & B. Gujja [2013], "*SRI: Transforming Rice Production with SRI (System of Rice Intensification) Knowledge and Practice*," National Consortium on SRI. [*Accessed May 31, 2014 from: http://www.agsri.com/images/documents/sri/sri_book_final_version.pdf*.]
41. Tilman, D. et al. [2002], *"Agricultural Sustainability and Intensive Production Practices,"* Nature, Vol. 418, pp 671–677.
42. Trewavas, A. [2001], "*Urban Myths of Organic Farming*," Nature, Vol. 410, pp 409–410.
43. UNEP (United Nations Environment Programme) [2013]. "The Emissions Gap Report 2013," United Nations Environment Programme (UNEP), Nairobi.
44. UNEP–WHRC (United Nations Environment Programme & The Woods Hole Research Center) [2007], "*Reactive Nitrogen in the Environment: Too Much or Too Little of a Good Thing,*" UNEP, Paris.
45. Vacari, D.A. [2009], "*Phosphorus: A Looming Crisis*," Scientific American, Vol.478, June 2009, pp. 54–59.
46. Wikipedia [2014], "*Soils*". [*Accessed May 28, 2014 from:* http://en.wikipedia.org/wiki/Soil.]
47. Wilkins, R.J. [*2008*], "*Eco-efficient approaches to land management: a case for increased integration of crop and animal production systems*," Phil. Transactions of the Royal Society B, Vol. 363, pp 517–525.