Increasing the Productivity of Underutilized Lands by Targeting Resource Conserving Technologies—A GIS/Remote Sensing Approach

A Case Study of Ballia District, Uttar Pradesh, in the Eastern Gangetic Plains

Parvesh Chandna, D.P. Hodson, U.P. Singh, A.N. Singh, A.K. Gosain, R.N. Sahoo, and R.K. Gupta

Asian Development Bank

CIMMYT.

International Maize and Wheat Improvement Center
Apdo. Postal 6-641, Mexico D.F., Mexico

Rice-Wheat Consortium for
Indo-Gangetic Plains

Increasing the Productivity of Underutilized Lands by Targeting Resource Conserving Technologies-A GIS/Remote Sensing Approach

A Case Study of Ballia District, Uttar Pradesh, in the Eastern Gangetic Plains

Parvesh Chandna, D.P. Hodson, U.P. Singh, A.N. Singh,
A.K. Gosain, R.N. Sahoo, and R.K. Gupta

CIMMYT® (www.cimmyt.org) is an internationally funded, not-for-profit organization that conducts research and training related to maize and wheat throughout the developing world. Drawing on strong science and effective partnerships, CIMMYT works to create, share, and use knowledge and technology to increase food security, improve the productivity and profitability of farming systems, and sustain natural resources. Financial support for CIMMYT's work comes from many sources, including the members of the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org), national governments, foundations, development banks, and other public and private agencies.

Correct citation: Chandna, P., D.P. Hodson, U.P. Singh, A.N. Singh, A.K. Gosain, R.N. Sahoo, and R.K. Gupta. 2004. *Increasing the Productivity of Underutilized Lands by Targeting Resource Conserving Technologies-A GIS/Remote Sensing Approach: A Case Study of Ballia District, Uttar Pradesh, in the Eastern Gangenic Plains.* Mexico D.F.: CIMMYT.

AGROVOC Descriptors: Production economics; Land resources; Land use; Wheat; Barley; Rice; Seedlings; Zero tillage; Cropping systems; Climatic factors; Irrigation water; Technology; Socioeconomic environment; South Asia

Additional Keywords: CIMMYT

AGRIS Category Codes: E16 Production Economics
F01 Crop Husbandry

Dewey Decimal Classif. 338.1

ISBN: 970-648-118-4

Authors

Parvesh Chandna: CIMMYT India/Rice Wheat Consortium, NASC Complex, Pusa, New Delhi-110012, India; Email: p.chandana@cgiar.org

D.P. Hodson: CIMMYT Mexico, Apdo Postal 6-641, C.P. 06600, Mexico D.F., Mexico

U.P. Singh: Dept. of Agronomy, Banaras Hindu University, Varanasi, U.P., India

A.N. Singh: Remote Sensing Application Centre U.P., Sector G, Jankipuram, Kursi Road, Lucknow, India

A.K. Gosain: Dept. of Civil Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110 016, India

R.N. Sahoo: Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi, 110 012, India

R.K. Gupta: CIMMYT India/Rice Wheat Consortium, NASC Complex, Pusa, New Delhi-110012, India

Acknowledgements

Supporting funds for this study were generously provided by the Asian Development Bank (ADB) under the auspices of the project "Study on Sustaining the Rice Wheat Production Systems of Asia". We gratefully acknowledge the support of ADB, and in particular ADB project officer Dr. Pratima Dayal.

Our sincere gratitude goes to Dr. Larry Harrington, Director, Natural Resource Group, CIMMYT Mexico for his support in analysis, publication of results, and inviting one of us (Parvesh Chandna) to the GIS laboratory in Mexico.

The authors thank the Director, Remote Sensing Application Centre, Lucknow, for allowing us to use remote sensing and digital analysis facilities for our study. Mr. Dharmesh Verma (Scientist, RASC, Lucknow) and Narender Kumar (Scientist, RASC, Lucknow) are gratefully thanked for their considerable help in image analysis and in data collection during field visits.

We are also indebted to Dr. Sandhya Rao from Indian Institute of Technology, New Delhi, and Dr. Madurama Sethi from Central Soil Salinity Research Institute, Karnal for their thoughtful inputs in many technical sessions during course of the study. Mr. Ashesh, Mr. Bhanu, and Mr. Pramod are thanked for their considerable help in data collection, ground truthing, and conduct of farmer participatory research trials for evaluating RCTs in different environments.

We thank all the project staff at CIMMYT-India who provided the logistic support and enabled field visits to be undertaken. Shahid Parwez (CIMMYT socioeconomist) is particularly thanked for substantial inputs into the socioeconomics section of the document.

CIMMYT science writer/editor David Poland is thanked for inputs that greatly improved the quality of the original document and Marcelo Ortiz for design and layout.

Abstract

The Indo Gangetic Plains (IGP) of South Asia, formed by the fluvial action of the Indus and Ganges River systems, is one of the world's major food grain producing regions. The region supports some of the most densely populated areas in the world, with more than 300 million people dependent on the predominant rice-wheat cropping system. Satisfying the demands of a growing population, preserving the agricultural natural resource base, and improving livelihoods are huge challenges. There is, however, a significant amount of underutilized land, particularly in the eastern IGP, following the main rice season. If this land was brought into full production, it could substantially improve local food supplies and enhance livelihoods. This case study describes the application of remote sensing/GIS methods to determine accurate distributions and extent of underutilized land in the district of Ballia, eastern Uttar Pradesh. Appropriate resource conserving and productivity enhancing technologies are described that offer promising solutions to the underutilized land problems identified in the study. The methodology described offers great potential for targeting and diffusing technologies in an efficient and effective way, and for assessing their impact. Scaling-up of the techniques and application to a wider area could be readily achieved.

Classification of temporal satellite data (IRS LISS III images) permitted the identification of all major categories of underutilized land during the post-rainy rabi season, with an accuracy of approximately 90%. Underutilized land types identified included current fallows, excessive moisture areas, waterlogged areas (*tal and chaur lands*), salt-affected lands and diara lands (riverside areas). Total underutilized land in 2001–02 covered 76,347 ha, which represented 26.70% of the district's total cultivable area. Current fallows were the predominant category of underutilized land, accounting for 48% of the total. As well, under-productive, late-planted wheat covered at least 60% of the district wheat area. Earlier planting dates alone, achieved through zero tillage crop establishment, could easily increase district wheat production by 70-75,000 tons. Technology options suited to each category of underutilized land were identified; these included zero tillage, bed planting, surface seeding and boro rice. Outputs from this case study may provide decision-makers with essential information to successfully plan and deploy appropriate technologies in the most effective manner. Resulting productivity and economic gains from underutilized lands are likely to benefit some of the region's poorest farmers.

Contents

Introduction

In the South Asia, in countries belonging to the Rice-Wheat Consortium (RWC)—Bangladesh, India, Nepal, and Pakistan—nearly half of the total land area is devoted to agriculture (401.72 million hectares) and used to feed and provide livelihoods for 1.8 billion people (FAO, 1999). Suitable thermal regimes for rice and wheat crops during the annual cycle, development of short duration cultivars, expansion of irrigation, use of external nutrient and chemical inputs have all helped to improve the soil-plant environment and productivity of these crops. Ever-increasing demand for food and market support were the driving forces for expanding acreage of rice-wheat systems during the Green Revolution of the 1970s. Rice wheat (RW) systems occupy in excess of 12 million hectares (Hobbs and Morris, 1996; Ladha et al., 2003), and contribute more than 80% of the total cereal production in the RWC countries (Timsina and Connor, 2001). Thus, intensively cultivated irrigated rice-wheat systems are fundamental to employment, income, and livelihoods for hundreds of millions of rural and urban poor of South Asia (Evans, 1993; Paroda et al., 1994). Recently, the sustainability of the system has been questioned with several reports indicating that continuous production of rice-wheat systems has fatigued the natural resource base (Abrol et al., 2000), thus threatening food security in the region.

Whereas the northwestern parts of the IGP experienced unprecedented growth in RW systems during the Green Revolution era, agriculture in drought and flood prone areas of the eastern IGP-embracing parts of the Indian states of Uttar Pradesh (UP), Bihar, West Bengal, as well as portions of Bangladesh and the eastern Terai of Nepal-was largely bypassed. The eastern IGP supports some of the most densely populated areas on earth, with more than 300 million people living on 34.64 million hectares (Census of India, 2001; World Development Indicator Database, 2000), and largely dependent on rice-wheat cropping systems. In India, the political strategy for food security has largely relied on transporting food produced in the northwestern states of Punjab and Haryana to feed people in the eastern Indian states. This illustrates that the input-intensive technology package and strategy used to develop irrigated agriculture in Haryana, Punjab, and western parts of UP and the Terai of Uttranchal were not as successful in the eastern IGP. This was largely due to the inability of farmers in the east to improve the soil-plant environments needed for improved performance of modern cultivars.

Rice-wheat cropping systems in northwestern IGP (transect one to three; see Fig. 1) are distinctly different from those in eastern IGP (transects four

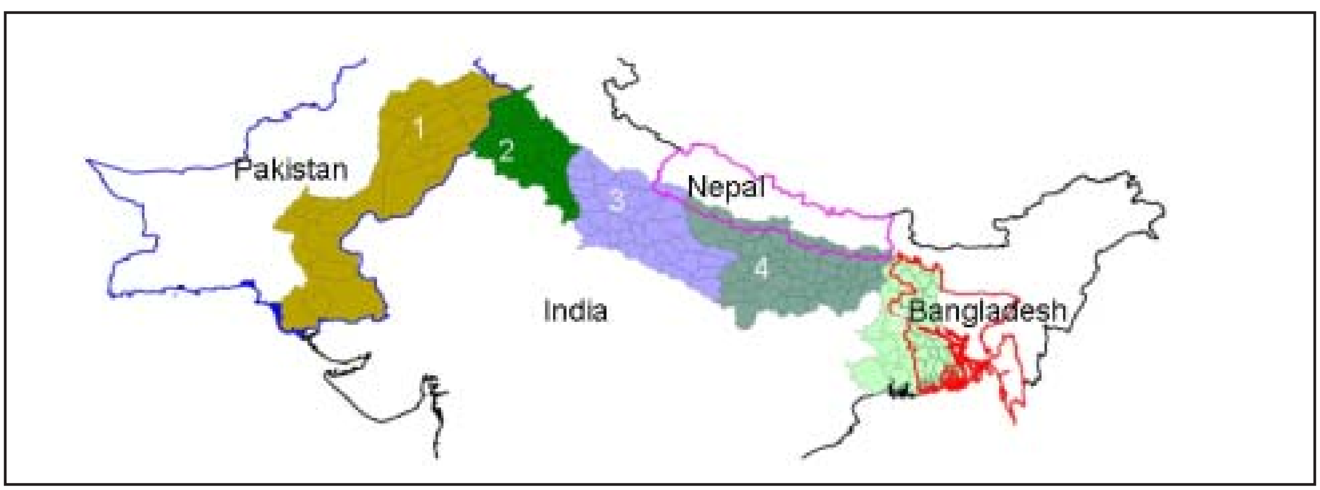


Figure 1. Transect map based on agro-ecological zones of Indo-Gangetic plains.

and five; see fig. 1). In the northwest, RW cropping systems are characterized by larger farm holdings that are highly mechanized, input intensive, and dependent on the conjunctive use of surface and ground waters. In eastern IGP, the RW system is labor intensive, less mechanized, uses low inputs and faces serious problems of excessive water during the monsoon season. Crop diversification is apparently greater in eastern regions because of higher risks associated with crop production as compared to the northwest. Socioeconomic endowments are relatively better in the northwestern IGP than in the eastern IGP. The RW cropping system encounters the problems of sustainability throughout the IGP, with low input–use efficiency in the northwestern region, and low production and productivity in the eastern region (Rai, 2002).

A major obstacle to productivity enhancement in the eastern IGP has been the absence of suitable tillage and planting techniques appropriate to subhumid climatic conditions. The resulting effect is that farmers cannot make the best use of their fertile land, plentiful water supplies, and abundant plant genetic resources, despite climatic conditions that favor several crops such as winter maize, wheat, potato, lentil, chickpea and boro rice.

To improve livelihoods for the rural poor of eastern IGP, the agricultural system must be rejuvenated through the introduction of a new generation of agronomic and crop management technologies appropriate to subhumid climates. Tremendous opportunities exist within the RW cropping systems of the eastern IGP, if underutilized but potentially productive land and water resources can be used to their full potential. Efficient and more effective utilization of existing resources could turn one of the most impoverished regions of South Asia into a granary and serve as a key source of productivity growth for meeting future food requirements.

It is a common knowledge that a large area in the eastern IGP remains fallow after the kharif/aman rice season (monsoon season). The main reasons for 'rice fallows' include

- unavailability of irrigation water for preparatory tillage in many uplands, mid-lands and diara lands [Note: Total diara lands in UP and Bihar is more than 2.40 million hectares (Gangwar, 1974).];
- excessive soil moisture precludes preparatory tillage for planting of winter season crops;
- floodwaters recede late in the winter crop season from tal lands (Note: Total flooded area annually in Bihar alone is typically more than 2 million hectares (UN report, 2002) and even larger areas of Bangladesh and West Bengal are flood prone);
- runoff water not vacating fields (waterlogging) in chaur lands (Note: Waterlogged areas in UP, Bihar, and West Bengal cover more than 0.7 million hectares (NAEB, 2003); and
- excessive presence of aquatic weeds.

It is estimated that 6.7 million hectares of potentially productive lands throughout the eastern IGP remain underutilized and fallow following the summer or kharif rice crop (Subbarao et al., 2001).

It is worth mentioning that the eastern IGP also suffers from monsoon season floods of varying intensity, duration, and timing. Government statistics indicate that flood affected areas in Bihar alone in the drought year of 2002 totaled 1.82 million hectares (UN, 2002) Therefore, it is essential that agricultural development in such environments consider risk management that fully incorporates flood-related information.

This case study focuses on the district of Ballia in eastern UP. It outlines major causal factors of land underutilization, describes potential technological solutions, and applies remote sensing/GIS methodology to determine the extent and spatial distribution of underutilized land. This information permits a matching of land use characteristics with available technologies, which can then guide the targeting of appropriate technologies and extension efforts aimed at enhancing agricultural productivity and improving livelihoods.

Cropping Systems, Climate, and Irrigation Trends in the Eastern Indo-Gangetic Plains: An Overview

Major Cropping Systems

In the RW cropping system, several temporal and spatial variations in the relations of the two crops of the system are observed. Rice and wheat may be grown (i) in the same plot, (ii) in different plots during a year, and /or (iii) in the same plot in different years. While rice and wheat may be the main crops grown in same plot in the same year, other crops such as maize, Indian-mustard, mungbean, lentil, sesame, black gram, pigeon pea, potato, and sugarcane are also replacement or intercrops in RW systems. In the eastern IGP (U.P., Bihar, West Bengal and Bangladesh), many farmers grow three rice crops in a year, namely the *aus* (April to July), *aman* (July to November), and *boro* rice crops (November to April). Boro rice is generally grown in poorly drained low-lying areas with access to supplemental irrigation. In low lying areas of eastern UP, Bihar, and parts of Bangladesh, where water recedes late or soils remain wet for long periods, farmers sow lentil, peas, and wheat—depending on the dryness of the soil—a couple of days before the harvesting of rice (Razzaque et al., 1995; Timsina and Connor, 2001; Gupta et al., 2002). Some farmers in the IGP grow greengram (mungbean) *(Phaseolus aureus* Roxb.*)* and cowpea *(Vigna sinensis* Salvi*)* during the transition phase between wheat and rice transplanting. In our understanding, farmers in the eastern IGP diversify the RW systems mainly as a risk management strategy in a region that is prone to drought and floods. Many farmers replace wheat with oilseeds (*Brassica juncea* Coss. *or napus*), pulses (pea, *Pisum sativum* L.), grass pea (*Lathyrus spp.*), chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medic), potato (*Solanum tuberosum* L.), or sugarcane (*Saccharum officinarum* L.), and occasionally, rice is replaced by pigeonpea (*Cajanus cajan* Milsp), maize (*Zea mays* L.), sunflower (*Helianthus annuus* L.), soybeans (*Glycine max* Merr.), and sorghum (*Sorghum bicolor* Moench). Winter maize is highly productive and very popular in Bihar and eastern UP, and Bangladesh.

In the eastern IGP, unless wheat is planted during the second half of November, yields decline drastically due to a shortened growing season. Consequently, to improve wheat productivity, it is crucial that rice vacates the fields early in the winter season. Herbicide resistance to isoproturon in *Phalaris minor* Retz., is not yet a major problem for wheat production in the eastern IGP.

The major cropping systems practiced by the farmers in the eastern IGP are outlined in Box 1.

Box 1. Major rice based cropping systems in eastern Indo-Gangetic Plains (all ecologies included: uplands, midlands and low lands)

- Rice-Potato-Wheat
- Rice-Jute/Rice
- Rice-Wheat/Boro Rice
- Rice-Potato-Winter Maize
- Rice-Potato-Rice (Boro)
- Pigeonpea + Greengram-Wheat
- Rice-Potato + Maize/Boro Rice
- Rice + sesame + Maize + Mungbean (Spring) - Boro Rice

There are wide variations in soil types, physical infrastructure, and market support systems in the eastern IGP. Irrigated and rainfed agriculture coexist in most districts. This has led to a mosaic pattern of agricultural development. A mentioned earlier, many areas in the eastern IGP are prone to seasonal floods during the monsoon season. The soils in eastern IGP are coarse textured in north Bihar and finer textured in south Bihar, eastern UP, and Bangladesh. Acidic soils are also found in the subhumid eastern plains and are generally deficient in boron. Most alluvial soils in the IGP are deficient in nitrogen. Deficiencies of phosphorus and zinc are next in order. Because of the micaceous nature of the soils, use of potassium fertilizers has been avoided. There is an urgent need for adoption of appropriate measures to optimize the NPK fertilizer use ratio.

The finer textured soils found in lowland ecologies have alluvial "vertic" characteristics leading to excessive cracking on drying or cloddiness when wet, making them often difficult to manage. Such areas in eastern UP and Bihar have inadequate groundwater development for irrigation, especially critical prior to the main monsoon season rice crop. As a result, farmers begin tillage operations for rice nurseries after the first monsoon shower. As a result of this delay farmers lose nearly 400 mm of precipitation and leave the rice crop vulnerable to terminal drought at the end of the season.

Water Availability

Rainfall patterns

In the eastern IGP most of the annual rainfall is received during the summer (June-September) monsoon season **(**Table 1). In the wheat **(***Triticum aestivum, T. durum***)** growing season, only a few showers fall between December and February.

From January to March, when the major wheat areas are in critical need of water, rainfall contributes only 6.4% of the annual rainfall in eastern UP and 15% in Gangetic West Bengal. Thus, the wheat crop's water requirement must be met through irrigation from surface and ground water sources. The eastern IGP lends itself to RW cropping systems by virtue of annual rainfall in the range of 750-1250 mm and soil moisture availability for plant growth for at least 150 days. In such areas, farmers generally need only protective irrigation to ameliorate the risk posed by drought to the rice crop. In the rest of IGP, having less than 750 mm rainfall, both rice and wheat crops depend largely on assured availability of irrigation water. In eastern parts of the IGP, with areas receiving less than 1000 mm rainfall, farmers generally grow rainfed rice and irrigate wheat through ground water development. It is in this zone that small interventions, which promote early rice seedling raising/transplanting, can have a major impact on overall system productivity. This is discussed in the following sections.

Table 1. Rainfall Pattern in the Indo-Gangetic Plains

S.No.	Name of ecozone	Annual rainfall (mm)	Percentage of annual rainfall			
			January-Feb.	March-May	June-Sept.	Oct. – Dec.
1.	GangeticWest Bengal	1425	2.7	12.4	75.6	9.8
2.	Bihar Plains	1202	2.9	6.1	85.0	6.0
3.	East Uttar Pradesh	1008	3.4	3.0	82.2	5.6
4.	West Uttar Pradesh	964	5.1	3.9	87.0	4.0

Moisture availability periods

An analysis of the range of moisture availability periods in different states of eastern India is presented in table 2. It indicates that in addition to a long humid period there are two relatively short moist periods (I and II) during which the rice crop undergoes drought-like conditions under existing farmers' practices. Unfortunately, farmers invariably use about 400–600 mm of rainfall in puddling and field preparations before transplanting, resulting in a water deficit during moist period-II (for 10–12 days) and reduced yields. Raising weir or peripheral field bund height to 15–20 cm could capture a lot of excess rainfall (Mishra et al., 1997), easing the drainage congestion and at the same time improving rice productivity. A similar recommendation has been made for the Sunderbans deltaic regions of West Bengal (Rao, 1994).

Mishra et al. (1997) have shown that when drainage congestion problems are eased, it encourages farmers to adopt improved technologies and use costly inputs (fertilizer, integrated pest management, and high yielding varieties [HYV]). In eastern India, this could increase productivity of rice by more than 20% on nearly 25 million hectares of cropped subhumid alluvial and red soils found in the region. To actualize this increased productivity, there would need to be additional investments in rainwater management and identification of the blockage points that clog the natural drainage system. Remote sensing methodologies could prove useful in speedy identification of critical areas for decongestion of natural drainage outlets and so enhance the pace of adoption for improved agronomic practices.

Table 2. Range of moisture availability period in different states in eastern India

States	Range of moisture availability periods, days		
	Moist-I	Long Humid	Moist-II
MadhyaPradesh (eastern)	10-16	103-147	12-21
Uttar Pradesh (eastern)	12-18	81-123	17-22
Bihar	12-18	95-139	17-22
Orissa	12-24	131-165	15-18
West Bengal	16-28	130-208	11-22
Assam	25-33	191-270	17-22
Other NE States	21-28	224-278	9-17

Source: Personal communication, S.R. Singh, Directorate of Water Management, Patna

Irrigated acreage of rice and wheat in the IGP

Assured availability of irrigation water and its judicious management plays a vital role in enhancing crop productivity along with the adoption of improved cultivars, and scientific soil fertility and pest management practices. Wheat area under irrigation in India varies from a low of about 88% in Bihar to a high of 97% in Punjab (Table 3). Likewise, rice area under irrigation ranges from 27% in West Bengal to 99.8% in Punjab.

Socioeconomic Aspects of the Indian Eastern Indo-Gangetic Plains

The eastern IGP of India consists of the states of Bihar, UP, and West Bengal. Uttar Pradesh is the most populous state in the country with an estimated population of 166 million (16% of the total population of the country) in 2001. Bihar is India's fifth largest state in terms of geographic area and the second most populous state with an estimated population of nearly 83 million. West Bengal accounts for 80 million people. Population densities are very high in the region. West Bengal has the highest number of persons at 904/km^2, followed by Bihar (880/km^2), and UP (689/km^2), in contrast to the national average of 324/km^2. The infant mortality rate for UP is 87 per 1000 live births, well above the national average of 75, while the corresponding figures for West Bengal and Bihar are 55 and 67, respectively.

Table 3. Percent irrigated area under rice and wheat in the Indian states of Indo-Gangetic plains during 1995-96

Name of the state	Percent irrigated area under rice	Percent irrigated area under wheat
West Bengal	27.2	89.3
Bihar	40.2	88.4
Uttar Pradesh	62.3	92.5
Haryana	99.4	98.3
Punjab	99.8	97.1

Source: Agricultural Statistics at a Glance, 1999, MOA, DAC. GOI

The estimated per capita net domestic products for Bihar, UP, and West Bengal, for 1995–96, were US $100, $179, and $274, respectively, compared with US $274 for India nationwide, and US $453 for Punjab, the nation's richest state. Nearly 87% of Bihar's population lives in rural areas, with 79% of the working population depending on agriculture. Agriculture contributes 59% of the gross domestic product originating from the state. Estimates for 1999-2000 indicate that in Bihar, 43% of the population was living below poverty line, as opposed to the national average of 26%. The corresponding figures for UP and West Bengal are 31% and 27%, respectively. Given the very large populations, this translates into vast numbers of poverty stricken people. Indeed, it is estimated that 8% of the world's poor live in UP (World Bank, 2002).

The states of the region are also among the most illiterate in the country. In 1999–2000, literacy rates for Bihar and UP were 48% and 57%, respectively, compared to the national average of 65%. Only West Bengal rated above the national average with a literacy rate of 69%. In terms of rural literacy, Bihar had the most illiterate rural population of the three states (55%) compared to the national average (44%). It is estimated that the proportion of agricultural laborers to the total workers in the state is 51% in Bihar (the highest percentage in the country [NIRD, 2001]), 29% in UP, and 33% in West Bengal, compared to the national average of 33%.

The eastern IGP of India may be characterized as a poverty stricken agrarian society. The farming community consists of small-scale, marginal, and landless laborers. The average landholding size is 0.89 ha (Thakur et al., 2000). The predominant cropping system is rice-wheat. In terms of agricultural technologies, most of the farmers use modern varieties of rice and wheat. There are a number of agricultural technologies being promoted by different institutions in the region. The Rice Wheat Consortium (RWC) is actively involved in promoting resource conserving technologies (RCTs). Among them, zero tillage in wheat after rice is spreading fast in Bihar and UP as it has helped farmers increase farm productivity and profitability and reduce fallow land area.

Major Causal Factors of Land Underutilization and Reduced Productivity

A variety of interlinked factors contribute to the underutilization of potentially productive lands or reduced productivity in the eastern IGP. The most important of these are outlined below.

Late Planting of Wheat and Barley

Rice (kharif, monsoon season), wheat, maize, barley (winter season) and boro rice are the main cereal crops grown in Ballia and other eastern districts. Late planted rice, often of long duration, or medium tall rice planted in midaltitude and lowlands, generally vacate the fields too late to permit optimal sowing of crops in the winter season. In addition, the common practice of drying rice *in situ* for several days before threshing delays quick drying of wet soils for conventional preparatory tillage and subsequent planting. Planting of winter season crops is also delayed due to very wet soils drying slowly in humid environments. In flood prone low-lying areas (chaur and tal lands), water recedes slowly, restricting timely access for land preparation. Late planting results in a substantial reduction in productivity (see Fig. 2). Significant improvements in the productivity of the RW system could be achieved through timely planting of rice and subsequent timely planting of wheat or other winter crops. To achieve this, farmers need to conserve some groundwater for raising rice nurseries to allow transplanting with the onset of the monsoon rains. Results from a large number of farmer participatory trials conducted for several years in a nearby district of Bihar (Patna) revealed that annual productivity of a RW system could be nearly 12 t/ha if rice is transplanted close to June 25–July 5. This scheduling would also facilitate utilization of 80–90% of the season's rain water.

Similarly for wheat, Oritz-Monasterio et al. (1994) reported a yield decline at the rate of 1–1.5% per day when wheat is planted after mid-November. Slope of the line varies by variety and year, but the general trend of declining yield is consistent. Late planting not only reduces yield, but also the input-use efficiency of the wheat crop. Optimal planting dates vary from region to region, depending on the agroclimatic conditions, but wheat planted in the third week of November yields best in eastern UP and Bihar. It is estimated that more than three-quarters of the total wheat planted in eastern IGP is under late planting.

Figure 3 illustrates the response of wheat to date of planting in the Indian Punjab and Bihar. Slopes of the response curves are gentle for the Punjab (Fig. 3a) compared to those in Bihar (Fig. 3b). Comparison of these yield response curves clearly indicates that late planting has a much greater negative effect on wheat yield in the eastern IGP than in the northwestern plains. These data indicate that farmers accumulate wheat yield losses of up to one metric ton per hectare by delaying planting until 5 December in the eastern plains.

Farmers in the northwestern IGP, however, suffer losses of only five quintals for the corresponding planting dates. Thus, rate of yield decline in the eastern IGP due to late planting is 1.5–2.0 times the rate found for northwestern IGP. This is primarily due to a short winter window available for growth and reproduction of wheat in the eastern IGP.

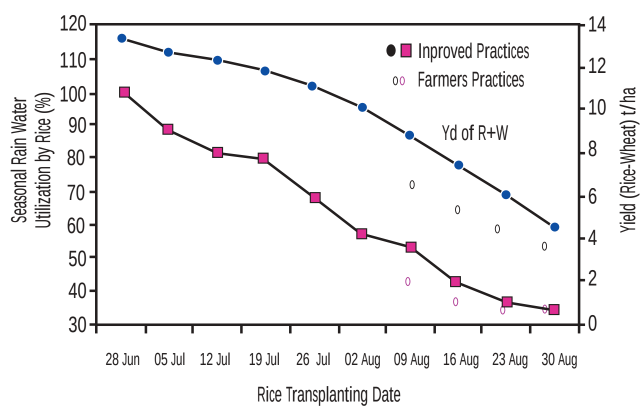


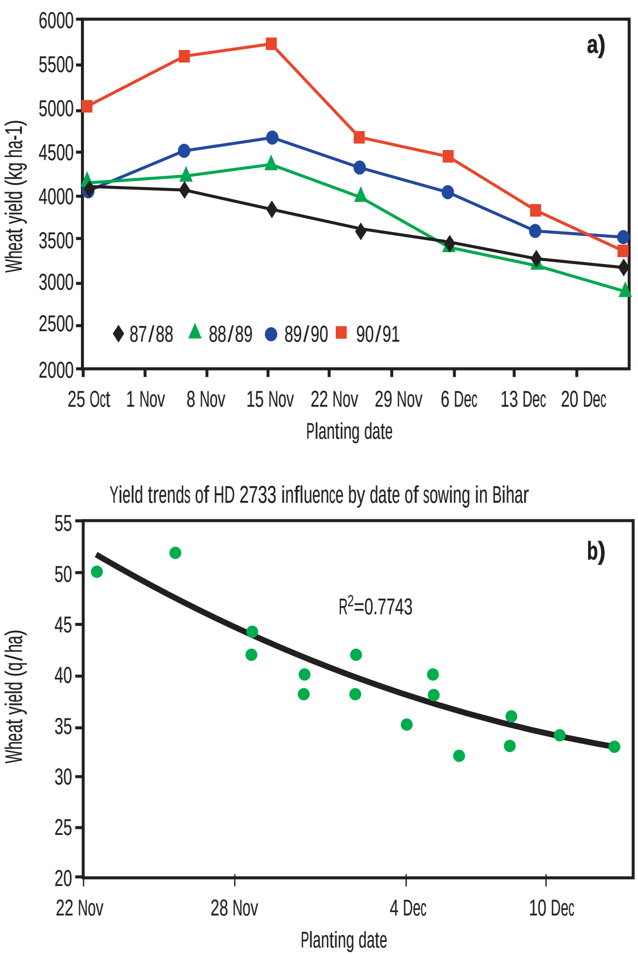
Figure 2. Effect of timely rice transplanting on rainwater utilization and productivity of the rice-wheat system (adapted from S.R. Singh, 2000, DWMR).

Waterlogging

Waterlogging can be caused either by ingress of water when rivers are in spate (in tal, chaur, and diara lands), congestion in the natural drainage system during heavy rains, late receding of floodwater, or local effects of perennial water bodies. The low-lying ecology of the eastern IGP makes this a widespread natural phenomenon and many areas remain fallow as a result. Runoff from uplands and midlands to low-lying areas also causes temporary waterlogging conditions in many areas.

Salinization and/or Alkalization

Salt-affected lands occupy more than 2.5 million hectares in the IGP of India (Gupta and Abrol, 1990).



Reference: RWC. 2003. Agenda Notes of the 11th Regional Technical Coordination Commitee Meeting, Kathmandu, Nepal. 4-6 March 2003. Rice-Wheat Consortium for the Indo - Gangetic Plains, New Delhi.

Figure 3. Effect of planting date on wheat yield (a) in the Indian Punjab, 1987/88 – 90/91 (after Hobbs and Gupta, 2001a) and (b) in Bihar (RWC, 2003).

In the eastern plains, most of the salt-affected lands are alkali in nature, have pHs >8.4; and exchangeable sodium percentage (ESP) >15. A Na/Cl or Na/($Cl+SO_4$) ratio > 1.0 reflects the presence of sodium carbonates in aqueous saturation paste extracts. With carbonate/sulfate salinization, the alkali soils of the eastern IGP exhibit electrical conductivities of saturated paste extracts often greater than 4dS/m at 25C. In alkali soils, adverse effects of high ESP and high pH on the soil's physical properties are most apparent after irrigation or when rain water stagnates for long periods in low relief spots. Upon drying, these soils become very hard and develop cracks. Cultivating these soils without chemical amendments leaves the surface cloddy, resulting in poor germination and spotty crop stands.

Nonavailability of Irrigation Water

In most parts of the eastern IGP, farmers generally do not develop groundwater for irrigation during the monsoon season. Groundwater development is mainly during the rabi season (winter season). Canal irrigation is mainly through diversion of surface water from river systems and/or lift irrigation systems based on perennial surface water bodies. Field observations indicate that lift irrigation systems are usually not fully functional and do not operate at times when water supplies are required, e.g., for pre-sowing irrigation or crop saving irrigation. As an example, the lift irrigation system based on Surah Tal in Ballia district, which serves a sizeable area around the tal, is virtually unutilized. Lack of proper irrigation facilities is thus a major cause of lands remaining fallow during the winter season in the eastern IGP. This problem is more severe in upland areas (rainfed agriculture), and the diara lands (riverside areas).

Available Technology Options

Tillage and agronomic practices for establishment of RW systems differ considerably between the eastern and northwestern IGP. Farmers in the eastern plains establish crops based on socioeconomic conditions, seasonality of labor, soil moisture availability, waterlogging/flood situations, local weather conditions, and availability of inputs and tractor power. Diverse combinations of these factors dictate how farmers plant. Therefore, a generalized package of agronomic and crop management recommendations is unlikely to work in upland and lowland areas and flood prone situations having variable infrastructure for irrigation. Farmers need options for addressing site-specific and complex natural resource management problems. Agronomic and crop management practices vary depending on how crops are established. Therefore, to effectively integrate improved interdisciplinary crop production activities, tillage and crop establishment methods must take precedence. This implies a need to fine tune existing tillage and crop establishment technologies for diverse agroecological situations. The final goal is to reduce "rice fallows," enhance productivity, reduce production costs and risks of drought/flood prone agriculture, and so move towards agricultural sustainability for the eastern IGP.

To make the best use of land and water resources and to reduce 'rice-fallow' lands, farmers must be able to plant the unutilized lands. Traditional tillage practices are inappropriate in excessively wet, waterlogged and dry soil conditions because they delay planting. Resource conserving technologies (RCTs), such as zero tillage, surface seeding, and bed planting have considerable potential to sustainably improve productivity of the RW systems in the eastern IGP (see Tables 4a, 4b), when appropriately targeted.

Many RCTs could significantly promote higher production on currently underutilized land. Through efforts of the RWC partners, the benefits of many of these RCTs have been demonstrated and are now being widely adopted by farmers. A brief overview of the main RCTs follows.

Zero Tillage

Zero tillage, as the name implies, is a crop planting system that entails no prepatory tillage (plowing, harrowing, etc.). Within the IGP this was first tested in Pakistan (Sheikh et al., 1993; Aslam et al., 1993) and has since spread throughout the IGP, following promotion by the RWC (Hobbs and Gupta, 2001a). With zero till seed-ferti-drills soil disturbance is minimal. The drill uses either 'inverted-T' or chisel type openers to create narrow slits (2–3 cm wide and 5–10 cm deep) for sowing of seed and incorporation of fertilizer while minimizing soil disturbance. The zero till-ferti-seed drills, originally developed in New Zealand, work well in the presence of anchored crop residues. Raking of residues is a problem with 'inverted-T' or chisel type openers when loose residues are present. If loose crop residues are present e.g., from previous combine harvested crops, a drill with coulter type double disk openers or punch planters can be used effectively.

If farmers do not have ready access to zero till ferti-seed drills and/or face excessive weed problems, reduced till options may be favored rather than zero till. In reduced tillage, farmers plough only once or

Table 4a. Average yields of improved rice cultivars in farmer participatory sites in Ballia, U.P. during the kharif season

		Rice Yield Under Different Practices			
S.N.	Variety	Bed Planting (t ha $^{-1}$)	Zero Till (t ha $^{-1}$)	Un-Puddled Transplanting (t ha $^{-1}$)	Conventional Tillage (t ha $^{-1}$)
1.	Sambha Mahsuri	3.75 (1)	3.7 (3)	4.4 (4)	3.6 (2)
2.	Sugandha	4.55 (4)	—	5.25 (2)	3.9 (2)
3.	Swarna	—	5 (3)	5.2 (1)	4.6 (2)
4.	Sonum	5 (2)	4.3 (1)	3.26 (1)	—
5.	Jallahri *	—	3.2 (2)	2.75 (1)	2.78 (1)
6.	Prabhat	4.8 (2)	—	4.96 (1)	4.2 (1)
7.	RVT -1	6.4 (1)	—	—	—
8.	Sarjoo-52	—	4 (2)	—	4 (1)

Table 4b. Average yields of improved wheat cultivars in farmer participatory sites in Ballia, U.P. during the rabi season

		Wheat Yield Under Different Practices		
S.N.	Variety	Bed Planting (t ha $^{-1}$)	Zero Till(t ha $^{-1}$)	Conventional Tillage(t ha $^{-1}$)
1.	PBW -343	5.2 (1)	4.23(10)	3.26 (3)
2.	PBW-154	3.7 (1)	4.1(5)	3.2 (2)
3.	HD- 2338	—	4.0(3)	—

* Indicates deep water variety,

Note: Number of participating farmers is given in brackets.

twice before seeding. The major benefits of these technologies are given below:

- Reduced costs due to savings in fuel and labor
- Timely planting of kharif and winter season crops, resulting in higher yields (Table 5, Fig. 4)
- Lower density of herbicide resistant *Phalaris minor* in comparison to traditional tillage, a major weed of rice wheat system
- Significant irrigation water savings (up to 15-20%)
- Improved input use efficiency because of the right placement of seed and fertilizer nutrients
- Better plant stands
- Less burning of crop resides

Surface Seeding

Surface seeding is the simplest zero tillage option. Seed is simply broadcast on a water saturated soil surface without any land preparation and in the presence of crop residues. This is very similar to traditional farmer practices for crop establishment of wheat, legumes, and other crops in many parts of the eastern IGP. The key difference being that in traditional systems farmers plow the land before broadcasting the seeds. Surface seeding is particularly suitable for areas with fine textured soils and poor drainage or where land preparation is difficult and often results in a cloddy tilth. A correct assessment of soil moisture and seeding at the correct time are critical to the success of this practice. If soil moisture is less than optimal, farmers may first broadcast seed and then apply irrigation to improve soil wetness to enhance seed germination and facilitate root penetration. The advantages of this system are its simplicity, making it accessible to even the poorest farmers, and it's enabling of timely sowing in areas where planting machinery is not available (Fig. 5).

Table 5. Yield of wheat as affected by tillage systems in eastern IGP (eastern UP and Bihar) in 2002.

			Average yields t / ha				
State	Districts	No. of Farmers	Zero Till	Reduced Till	Beds	Surface Seeding	Conventional Till
Bihar	12	1800	3.35	3.20		3.3	2.98
Eastern UP	16	1500	3.65	3.42	4.5	3.2	2.67
Bangladesh	-	-			5.21	-	4.02

Source: Kumar and Singh, 2002, S.R. Singh pers communication, and RTCC report 2002.

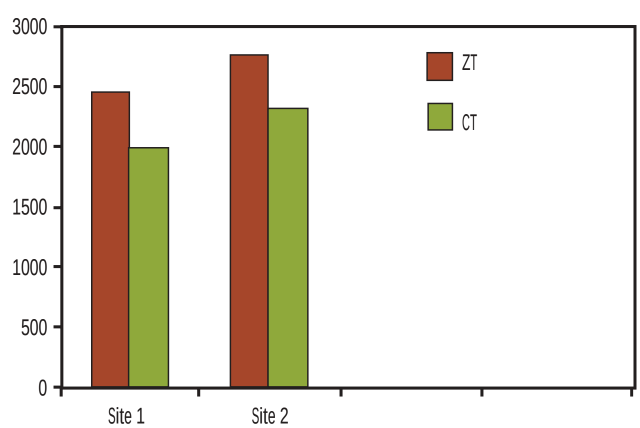


Figure 4. Wheat productivity enhancement through zero tillage (ZT) in comparison to conventional tillage (CT) at two sites in Phulwari Sharif, Bihar.

Furrow-Irrigated Raised Bed Planting

In furrow-irrigated raised bed planting systems (FIRB), crops are grown on raised beds and furrows are used for irrigation. Sometimes farmers also plant an intercrop (e.g., mint, linseed, maize, and sugarcane) on the sill of the furrows, with the main crop planted on the ridges. This technology provides farmers with an opportunity for crop intensification, plus substantial savings of irrigation water. The FIRB planting system is suitable for areas where water supplies are scarce and where temporary waterlogging conditions adversely affect crop yields. The FIRB systems are also suitable for partially reclaimed alkali soils because they increase the soil depth for rooting. Based on estimates from experiments carried out by the RWC, there is a water

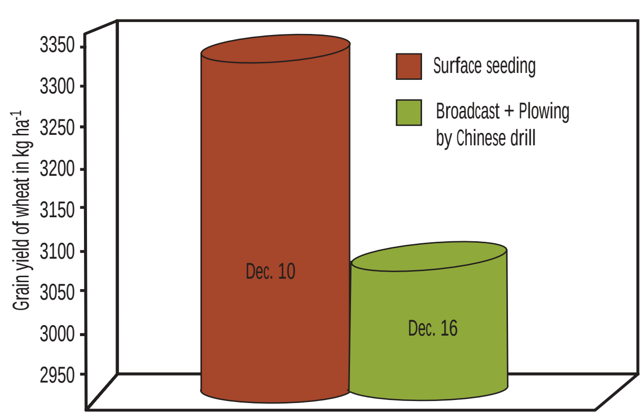


Figure 5. Beneficial effects of surface seeding on planting date and wheat yield in Hazipur, Bihar.

saving of 30–40% compared to conventional practice (Mann and Meisner, 2003). Benefits include

- improved irrigation water use;
- fewer weeds, and these can be controlled mechanically;
- facilitation of seeding into relatively dry soils and post sowing irrigation;
- better plant stands and more vigorous seed;
- lower seeding rates;
- less lodging;
- better drainage, which result in less waterlogging and crop damage;
- improved rainwater conservation; and
- improved crop productivity (Fig. 6).

Targeting Solutions to Problems

Effective promotion of RCTs for underutilized lands will require a well-organized database of land information that includes distribution and extent of certain land types and areas with specific problems (e.g., soil moisture shortages, excessive wetness, salt-affected lands, and flood events). Geographic information systems and remote sensing technologies provide unique tools for achieving this goal and backstopping planning for and up-scaling of agronomic practices in problem areas. Application of remote sensing can help gather important data for pre-planning diffusion and targeting strategies of RCTs. Such data includes

- geographic occurrence and extent of underutilized areas;
- qualitative description of the causal factors for the lands remaining unutilized (e.g., waterlogging, excessive wetness, and salinity);
- extent of flood-affected areas, periodicity, and duration of floods;
- congestion points in natural drainage systems;
- drainage patterns of natural water bodies and areas becoming available for planting on different dates; and
- arable lands planted late in the season.

This information can greatly help in appropriately targeting the RCTs in a focused and precise manner on a regional scale, with the overall objective being more efficient use of scarce resources and effective technology transfer.

The current study applies GIS tools and remote sensing techniques to identify and quantify underutilized lands in order to accelerate the efficiency and precision of scaling-up of RCTs. Remote sensing, in particular, using time series data, can play an important role in the identification and demarcation of underutilized lands on a regional basis.

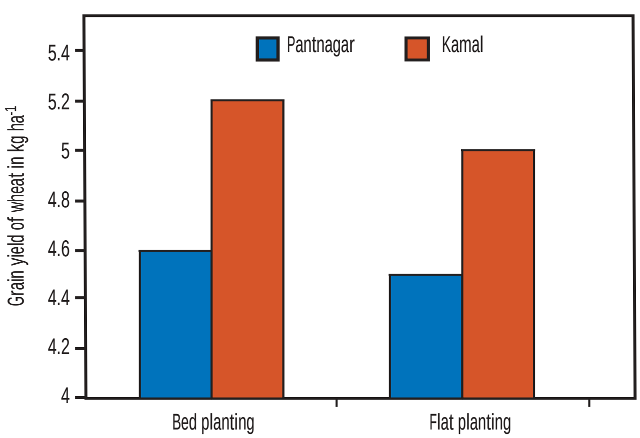


Figure 6. Comparison of bed versus flat planting in farmer fields in Pantnagar (n=3) and Karnal (n=8), India 1998-99 (Hobbs, 2001).

Materials and Methods

Study Area

This case study, undertaken in 2001–02, focused on Ballia district, eastern UP, India (Fig. 7). Ballia district covers 329,023 hectares and lies on the border of UP and Bihar, between 25º 33′ to 26º 11′ north latitude and 83º 40′ to 84º 38′ east longitude. Total cultivatable area of the district was estimated to be 285,361 hectares.

Ballia district is situated in alluvial plains between the Ganges and Ghagara river systems. The Ganges flows along its southern border while the Ghagara flows along its northern border, joining the former at some 60–70 km east of Ballia town. Within the district there are numerous natural riparian features like, tals (standing water bodies), oxbow lakes, point bar complexes, cut off meanders, buried channels, diara lands, and other natural depressions. These natural features create conditions of excessive moisture, sodicity due to high watertables, and waterlogging in lowland parts of the terrain following major rainfall or when rivers change courses.

Figure 7. The geographical location of Ballia, eastern U.P, India. The pink shaded area represents transect four of the IGP.

Agriculture is the predominant economic activity and land use in the district. Cereal based (rice, wheat, barley) cropping systems occupy most arable lands in the district, making it representative of the agricultural systems typical of the surrounding region. Sugarcane is grown in the Ghagara river belt and in part of Rasra Block in the northwest of the district. Other rotations are wheat-maize, wheat–mungbean, rice-mustard, maize-potato, rice–linseed, rice-cucerbits, rice-lentils etc. Many farmers grow pigeon pea in uplands and chickpea and lentil in lowland and tal areas. In diara lands, wheat is grown during the rabi season and boro rice during March/April after wheat. Boro rice is very popular in the diara lands of Ghagara River and in areas close to Parbodpur village in southeast Ballia. Major cropping patterns throughout the year are illustrated in the crop calendar (Fig. 8).

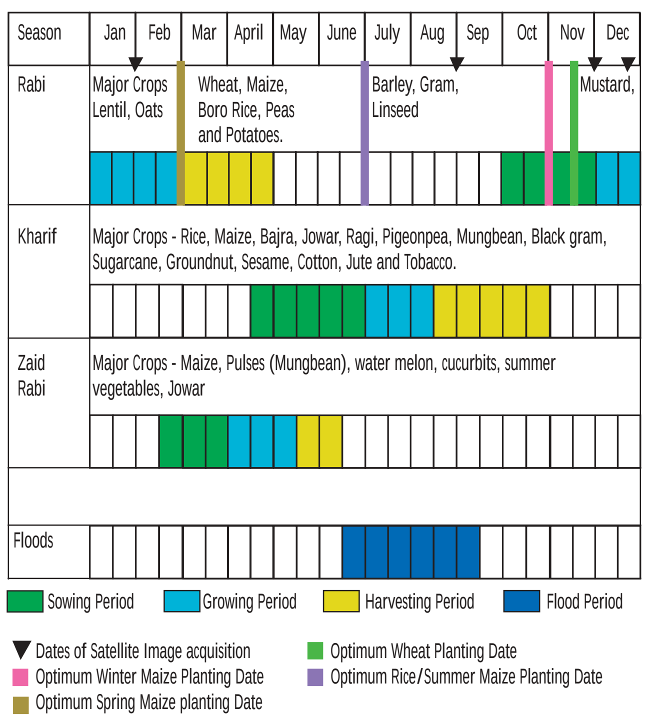


Figure 8. Generalized cropping calendar for Ballia district, indicating optimal planting dates and satellite image acquisition dates.

Soils in Ballia district are very deep, having developed from alluvium of the rivers Ganges and Ghagara. Alfisol, inceptisol, entisol and vertisol (USDA soil taxonomy) account for most of the soils in the district. Haplustalfs, Natrustalfs, Ustochrepts, Endoaquepts, Halaquepts, Ustorthents, Haplusterts, Ustifluvents great groups and mixed mineralogy are predominant. The soils in Ballia are generally fertile, calcareous deep alluviums. They vary in texture from silt loam to silty clay loam, and poorly, and/or imperfectly drained. In the western areas of the district, there is a high incidence of alkali soils with high pH and sodicity, which are rich in calcium carbonate. Alluvial soils found in the dry riverbeds and bends of the Ganges show very wide (15–40 cm) and deep (more than 100 cm) cracks during the summer season (see Fig. 9). These sediments are unique to Ballia and parts of nearby districts. The origin of the alluviums with 'vertic' character seems to be eroded material from the igneous rocks of Satpura and Vindhayachal ranges in Madhya Pradesh, carried to the district by upstream tributaries of the Ganges.

The climate of the study area is continental monsoon type, with mild dry winters and hot summers. The average annual rainfall of Ballia district is 1,013 mm, but there is considerable year-to-year variation ranging from 801 to 1,300 mm. About 88% of the annual rainfall is received during the southwest monsoon months from June to September, with August being the wettest month (305.3 mm on average). Very little rainfall is received between November and May, with April being the driest month (0.6 mm on average). Temperatures peak in May (mean max. temp. 41.8˚C), prior to the onset of the monsoon, then decline after the withdrawal of the monsoon in early October, reaching their low point in January (mean max. temp. 23.9˚C) (RSAC, 2001).

Figure 9. Alluvial soils in Ballia. Many of these soils develop wide and deep cracks. Farmers grow zero till wheat / mustard in winter, and cucurbits and boro rice during dry season.

In socioeconomic terms, Ballia represents one of the most underdeveloped districts in UP. Results of the 2001 population census (Census of India, 2001), revealed a total population of 2,752,412, with 90% living in rural areas. The district is characterized by high population densities, with an average of 923 people/sq km (this compares to the state average of 689 people/sq km). Literacy rates are low (58.88% overall), particularly for the female population (43.92%).

The agroecological environment, farming practices, and socioeconomic conditions make Ballia a representative area of the eastern IGP and an ideal location in which to develop and validate methodology for the estimation of underutilized lands. In addition, the RWC has ongoing work for promotion and diffusion of RCTs within the district. Current areas of RWC activities involving farmer participatory trials using RCTs within Baillia are illustrated in figure 10.

Estimation and Identification of Crop Areas and Underutilized Lands

The overall scheme used to determine underutilized lands and causal factors in Ballia is illustrated in figure 11. This methodology flow chart outlines the entire process from selection of datasets, data collection, ground truthing for accuracy assessment, data processing, and analysis of processed information, through to final outputs.

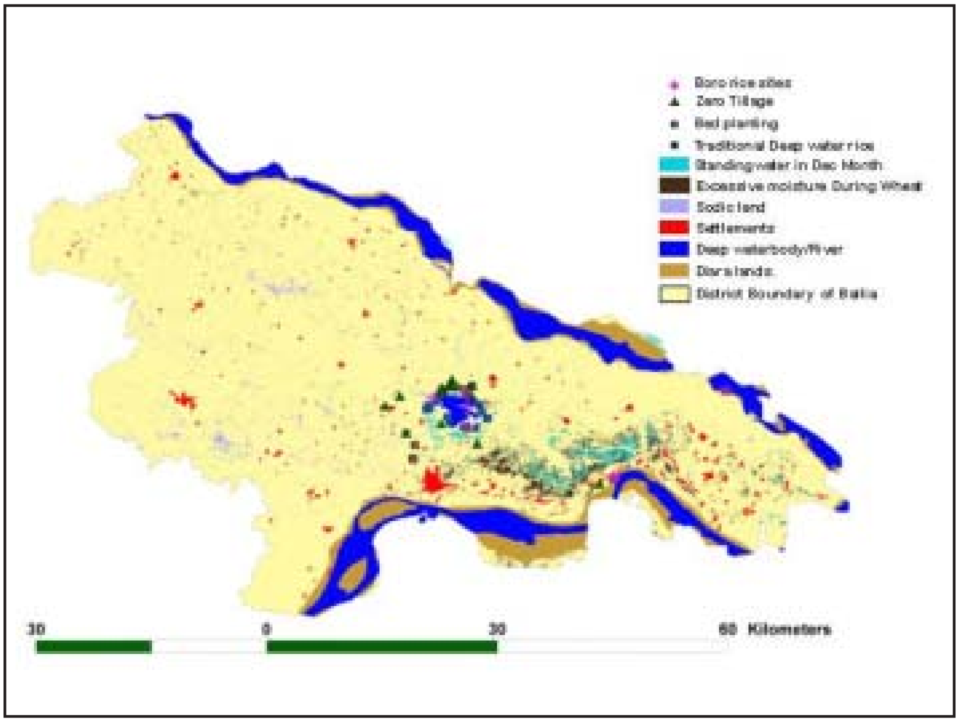


Figure 10. Locations of Rice Wheat Consortium activities within the district of Ballia.

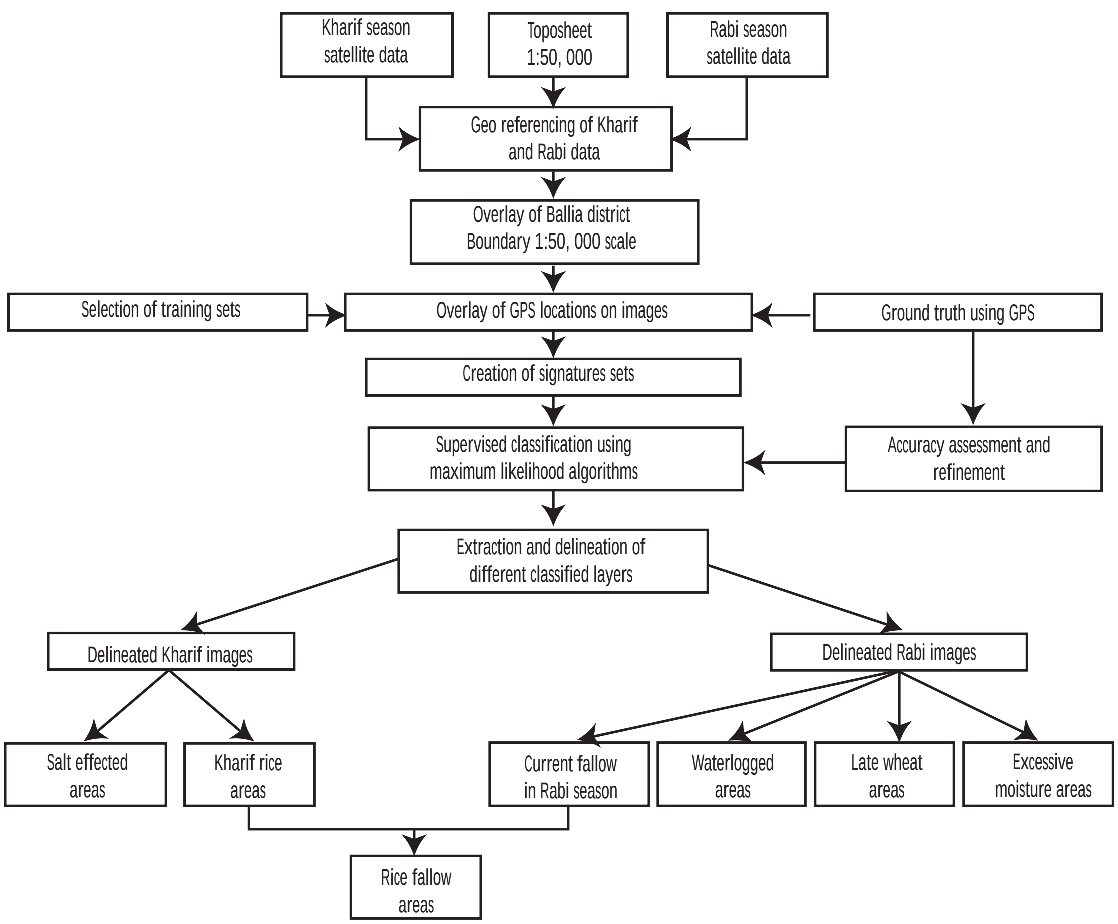


Figure 11. Methodology flow chart for the determination of underutilized lands and causal factors.

To assess crop distributions and identify underutilized lands, IRS ID - LISS III satellite data on four different dates were utilized (see Table 6). LISS III images are highly suited for this type of land classification because they provide reflectance data in green, red, and near infrared bands, at 23.5 m spatial resolution, on a 24-day revisit schedule, and cover a swath of about 141 km.

Selection of data sets

To obtain the required information and successfully discriminate key features, careful selection of the satellite data set is essential. Good knowledge of the cropping calendar is also needed in order to determine the optimal dates for image acquisition (see Fig. 8 for dates of image acquisition in relation to the cropping calendar).

Images acquired on different dates provide a series of snapshots of changing patterns of land use in farmer's fields over time. This time-series data provides powerful discriminatory information that permits the identification of different features. For example, in order to determine the area of 'rice fallows,' at least two images are needed. One image from September or October is needed, when the main kharif season rice crop is still in the ground, to provide information on the area planted to rice in the kharif season. A second image is needed in February to identify areas that were planted to rice in kharif, but have remained fallow during the following winter season. A simple comparison between the two images allows the identification of "rice fallows,' i.e., lands that remains unused following the main kharif rice crop.

Similarly, late-planted wheat areas were determined from the analysis of three images (early December, late December, and early February). The February image provides information on the total area grown to wheat, the same areas can then be checked to see if they had a wheat crop in December. Timely planted wheat (November, 15–25) would be visible in both early and late December images, whereas late-planted wheat would be visible in the late December image only.

Table 6. Specifications of satellite data and image acquisition

Sensor Used	Resolution (m)	Revisit Time (days)	Swath (km)	Kharif Data– Date of Image Acquisition	Rabi Data– Date of Image Acquisition
IRS ID-LISS III (Linear Image Self Scanning System)	23.5	24	141	14 October 2001	6th December 2001 28th December 2001 2nd Feb 2002

The December and February images were also used to determine waterlogged and excessive soil moisture areas. An area is said to be waterlogged when the water table is close to the soil surface such that it saturates a large fraction of the soil pores in the root zones, adversely affecting aeration and root respiration. It is not simple to differentiate the excessive moisture soils from the waterlogged soils and there is often confusion between the two. In this study, we have used the following criteria to distinguish the two conditions.

- Excessive moisture soils are defined as the lands where farmers have not been able to do preparatory tillage due to saturated conditions of the soils. The soils were too wet to permit access of machinery, but there was no standing surface water.
- Surface waterlogged areas are defined as those lowland areas where water is standing or flowing over the surface, but it is not a permanent body of water such as a river or lake.

Processing of data sets

The processing of data sets is an extended and complex process running from geo-referencing of satellite images through to accuracy assessment.

Geo-referencing of satellite images

This is an essential pre-processing step to align all the satellite images into the same geographic coordinates. It also permits other spatial layers, e.g., administrative boundaries, to be overlaid correctly.

The Survey of India (SOI) 1:50,000 scale topographic sheet was used as a base map to which the images were referenced. These topographic sheets had a Polyconic projection with a Modified Everest datum. The LISS III satellite image acquired on 2 Feb 2002 was regarded as the master image and was geo-referenced to the base map; subsequently other images were aligned to this master image. During this process, an adequate number of well distributed "ground control points" (specific features that can be identified on both the base map and the image) were identified and used for geo-referencing.

An administrative district boundary of Ballia was overlaid on top of the geo-referenced satellite images to create district level information. Habitation and aquatic masks were also overlaid and were excluded during the classification phase because the spectral signatures of river beds (sand) and aquatic weeds can mirror that of habitation and deep-water rice, respectively.

Ground truth information

Ground truthing-taking actual *in situ* field observations and matching them to the image information-is an essential aspect of any remote sensing study. This information is vital at all stages of the study and helps in the selection of training sites, creation of spectral signatures, performing the accuracy assessment, and in the analysis of classified information.

For this study, precise locations of several hundred field observations were recorded using a Garmin GPS unit, which provided a horizontal accuracy of approximately 10–15 meters. More than 100 geo-referenced soil samples of various soil types (including some samples from salt effected lands) were also taken to study the spectral responses of differing soil moistures in relation to their color and texture.

Post-processing phase/classification and accuracy assessment

The major component of post-processing is image classification, accuracy assessment, and extraction of different layers. Image classification is the process of arranging all pixels into categories based on their spectral values. Supervised classification with maximum likelihood algorithms was used to classify images of the study area. In this process prior or acquired knowledge of the classes in a scene are used to set up training sites to estimate and identify the spectral characteristics of each class. Selection of training sets and creation of spectral signatures were based on practical observations and intensive ground truthing.

Supervised classification

Supervised classification can be defined as the process of using samples of known identity to classify pixels of unknown identity. Training sites are the examples of known identity. Pixels located within these areas, termed the training samples, are used to guide the classification algorithm to assign specific values of the appropriate information class to unknown pixels. The basic steps involved in a typical supervised classification procedure are

1. Training stage
2. Feature selection
3. Selection of appropriate classification algorithm
4. Post classification smoothing
5. Accuracy assessment

Training sites are uniform areas of known identity delineated on the digital image. The objective is to identify a set of pixels that accurately represents the spectral variation present within each information region. The key point is there should be sufficient numbers of pixels (more than 100 pixels) representing each category and they should be uniform. Experience indicates that it is always better to define many small training sites, rather than use a few large training sites.

Maximum likelihood classification algorithm

This is a commonly used image classification technique. It takes a known data set that has already been classified and calculates for each class (e.g., land use or crop type) the variance, covariance, and mean values of each waveband. The resulting probability functions are then used to allocate other image pixels to the classes to which they have the maximum likelihood of belonging. The technique assumes that the training data statistics for each class in each band are normally distributed, i.e., Gaussian in nature. If normal distribution is not observed, the individual modes probably represent individual classes that should be trained individually and labeled as separate classes. This would then produce a unimodel, Gaussian training class statistic that would fulfill the normal distribution requirement.

Maximum likelihood classification makes use of the following statistics:

Decide X is in class C if

$P_c \geq Pi$ where i = 1, 2,3,…..m possible classes

$P_c = \{ - 0.5 \log_c [\det(V_c)]\} - [0.5(X-M_c)^T Vc^{-1} (X-M_c)]$

Where

X = measurement vector of an unknown pixel

P_c = probability of belonging to class C

V_c = covariance matrix value for class

det (V_c) = determinate of the covariance matrix V_c

The maximum likelihood decision rule computes the value p_c for each class, then it assigns the pixel to the class that has the target (or minimum) value (e.g., Sampei, 1997; Chandna et al., 2002).

Post classification smoothing

After applying the maximum likelihood classification algorithm, a majority filter is applied to the image, which selects the predominant value of a pixel and its eight neighbors. The zero majority filter selects only the predominant value if the central pixel is zero, which thus removes isolated unclassified pixels and assigns the pixels to the surrounding class (Sampei, 1997; Chandna et al., 2002).

Accuracy assessment

Accuracy assessment is a very important part of post-processing following classification. A confusion table or error matrix /contingency table was used in order to compare actual reference values (true classes) with classified values (remote sensing derived classes). In a confusion table, the diagonal elements represent observations that agree on the reference and classified map, and the non-diagonal axis indicates where observations do not agree. All classified outputs were verified and refined through field observations and GPS. The total accuracy calculated from the classified map (rabi season) of the study area is given below.

Average accuracy: 90.42
Overall accuracy: 92.87
Overall Kappa coefficient: 0.89819
Standard deviation: 0.00436

After classification of the different images, each category was extracted and converted into thematic GIS layers for further overlay and analysis. Arc View (v3.2a), GIS software from ESRI, was used for overlay, area calculation, and spatial analysis of the thematic layers. All image processing was undertaken using Geomatica (version 5.0) image processing software.

Results

Delineation of Underutilized Lands and Crop Areas

Based on satellite image analysis, the different layers representing the underutilized lands were estimated and demarcated for their spatial distribution and extent. The methodology permitted the estimation of the following major layers:

- total wheat / barley areas;
- late planted wheat / barley areas;
- total rice area (rabi, and kharif seasons);
- current fallow areas;
- excessive moisture lands;
- waterlogged areas;
- sodic lands; and
- total diara land area.

Total areas and proportional areas of each of these categories are given in table 7. Total area of Ballia district is 329,023 hectares and total cultivatable area of the district was estimated to be 285,361 hectares.

Total wheat / barley

The total area planted to wheat / barley in Ballia during the 2001-02 rabi season, irrespective of whether it was timely or late planted, was estimated to be 128,970 hectares; the distribution is given in plate 1. This estimate closely matches the official Indian government agricultural census estimate of 121,418 hectares in 1994. It also highlights the predominance of wheat / barley as a rabi crop within Ballia, as this represents 39.15% of the total area of the district and 45.19% of the total cultivable land.

Table 7. Areas and proportional areas of classified land types identified by remote sensing

Name of Classified Layer	Area in Hectares	Classified area as percent of total cultivable area (%)	Classified area as percent of total geographical area of the District (%)
Total Wheat / Barley	128,970	45.19	39.15
Late Wheat / Barley	74,123	25.97	22.50
Rice	110,558	38.74	33.56
Current Fallows (including Rice fallow)	36,907	12.93	11.00
Rice fallows	16,675	5.84	5.06
Excessive moisture + Tal areas	9,817+2,035 = 11,852	4.51	3.59
Diara lands	18,247	6.39	5.54
Surface Waterlogged lands	5,217	1.82	1.58
Alkali /Sodic lands	4,125	1.44	1.25

Late wheat / barley

The total area of late planted wheat / barley in Ballia was estimated to be 74,123 hectares, which represents almost 60% of total wheat / barley area in the district. Extent and distribution of late-planted wheat / barley is given in plate 2. However, due to the timing of available satellite images, it is considered that this value is actually an underestimate of the actual late-planted area. In Ballia, the optimal planting date for wheat / barley is 15 November (Hobbs and Gupta, 2001b), but constraints on available satellite images meant that any wheat / barley planted during 20–30 November had to be incorrectly classified as "timely planted." This erroneous classification implies that in reality a much greater proportion of the wheat / barley planted in Ballia would fall into the late-planted category.

Rice

The total rice paddy area during the kharif season of 2001 was estimated to be 110,558 hectares; the distribution is given in plate 3. As with wheat / barley, this estimate closely matches the official Indian government agricultural census data of 110,342 hectares in 1994. Rice is the predominant kharif season crop, representing 33.56% of the total area of the district and 38.74% of the total cultivable land.

Rice wheat system

Combining the information in plates 1 and 3, the total area under a RW cropping system was 35,020 hectares, representing 12.27 % of total cultivable area of Ballia (Plate 4).

Current fallow

The total area of lands that remained fallow in the rabi season of 2001-02 was estimated to be 36,907 hectares; the distribution is illustrated in plate 5. Of these, 16,675 hectares (45%) were classed as rice fallows since a kharif season rice crop had been grown previously on the land (Plate 6), but there was no subsequent rabi crop. Rabi season fallow lands accounted for almost 11% of the total area of the district and 12.93% of the total cultivable area.

Excessive moisture lands

The estimated layer covers all areas where the land preparation was difficult due to saturated soil conditions in November and December 2001 and that remained fallow up to February 2002 (Plate 7). The area covered by this layer was 9,817 hectares, almost 3% of the total area of the district and 3.44% of the cultivable area. In addition, excessive moisture areas surrounding deep water bodies (tal lands) accounted for an additional 2,035 hectares, making the total area under excessive moisture conditions 11,852 hectares (3.59% of total area).

Waterlogged areas

The estimated layer covers all those areas where surface water was present in December 2001 and that remained fallow up to February 2002 (Plate 7). The area covered by this layer was 5,217 hectares, which represents 1.58% of the total area of the district and 1.82% of the cultivable area.

Alkali / sodic lands

These are easily identified in the dry post-monsoon period due to their unique spectral signature. It was found that these lands were distributed in small patches throughout the district (Plate 8). The total estimated area of these salt effected areas was 4,125 hectares, representing 1.25% of the total area of the district and 1.44% of the cultivable area.

Diara lands

The estimated layer covers all those areas that lie in between the river bed and levees (see Plate 9). Total area, including that covered by river water, was estimated to be 45,885 hectares. Of this, 18,247 hectares were considered to be potentially useful for agricultural purposes, which represent 5.54% of the total district area and 6.39% of the cultivable land.

Overview of underutilized lands

Using the data from table 7, the total area of underutilized land during the 2001-02 rabi season in Ballia was estimated to be 76,347 hectares (Plate 9). This includes current fallows, sodic lands, excessive moisture areas (including tal lands), waterlogged areas, and usable diara lands. Late planted wheat / barley areas are not included in this calculation of underutilized land area. The proportions of this underutilized area by land type are illustrated in fig. 12, current fallows and diara combined account for over 72%. This underutilized land represents 23.2% of the total area of Ballia and 26.7% of the cultivable area.

Matching Technologies to Land Types

Through identification and mapping of the different land types, it is now possible to make recommendations on technologies that could be beneficial in certain conditions. Plate 10 illustrates the overall distribution of classified land types in Ballia and highlights some conditions where different technologies may have the greatest impact. It is important to note that the technologies highlighted in this section are only examples of applications, most of these RCTs have proven beneficial effects in other areas or parts of the farming system, e.g., bed planting systems have much wider utility than just in sodic lands. Similarly, advancement of planting dates is only one of many benefits conferred by zero tillage systems.

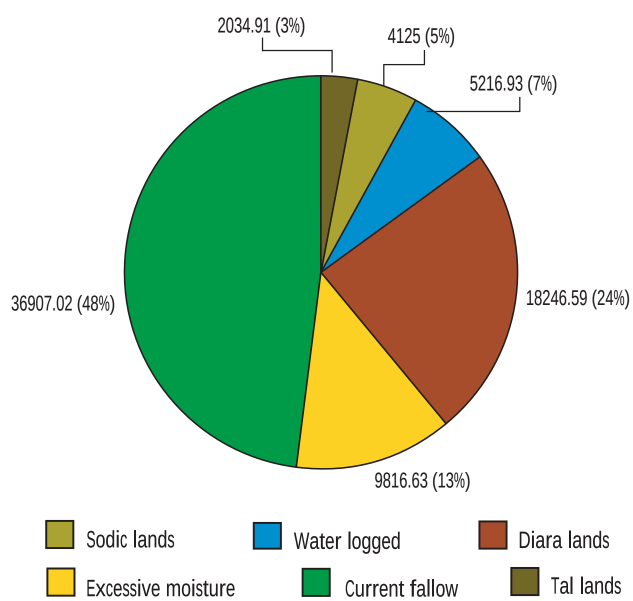


Figure 12. Proportions of underutilized lands in Ballia by land type.

Table 8 illustrates in very general terms some examples of the technology options that could be applied to different land types that are currently underutilized.

Late planting and zero tillage: a successful combination to advance sowing dates

Analysis of time series satellite imagery clearly showed that late planting of wheat / barley is a huge problem in the study area, mainly arising from late transplanting or direct sowing of rice. A very conservative estimate indicates nearly 60% of the total area under rabi wheat / barley is planted late.

This finding was not totally unexpected as it reflects the poor prevailing situation regarding the late planting of wheat in the eastern IGP. Further east in Bihar, West Bengal, and Bangladesh, it is estimated that more than 75% of the wheat cropped area is late planted. This represents an enormous area in which significant productivity gains could be achieved simply by advancing planting dates for wheat.

Late planting of wheat / barley can result from a variety of factors including long turn-around time following rice harvest (land preparation); use of long duration, scented rice land races and modern varieties; late planting of rice; and soils not coming to proper tilth due to excessive wetness. Growing medium and short duration rice in combination with zero tillage can be a good solution for timely planting of wheat / barley, because land preparation time is drastically reduced (by 20-30 days) compared to conventional tillage practices. Such time savings can significantly advance sowing dates for wheat and other winter season crops, thereby increasing yields. Timely planted wheat also makes use of the residual moisture of rice fields and so saves irrigation water.

Table 8. Generalized examples of recommended practices and crops for problematic areas

Problematic Area	Example of recommended practice / crop
Late planted wheat / barley	Advance rice planting, zero tillage and surface seeding, medium to short duration rice cultivars
Late planted rice	Direct seeded rice, advance the nursery raising and transplanting of rice; ground water development, reschedule operation of lift canals.
Alkali / sodic lands	Gypsum / pyrites amendments and adoption of FIRB planting methods
Excessive moisture Diara lands	Surface seeding and residue management Zero tillage, soil moisture conservation practices, introduction of legumes and appropriate crop cultivars
Waterlogged areas (rabi)	Transplanted boro rice
Waterlogged (kharif)	Rice cultivars suited to deep and medium deep standing water conditions.
'Alluvial vertisols' in diara lands and riverbeds	Boro rice, cucurbits, vegetables with sprinkler irrigation systems
Risk management in flood prone areas	Mixed intercropping with zero till system, basal application of fertilizer inputs and appropriate choice of cultivars.

Solely through planting at optimal sowing dates, experimental results demonstrate that average wheat production can be increased by up to 1 t/ha without additional inputs or changes. Based on the findings of the present study, in Ballia district timely planting alone has the potential to increase total wheat production by 70–75,000 tons. Methodology developed in the present study also has considerable potential for monitoring the success and impact of technologies like zero tillage, as reductions in late planted wheat areas could easily be detected.

Advancing the planting date of winter wheat through the use of zero tillage for crop establishment has the additional benefit of possibly allowing the planting of a third crop in an annual cycle. A short duration mungbean crop, established using zero tillage and following the rabi wheat crop, has great potential. Zero tillage permits timely planting of the extra short duration mungbean during the first week of April, so escapes untimely rains and problems with yellow mosaic virus. The practice has proven successful and is being adopted by hundreds of farmers in Bihar and eastern UP (including Ballia), following participatory research trials of RWC designed to increase the diversification of the RW system.

Surface seeding: a productivity enhancing solution for excessive moisture soils

Excessive moisture soils are a major problem in low lying lands of the RW cropping system of eastern IGP. Causal factors include heavy rain, low land ecologies, residual moisture from the last crop, and poor drainage systems. The result of these factors either singly or in combination is either very late planting or no planting at all (land remains fallow).

Results from this study indicate that in Ballia nearly 4% of the total district area (if tal lands, which remain fallow up to December, were included) suffered from problems due to excessive soil moisture. However, it should be noted that the problem of excessive moisture increases in regions to the east of Ballia. The lowlands of Bihar, West Bengal and Bangladesh suffer frequent flooding during the kharif season, which subsequently results in excessive soil moisture and waterlogging problems (NAEB, 2003). To give some indication of the scale of vulnerable areas, eastern UP, Bihar, and West Bengal contain more than 9.7 million hectares of lowland areas, roughly 60% of the total lowland area (16 million hectares) of South Asia (Paris et al., 1999).

If excessive soil moisture prevents access to fields by machinery, surface seeding is one of the best options available to farmers for timely crop establishment. The practice is well suited to fine textured and poorly drained soils, or where land preparation is difficult and often results in a cloddy tilth. Also important is its simplicity, with no requirement for machinery, hence any farmer can adopt this practice (Fig. 13). Surface seeding of wheat has also proven to be cost effective for cropping on excessively wet soils (Table 9); it saves labour, fuel, and tillage costs and also makes use of residual soil moisture and improves crop productivity through timely planting.

Success depends on seeding into soil with appropriate moisture content. Too much soil moisture can cause the seed to rot and too little can result in low germination. Good crop stands can be established with surface seeding when soil moisture glistens under applied pressure. If soil moisture is less than optimum, the best practice is to seed and then apply additional water to reduce the mechanical strength of the soil and permit root penetration. Seeds tossed onto a moist soil surface, germinate and the roots follow the saturation fringe as it drains down into the soil profile. The high soil moisture reduces soil strength and thus eliminates the need for tillage (Hobbs and Gupta, 2001a).

Surface seeding, like zero tillage, advances planting dates and creates options for a third crop. Pulses, such as mungbean, are a very suitable choice following surface seeded wheat.

Standing water/waterlogged areas in December and potential for boro rice

This land type represents the extreme lowland areas, which remain inundated with water most of the year, and from which no crop or a single short duration crop is generally harvested. Water may stand at variable depths for long periods. In very deep-water situations, farmers often grow floating rice cultivars during kharif season. Whereas low lying positions (e.g., fringe areas of permanent water bodies) where water recedes, provide natural niches for cultivation of boro rice in winter season.

Although Ballia district has not had any direct flood from the river in recent years, the waterlogged area detected in this study still covered 5,217 ha. Bihar and Bangladesh, which are particularly flood prone, have extensive areas of this land type, which could total more than 1 million hectares (NAEB, 2003).

Figure 13. Farmer surface seeding wheat in eastern IGP.

Table 9. Yield comparison for surface seeded wheat in relation to other establishment practices after rice harvest in Bhairahawa (Nepal) and Patna (India).

	Wheat Yield (kg/ha)	
Method	Bhairahawa (Nepal)	Patna , Bihar
Surface Seeding	2775a	3330a
Chinese Seed drill/ Reduced tillage	2831a	3070b
Farmer's practice	2314b	2810c

Note: Figures followed by the same letter are not significantly different at 5% probability using DMRT
Sources: Report of the Bhairahawa Agricultural Farm, Nepal, 1993-94; B.K. Singh, personal communication, RAU Patna, 2001.

These lands could be used for productivity enhancement; one strong potential option in irrigated areas that remain under water until January or February is boro rice. Boro rice is seeded in November-December, germinates, and young seedlings undergo chilling treatment in the winter months (January and February) before transplanting in early March. There are two methods) for raising nurseries prior to transplanting into waterlogged soils: conventional and the *dapog* method. The boro rice crop then matures before the upcoming season's monsoons or floods caused by runoff water from upper catchments. The presence of standing water in fields into February is an additional benefit because it reduces irrigation costs at the time of transplanting and during the growth period. Yield potential of improved boro rice varieties is high (Table 10) and economic returns to the farmer are good, making it an attractive component in the farming system.

Table 10. Average yields of improved boro cultivars in on-station experimental trials at Samastipur, Bihar, and BHU Farms at Varanasi (UP)

		Yields t/ha	
Boro cultivar	**Days to Maturity**	**Bihar #**	**Eastern UP****
Gautam	170	6.5	6.85
Richarya	150	5.0	-
DhanLuxmi	160	5.5	-
Saroj	172	6.5	-
Prabhat	160	5.5	6.55
Sarjoo-52			6.80
Pant-4			6.66
IR-64			7.15
Krishna Hansa			6.75

Sources: *Mrithyunjaya Kumar, RAU, Bihar unpublished data; ** UP Singh 2003, personal communication (average yield of boro rice in Varanasi district during 2002-2003).

In the low lying waterlogged areas, providing supplementary irrigation water is usually not a major problem. This can often be achieved at little cost through the use of bamboo tubes or clay pipes (Kumar et al., 2002).

Given the high productivity potential of boro rice, efforts are being made to relocate the crop to irrigated mid- and uplands (nontraditional areas for this crop). A good example of this is the development of a very innovative intercropping system-rice (short duration), followed by potato + maize // boro rice-currently undergoing farmer participatory trials in eastern IGP (Fig. 14).

It is estimated that more than 3,000 ha of low lying waterlogged lands located east of Ballia city, remains waterlogged during both rabi and kharif seasons (see Plate 7). On occasion, farmers may plant a short duration rice crop, however, profitable potential alternatives, e.g., boro and deep water kharif rice, exists for these areas. Elsewhere in the district, around Surha Tal, farmers grow traditional deep water and floating rice varieties (*Jaisurya*, *Tudahiya, Kalanigee*). For wider adoption of these rice technologies, improvements in the land tenure system may need to occur and some financial assistance given to leased land farmers to assist them with cultivation and harvest of these varieties. Deep water and floating rice are usually harvested using boats. Improvements in deep water and floating rice and sugarcane varieties can help expand agriculture into other waterlogged areas. It is noteworthy that the local sugarcane landrace named 'Bansa' is able to withstand a meter of standing water for several months.

Figure 14. Intercropped rice with maize (detached tops) in rice-potato+maize // boro rice system irrigated uplands in Samastipur, Bihar. A view of boro rice crop at flowering (right) after harvest of winter maize.

Risk management in flood prone environments

Monsoon rainfall in the eastern IGP is highly variable. In India, monthly rainfall variability solely within districts can be as high as 40–50%, even in the rainiest months of July and August (National Commission on Agriculture, 1976). Drought and flood conditions may occur simultaneously even within the same district. Floods received through tributaries of the Ganges (Gandak, Sone, Ghaghara, Budi, Gandak, Kosi, Chambal and Yamuna) in the eastern plains are of varying intensity and duration, showing no consistent patterns or trends, and have serious implications for rural livelihoods and farm incomes. Crop planning must take flood risk into account, as much as possible, in order to minimize risks and potential crop failures.

Remote sensing and GIS tools can help the farming community a great deal in crop planning in the region. With a better information base on duration and intensity of floods, risks and uncertainty can be reduced substantially. An example of this approach, showing flood extent in Bihar on selected dates, is given in fig. 15.

Results of numerous farmer participatory field trials (Table 11) show that adverse effects of floods on crop productivity in flood-prone low lying areas can be substantially offset by mixed cropping systems and timely planting using zero till crop establishment

Table 11. Productivity (Q/ha) and economics of different cropping systems in different ecologies of north Bihar (Kharif 2002 to summer 2003)

Sl. No	Ecology / Cropping systems	Variety	Yield (q/ha)	Net return (US$ / ha)
1.	Irrigated uplands Rice-Potato + Maize	Rice (Prabhat)	42.5	155
		Potato (Kufri Ashok)	23.0	837
		QPM Maize (Shaktiman-I)	57.2	299
		Total Net Income		**1291**
2.	Irrigated Midlands Rice-Wheat- Mungbean	Rice (Rajshree/ PR-114)	46.1	179
		Wheat (HD 2733/ HUW 234)	40.8	248
		Mungbean (Local Sona)	6.9	138
		Total Net Income		**565**
3.	Flood prone lowlands Deepwater rice + Mungbean +Sesame-Wheat	Rice (Vaidehi)	25.0	126
		Mungbean (Local)	3.4	67
		Sesame (Local)	4.8	90
		Surface seeded Wheat (HUW 234)	27.0	185
		Total Net Income		**468**

Exchange rate; 1US$ = INR46

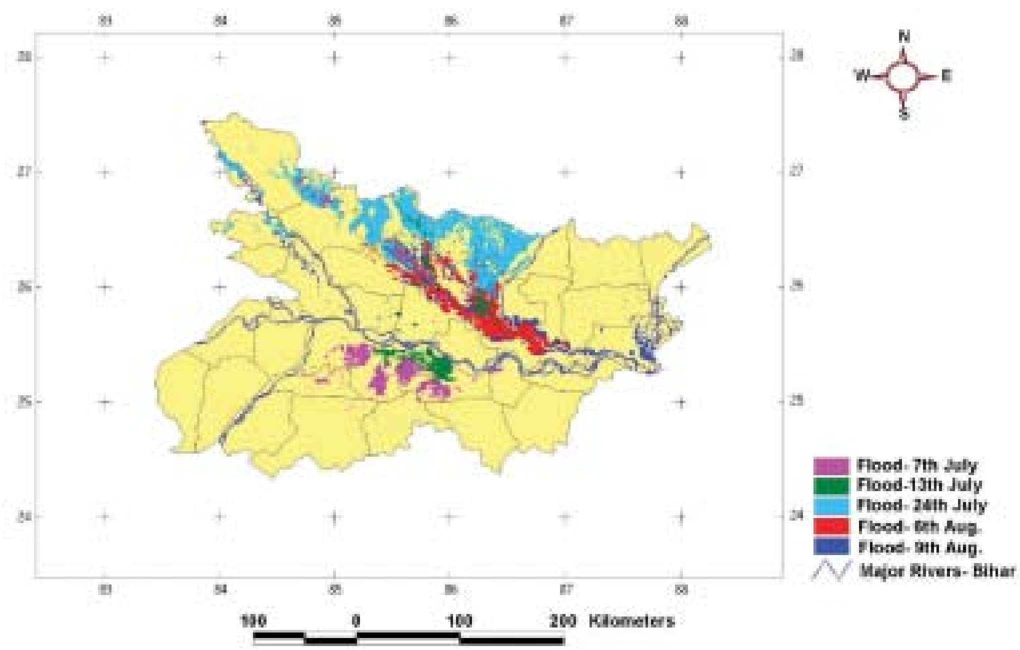


Figure 15. Temporal and spatial distribution of flooding in Bihar, 2002 derived from remote sensing.

techniques. Use of these diversified systems (Fig. 16) can raise farmers' incomes in flood prone areas to nearly that of farmers in more favorable irrigated midlands.

Alkali / sodic lands and bed planting: A potential combination to be scaled up

Soil salinity is another major cause for potentially productive lands remaining underutilized. In UP alone, an estimated 1.2 million hectares are currently unused because of a high buildup of salts (World Bank, 2000). Lowland areas of the eastern IGP generally suffer from waterlogging and poor drainage, which in combination with a high concentration of soluble salts in the water, can lead to an accumulation of salts in the soil. Most of the salt effected areas in eastern UP and Bihar are sodic in nature; these have an exchangeable sodium percentage (ESP) value of more than 15% and variable amounts of soluble salts ($4dSm^{-1}$ < electrical conductivity > $4dSm^{-1}$). In Ballia, alkali soils were found to cover an area of 4,125 ha, constituting 1.25% of the total district area. Wheat is the most affected crop, with high sodicity adversely affecting yields.

These soils can be reclaimed through the use of chemical amendments such as gypsum and iron pyrite, as well as leaching of reaction products out of the rootzone (Gupta and Abrol, 1990). Gypsum usage reclaims the surface soil layers fully, but the underlying layers remain at various levels of reclamation. Tillage brings unreclaimed soil to the surface, increasing sodicity in the surface layers. This reduces seed germination of salt sensitive cultivars. Thus, if crops are planted with zero till and/or on raised beds, crop stands and productivity will continue to improve. In the furrow-irrigated, bed planting (FIRB) system, raised beds are made using reclaimed surface soil. This nearly doubles the rooting depth and permits healthy growth of crop plants. The value of bed planting in sodic lands has now been confirmed in trials conducted by RWC partners at various locations throughout the IGP, including the village of Nagri in Ballia (Fig. 17).

Figure 17. Wheat planted in FIRB planting system in a gypsum amended partially reclaimed alkali soil (Sita Ram Yadav farmer field, Nagri village, Ballia).

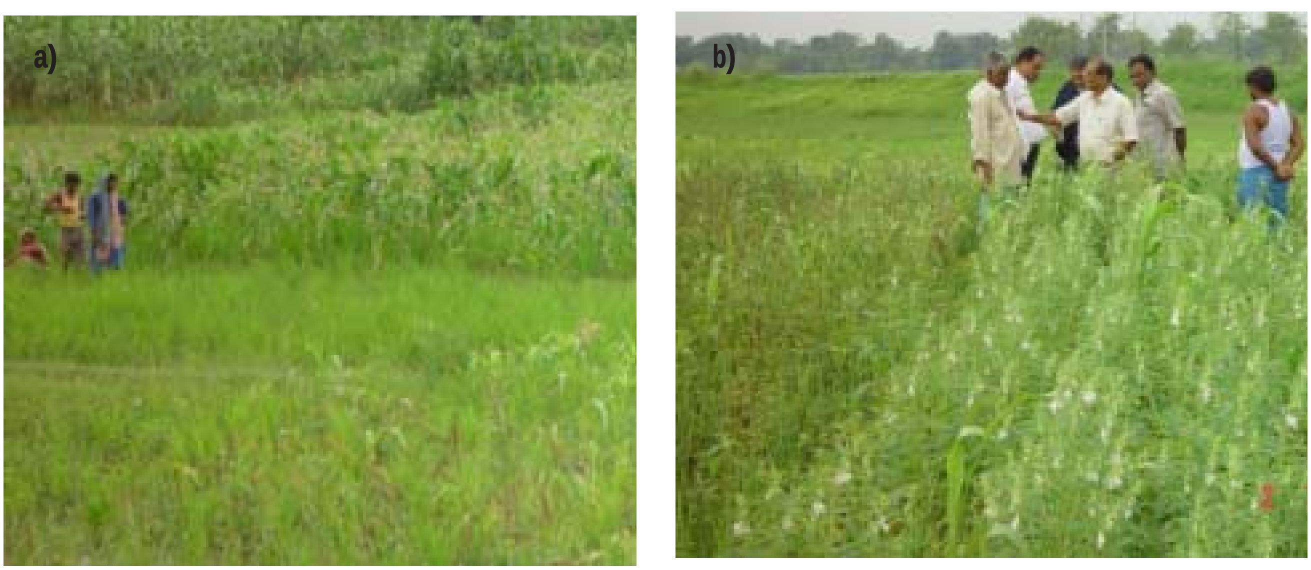


Figure 16. (a) Mixed cropping of rice, maize and sorghum in flood affected plots. (b) Zero tilled crop mixtures of rice+mungbean+sesame+maize (right-hand side of photo) compared with traditional tillage and crop establishment practices (left-hand side of photo).

Once already formed for planting wheat, the raised beds can readily be used for planting other crops with a zero till ferti-seed drill in the next season without, dismantling the beds.

Rice fallows: diversification of the cropping system through introduction of legumes

Current fallow and rice fallow lands constitute a major portion of the total underutilized lands in south Asia and more specifically in the eastern IGP. Subbarao et al. (2001) earlier estimated that total area of rice fallow lands in south Asia (Bangladesh, India, Nepal, and Pakistan) is more than 14 million hectares, with nearly 50% occurring in the eastern IGP. However, this study may under-represent the true total, because it failed to identify any 'rice fallow' lands in Ballia district. The current study identified nearly 17,000 ha of rice fallows in Ballia during 2001–02. Total current fallow land (including rice fallows) in Ballia was estimated by the current study to be 36,907 ha.

Major causal factors for lands to remain fallow include lack of irrigation facilities, and rice vacating the fields too late to permit planting of a second crop during the winter season. Such conditions are typical of the tal, chaur and diara lands. In many upland and midland areas, where there is no groundwater development for irrigation, land also remains fallow. These rainfed areas are often planted to rice during the kharif season. Rice fallow lands generally belong to poorer farmers having no irrigation facilities. These farmers mainly depend on monsoon rains for crop production under hot subhumid climatic conditions.

In areas that lack irrigation facilities, timely seeding that taps the residual moisture of the previous rice crop, and relay cropping or surface seeding of cereals and legumes could offer potentially good cost effective options for resource poor farmers. Certainly, surface seeding has the potential to reduce the area of rice fallows and increase farm incomes. Residual soil moisture contents in these deep alluvial soils after rice are sufficient for taking short duration legumes such as lentil and chickpea. These crops not only increase the diversification in the cropping system, but also contribute to soil fertility. Subbarao et al. (2001) observed that eastern farmers are not well versed with workable and available technology options to reduce rice fallows. Therefore, diffusion of knowledge about RCTs appropriate to the complex ecologies of the eastern IGP is likely to bring about substantial benefits to the farming communities.

It is believed that with appropriate development of groundwater, to supplement rains and surface irrigation, most of the rice fallow lands could be put under crop production using surface seeding and zero till planting techniques.

Diara lands

Diara lands, adjacent to the rivers, receive fresh sediments on an annual basis during the rainy season. Those with agricultural potential were found to occupy 18,246 ha in the study area, constituting 6.39% of the total cultivable lands and 24% of the total underutilized lands in Ballia. The highly fertile soils of the diara lands have good potential for a variety of crops in comparison to other underutilized lands (Fig. 18). A unique characteristic of the diara lands in Ballia, is that the alluvial soils have a vertic character analogous to vertisols (see Fig. 9).

Land tenure and ownership in diaras is a major constraint to their utilization. Farmers traditionally grow chickpea, lentil, wheat, and Indian mustard in the winter season. Rice, pigeonpea, sorghum, maize, and sugarcane are grown in kharif season. Many landless farmers take diara land on lease, and develop groundwater on a temporary basis to grow vegetables and boro rice in March and April. Direct seeded zero till rice, wheat, and other crops can be grown in these soils. In cracking soils where boro rice is grown, best practice is to install sprinkler irrigation systems with tubewells to reduce fuel costs. Where irrigation is a problem, legumes with deep-rooted systems (to utilize stored soil profile moisture) can be grown using minimum tillage, providing weeds are not a major problem.

Figure 18. A general view of diara lands being conventionally tilled after monsoon season for sowing of winter season crops.

Potential Impacts and Limitations

All of the technologies outlined in the previous section have considerable potential to sustainably enhance productivity and improve livelihoods in one of the poorest regions of south Asia. The ability to accurately identify certain land types, as outlined in this study, in which these technologies have a role to play has major implications for planning, diffusing, and monitoring impact of the available technologies. Most of the underutilized lands in the eastern IGP belong to extremely resource-poor farmers, so they are the primary potential beneficiaries of these technologies. Hence, the combination of appropriate technologies applied to the right niches in the farming landscape has considerable potential for enhancing productivity and improving livelihoods for some of the poorest segments of the community. However, the fact that these underutilized lands coincide with extreme poverty creates additional challenges for the diffusion and adoption of the technologies. Farmers in these areas have extremely limited resources; so only technologies that require minimal investment and produce favorable returns are likely to be rapidly adopted. Similarly, complex technologies requiring extensive detailed knowledge to implement are unlikely to be successful. Several of the technologies outlined in this paper have the potential to be adopted by even the most marginal farmers; lack of knowledge on available options is often the major limiting factor. Having reliable information on where problematic lands occur and their extent means that effective extension efforts, such as on-farm demonstrations or farmer participatory experiments, can be targeted to areas of greatest need. It is important to ensure that specific knowledge is transferred into areas where it has the greatest potential utility.

Within the Ballia study area, the tribal 'Mallah' boatman community is most likely to benefit substantially from the introduction and promotion of boro and deep water rice. The Mallah community is considered to be one of the poorest communities in the area, depending on fishing, ferryboats and agricultural labor for their livelihoods. They are noted for their traditional expertise in boro and deep water rice cultivation, which is usually applied on leased land. Many of the current fallow lands in tal, chaur, and diara areas farmed by this community, hence technology targeting could bring significant benefits to this currently marginalized group.

Surface seeding of wheat or other crops is another practice that is very appropriate for resource poor farmers. Wheat established in this way does not usually require additional irrigation, because one or two rain showers during the growing period is sufficient for crop growth. These rainfall events in the winter are common throughout the region. In addition, surface seeding does not require any special infrastructure or machinery for adoption. These factors make it an appropriate technology for even the poorest of farmers.

Similarly, introduction of appropriate technologies in diara lands has high potential to reduce poverty levels of some of the poorest farmers. In these areas, awareness of potential technologies is extremely low and mainly very old traditional methods of cultivation are practiced. Several extremely promising options exist for these areas that could substantially improve livelihoods of farming families dependant on this land type. Currently there has been little recorded adoption of RCTs within diara lands, and there is a clear need to increase efforts to disseminate appropriate technologies into these areas.

Zero tillage and bed planting techniques currently require tractor power, although both lead to significant cost savings for farmers along with higher yields. Despite the need for mechanization, the RWC experience has shown that even small-scale farmers take advantage of planting crops on raised beds because it helps overcome the ill effects of poor soil aeration. In addition, small-scale, marginal, and landless farmers are found to take maximum advantage of zero tillage technology in flat and raised bed systems. Some farmers who have tractors are turning to becoming service providers for non-mechanized farmers, resulting in additional employment and income generation.

Application to Wider Areas

Technology targeting has, in theory, potential application to any agricultural region of the world where the distribution and spatial extent of problematic landscape features can be mapped and appropriate technology solutions exist. Undoubtedly, the technique will favor relatively homogenous farming landscapes and is unlikely to be very successful in extremely heterogeneous rainfed systems. More specifically within the IGP, it is widely thought that technology targeting has more potential in the eastern plains (eastern UP, Bihar, West Bengal, eastern Terai of Nepal, and Bangladesh) because this is where most of the underutilized and problematic lands occur, and there is little awareness of new technologies.

Methods and technologies developed and validated in Ballia, for various underutilized lands, should have direct application to IGP transect four (eastern UP and Bihar) because of their very similar agro-climatic conditions. Extrapolation to transect five (west Bengal and Bangladesh) is also considered extremely feasible. In IGP transect five only a small amount of validation to local agro-climatic conditions would be needed. Remote sensing methodology developed in this case study is very scalable; given available imagery and a limited amount of local ground truthing, similar classifications could easily be made for much larger regions.

Limitations

In previous pages, this study identified feasible approaches to identify underutilized lands and outlined potential technology options for different land types. There are however several limiting factors-technical, logistical, and environmental/ socioeconomic in nature-that need to be taken into account because they may impede the smooth and successful transfer of technologies.

Availability of satellite imagery

Long revisit time (24 days) of the IRS satellites means that optimal acquisition dates are not always possible. A good example of this is in the assessment of timely planted wheat. Optimal image acquisition date for this region would be around 25 November rather than 6 December. As a result, late planted wheat areas are underestimated. Cloud cover on satellite images is another issue that can cause problems; this is particularly true for imagery during the kharif rainy season.

Lack of irrigation facilities

Many of the underutilized lands belong to resource poor farmers who do not have irrigation facilities. Lack of irrigation may severely limit the technology options available to these farmers. Some options, such as surface seeding, may be more suitable than others in these circumstances. Frequent flooding is another barrier to the promotion of irrigation facilities. Farmers are reluctant to invest in new tubewells in flood prone areas because maintenance costs are high. Alternative strategies may be clay pipe or bamboo tubewells in flood prone areas or in diara/tal lands. These are a much less expensive and very viable option due to the high water table in these areas.

Lack of machinery

Zero tillage and bed planting have machinery requirements. This generates two major problems. Firstly, suitable machines may not be available and even if machines are available, spare parts or maintenance may be a problem. Secondly, resource poor farmers will have difficulty in gaining access to mechanized systems. Some encouraging developments are occurring to address the machinery issue. Local manufacture of suitable machinery for zero tillage/bed planting is beginning to occur in parts of the IGP, driven by farmer demand. However, local machinery manufacture is not currently widespread in the eastern plains, a situation that could change with successful promotion and adoption. Through the RWC and partners, machinery is being made available to farmers for testing and demonstrations. Elsewhere in the IGP, even small-scale farmers are managing to adopt the technologies, not through machinery ownership but by contracting service providers to undertake the work on their land. This is not to say that these technologies will be available to all farmers, but more than just large-scale farmers are likely beneficiaries.

Lack of land tenure and insecurity

Lack of land tenure and insecure holdings are major problems in the diara lands where cultivation rights are often secured by force and use of firearms. Planted crops may be stolen by force at harvest time. Security issues make fieldwork and technology dissemination very difficult in these areas (Fig. 19).

Figure 19. RWC survey team in Diara lands of Bihar with gunman for security.

In addition, lack of infrastructure and accessibility problems also contribute to poor dissemination of technologies. All of these factors contribute to very low current levels of information, and hence adoption in these areas

Aquatic weeds

Aquatic weeds are a big problem in waterlogged and swampy areas and hinder the adoption of boro rice. Farmers are often unwilling to devout resources to clear these.

Conclusions

The use of temporal remote sensing data and GIS tools permitted the accurate, rapid, and cost-effective delineation and mapping of underproductive and problematic land types within the district of Ballia, UP. The methodology developed for this study permitted the characterization of five major land types (current fallow, excessive moisture areas, waterlogged areas, sodic lands, and diara lands) that are not currently reaching their full potential. The total area of all of these underutilized lands combined accounted for more than a quarter of the total cultivatable area in the district during the rabi season. In addition, a large part (at least 60% and up to 80%) of the district wheat area was considered to have suboptimal productivity, simply because it was late planted.

For each of the problematic or underutilized land types identified, specific resource conserving and productivity enhancing technologies were described that had significant potential for improving productivity in these specific areas. All of the technologies described were part of the suite of technologies being promoted by the RWC, and which have proven utility for farmers of the IGP.

Given that proven technologies exist to ameliorate many of the problems encountered in underutilized lands, the work undertaken in this study has enormous potential to increase the efficiency of technology transfer. Having an accurate picture of where the problematic areas are, what type of problems need to be addressed, and the total extent or relative importance of each problem are extremely important for planning, priority setting, and diffusion of technologies. Targeting appropriate technologies in this way can help ensure that maximum benefits are obtained from scarce resources.

Major benefits can also arise in the area of impact assessment. Take for example the problem of late planted wheat; if zero tillage systems are successfully deployed into the right areas and permit timely planting over a sizeable area, then that beneficial change could easily be detected by the current methodology. Likewise, reductions in fallow land areas could easily be detected. Monitoring impact in such a way obviously has limitations, since it focuses solely on the biophysical or productivity issues and omits socio-economic or livelihood aspects. However, detection of areas undergoing such changes would provide an excellent framework around which socio-economic surveys could be targeted. Circumstantial evidence from Ballia suggest that many of the underutilized lands detected are in the hands of the more marginal farmers, so enhancement of productivity in those areas could have significant impacts on poverty alleviation and livelihoods.

Ballia was chosen as a study site for methodology development since it was considered to be representative (in terms of farming systems and practices, agroecologies, and level of development, etc.) of the wider region-particularly transect four, but also transect five of the eastern IGP. It is believed that methodologies developed in this study could easily be scaled-up and applied to surrounding areas including Bihar, West Bengal, and Bangladesh.

Future Directions

The current case study has demonstrated the feasibility of applying remote sensing/GIS techniques to provide an accurate estimate of the location and extent of underutilized lands. It has also demonstrated the enormous potential of this type of information for guiding planning and decision-making activities related to the targeting of resource conserving and productivity enhancing technologies. Future directions that could be pursued include the following:

1. Identification and demarcation of the spatial distribution and extent of underutilized lands, and subsequent technology targeting, in Transects 4 and 5 of the eastern IGP (potential target areas include eastern UP, Bihar, West Bengal, eastern Terai of Nepal, and Bangladesh).
2. Linkage to socioeconomic studies. How does technology targeting affect livelihoods? Combination with high-resolution poverty mapping techniques could further enhance priority setting and decision making.
3. Monitoring of adoption following technology promotion and diffusion. Can beneficial effects be detected?
4. District/block-wide cropping system analysis through remote sensing/GIS and change monitoring over time (currently district-wide information on cropping systems is not available for eastern IGP)
5. Year to year variability in underutilized land classes. The current case study was carried out in average rainfall year, so core areas are not expected to change drastically, but variation needs to be investigated.

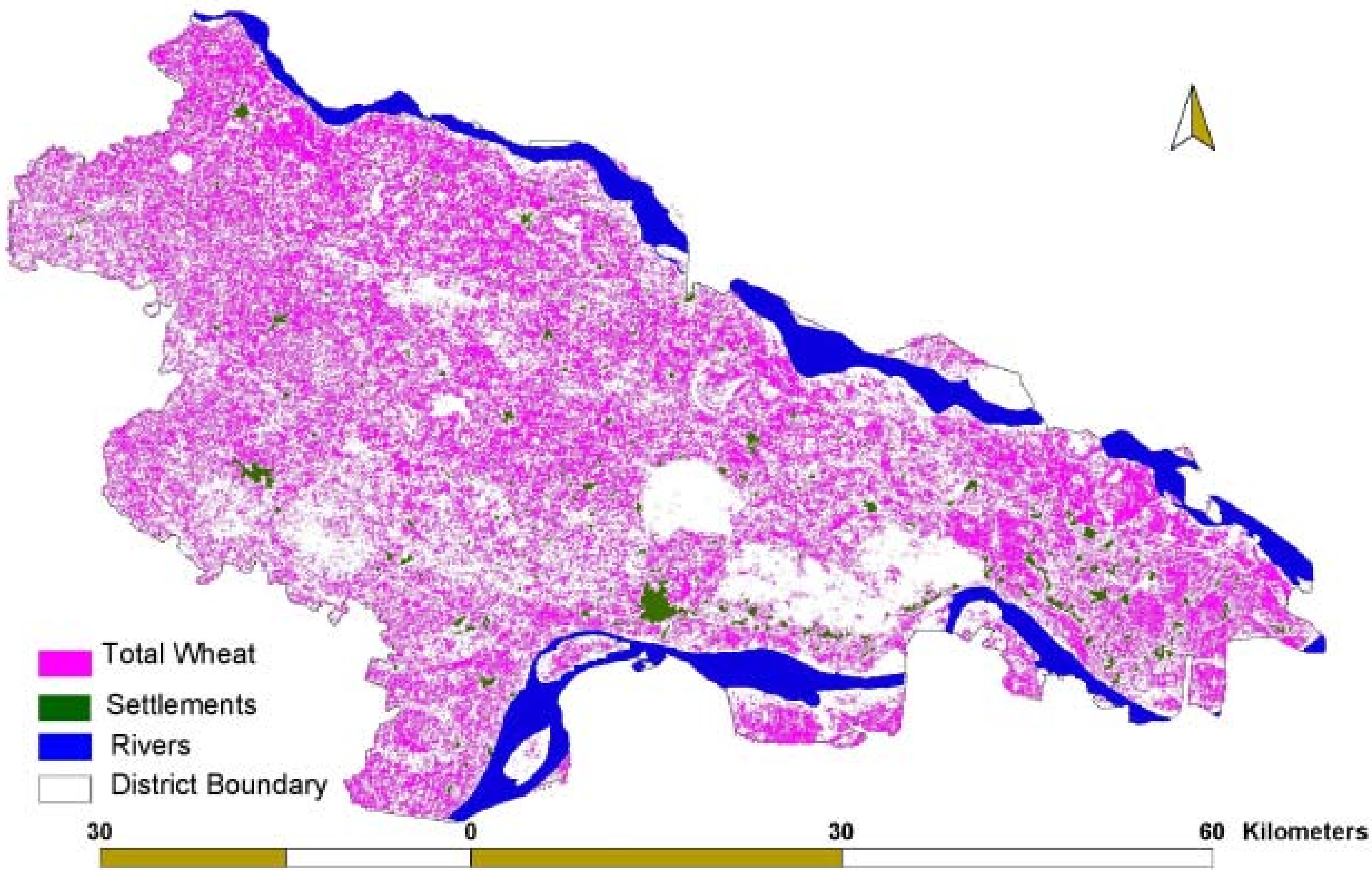


Plate 1. Spatial distribution of wheat within Ballia during the rabi season of 2001 – 02

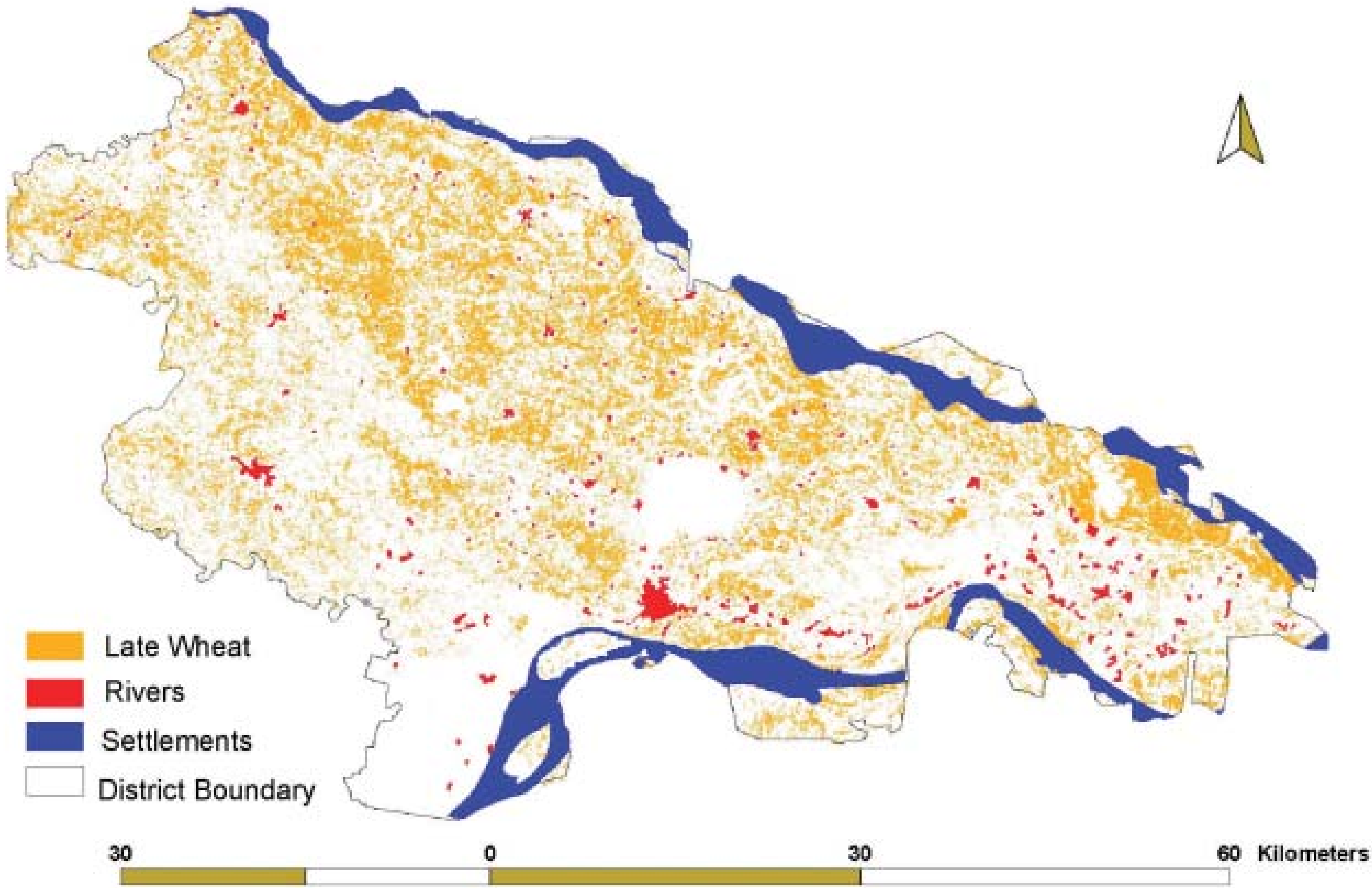


Plate 2. Spatial distribution of late-planted wheat within Ballia during the rabi season of 2001 – 02

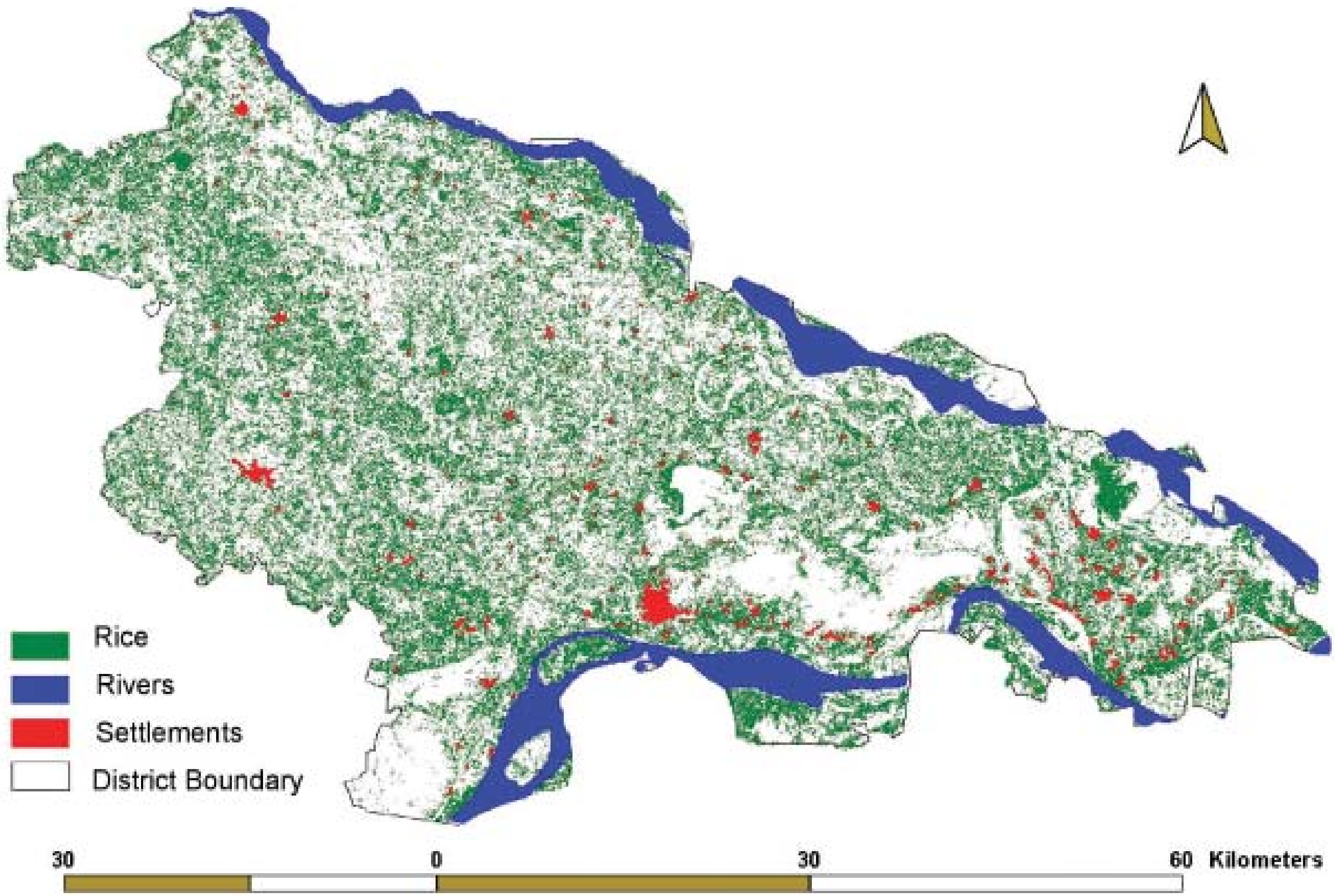


Plate 3. Spatial distribution of rice within Ballia during the kharif season of 2001

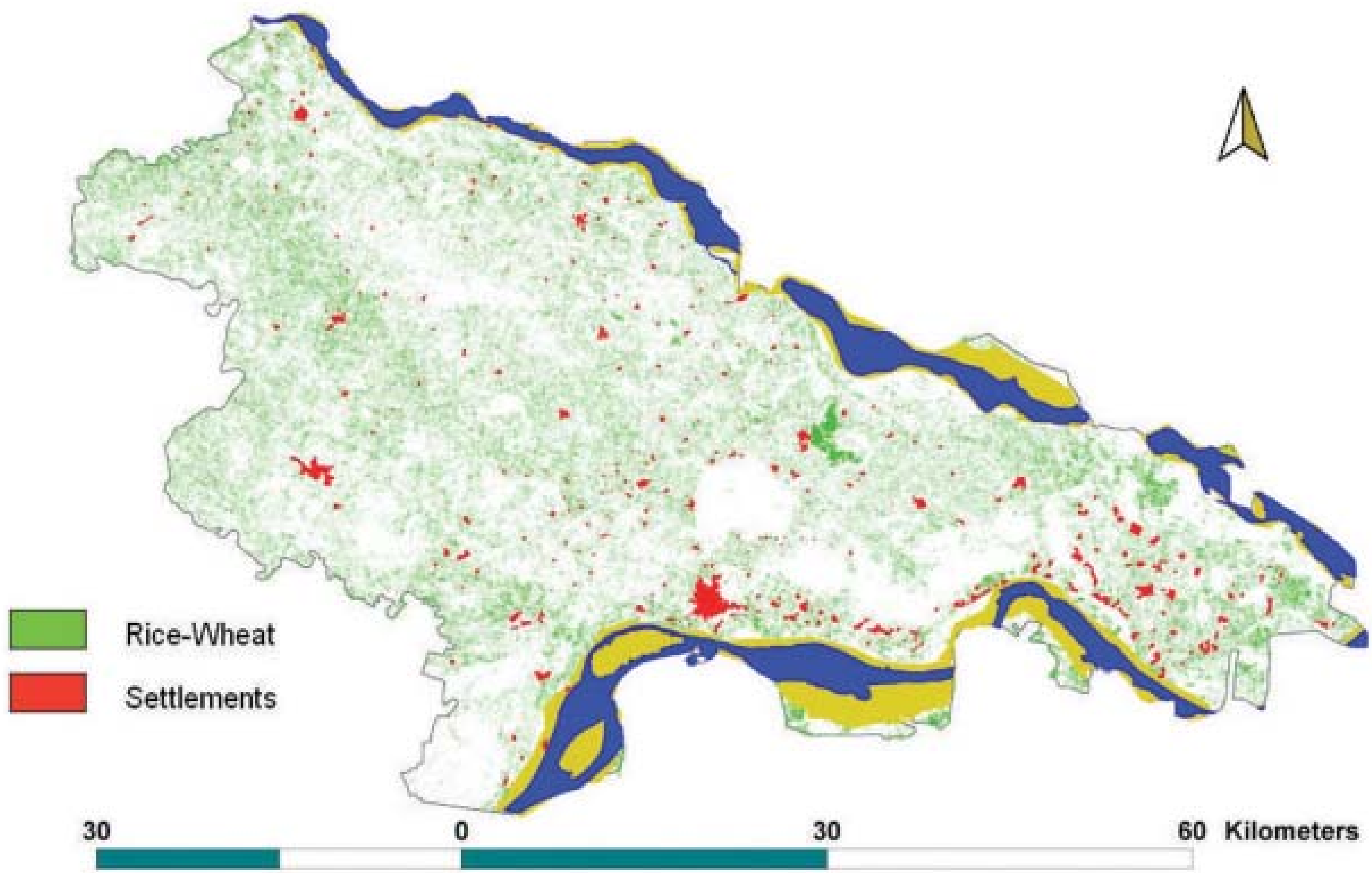


Plate 4. Spatial distribution of land under a rice-wheat cropping system within Ballia during 2001 - 02

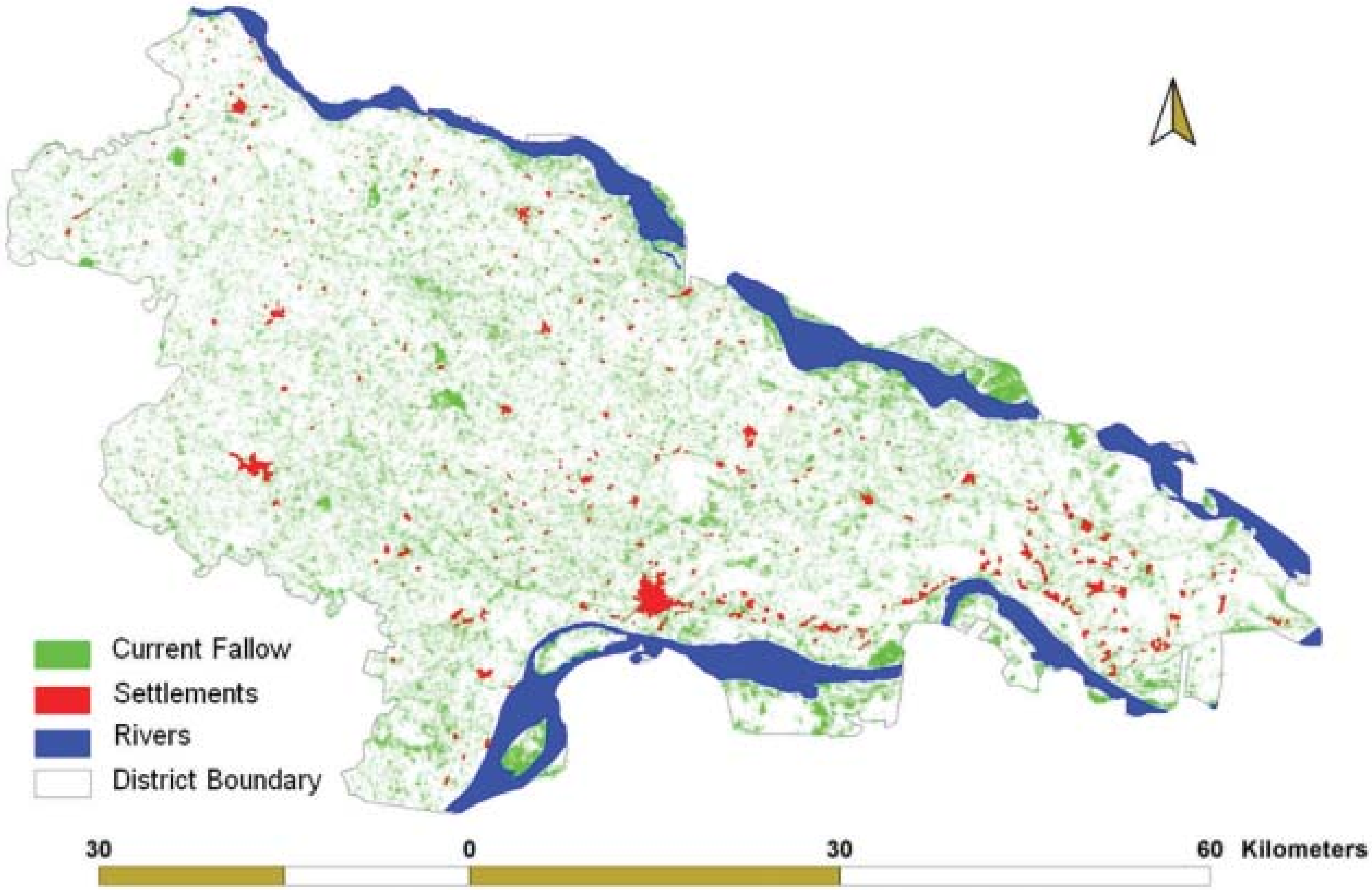


Plate 5. Spatial distribution of total current fallow lands within Ballia during the rabi season of 2001 – 02

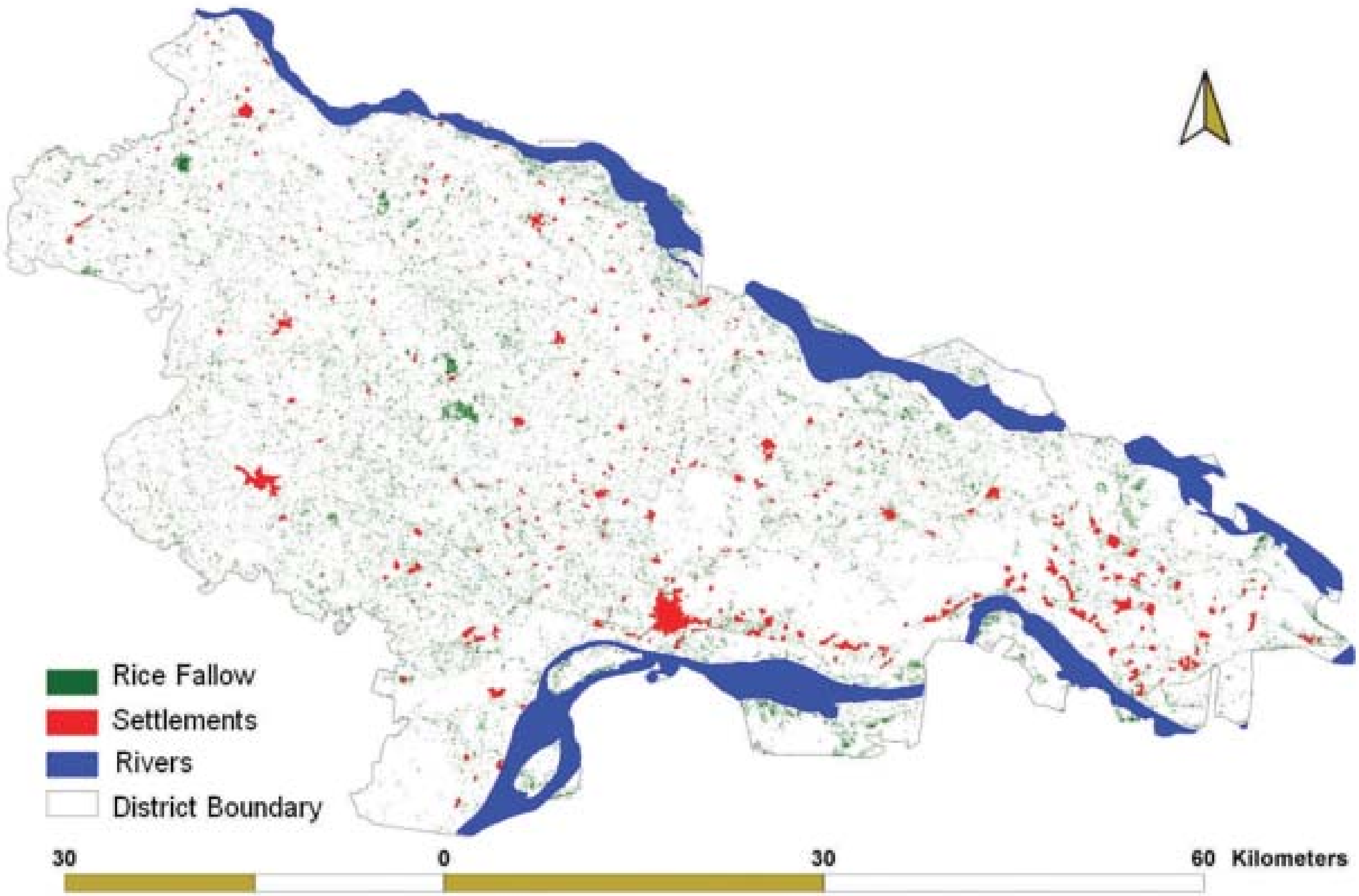


Plate 6. Spatial distribution of rice fallow lands within Ballia during 2001 – 02

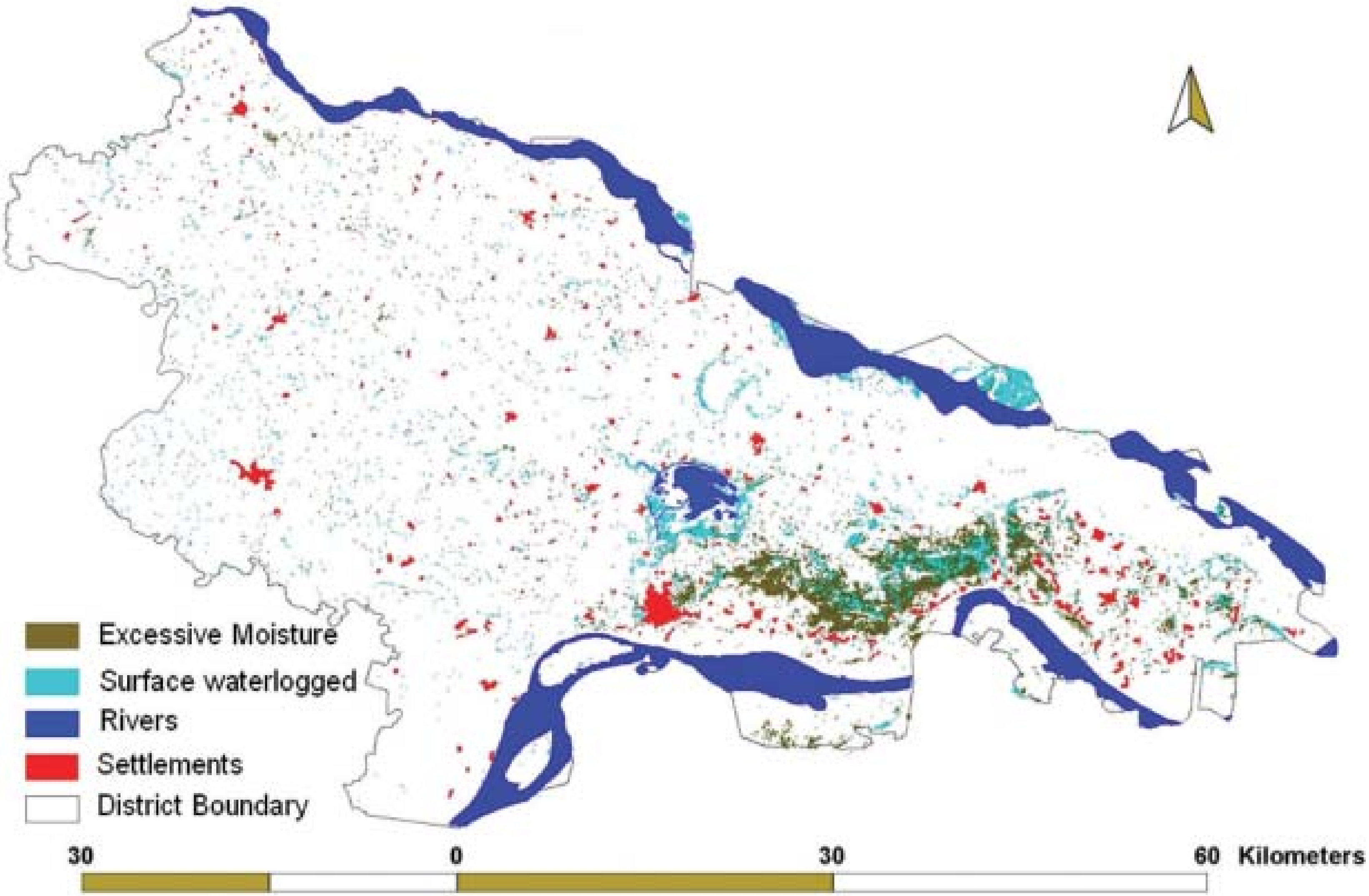


Plate 7. Spatial distribution of excessive moisture and water-logged lands within Ballia during the rabi season of 2001 – 02

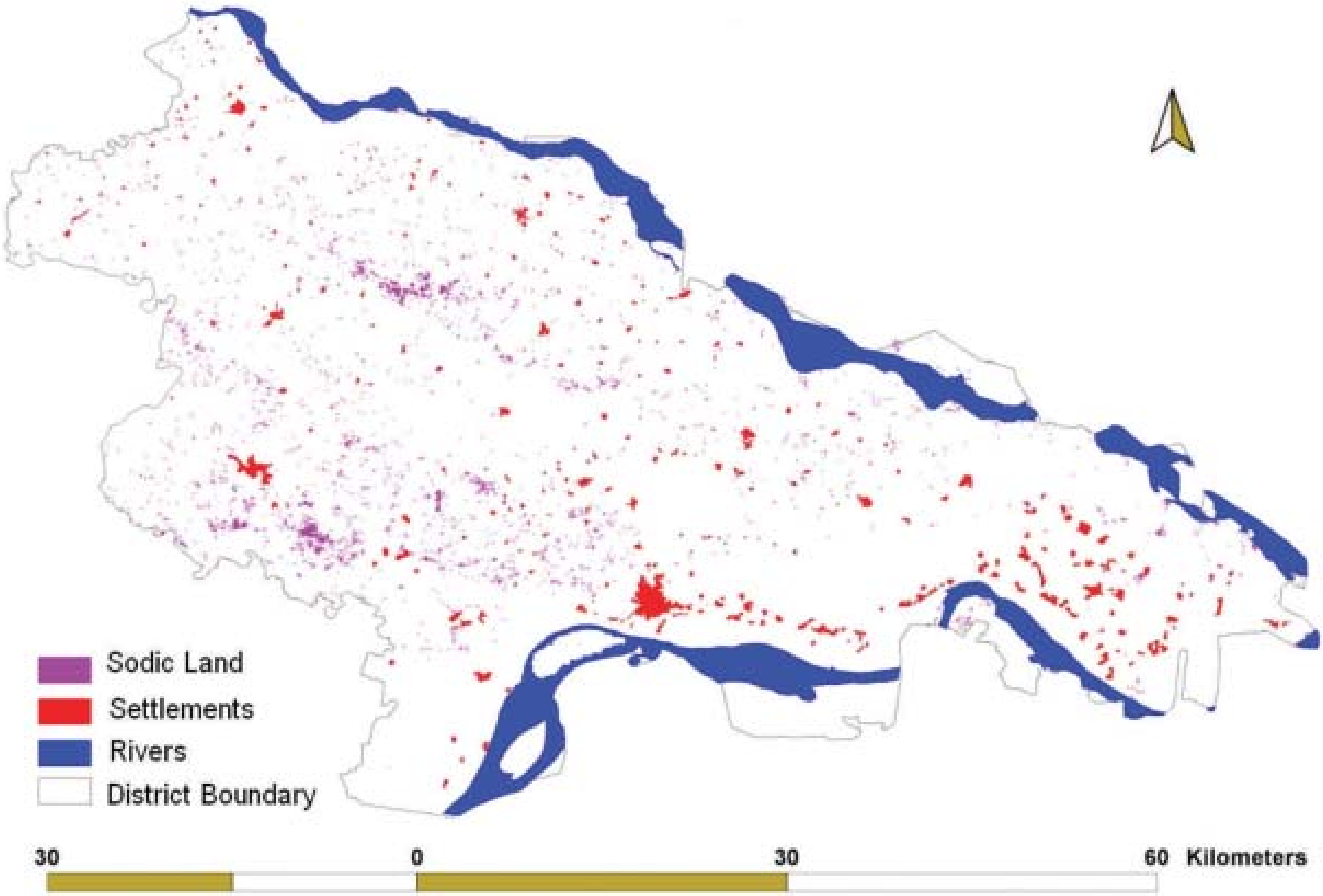


Plate 8. Spatial distribution of alkali / sodic lands within Ballia during 2001 – 02

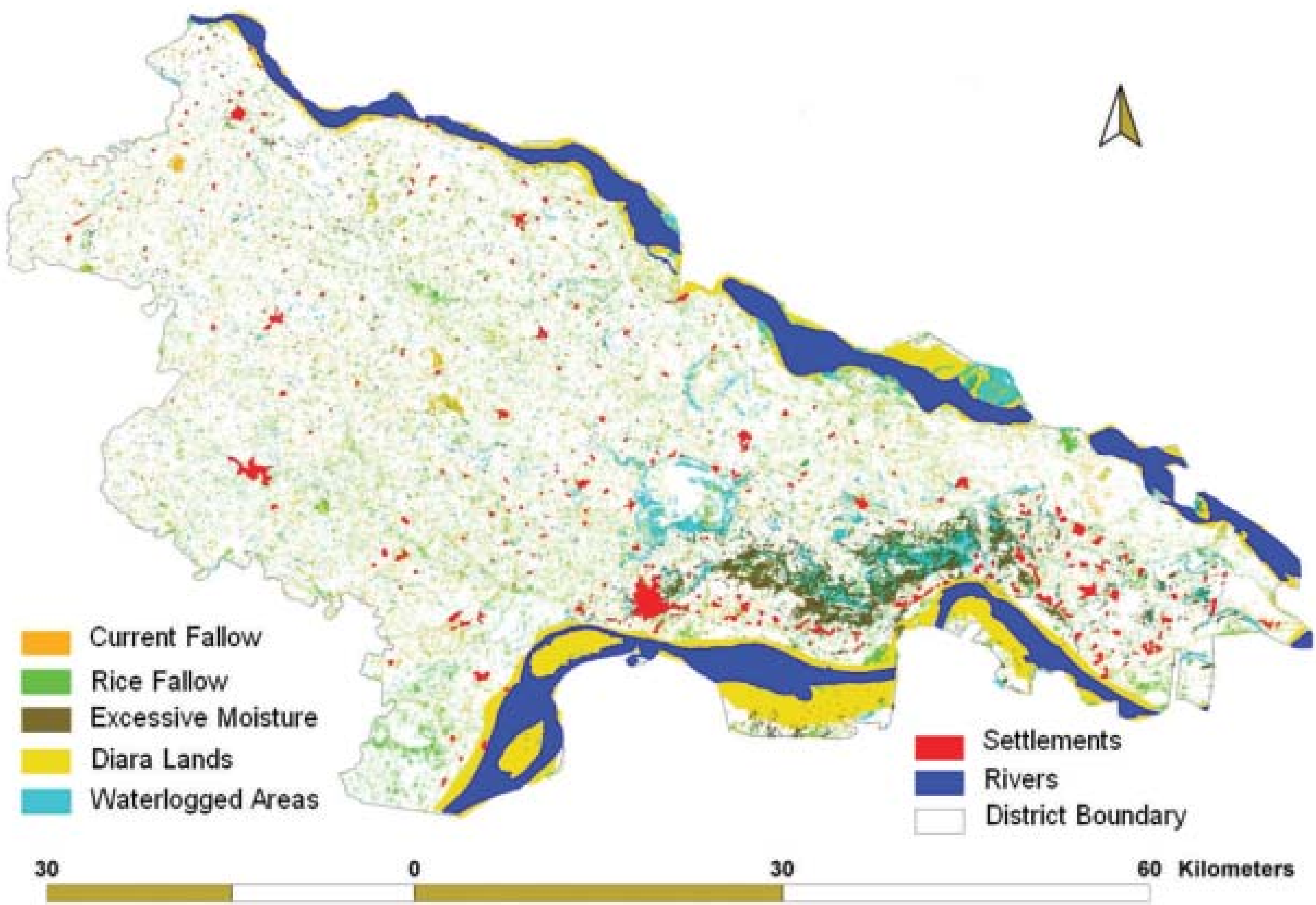


Plate 9. Spatial distribution of all underutilized land types within Ballia during 2001 – 02

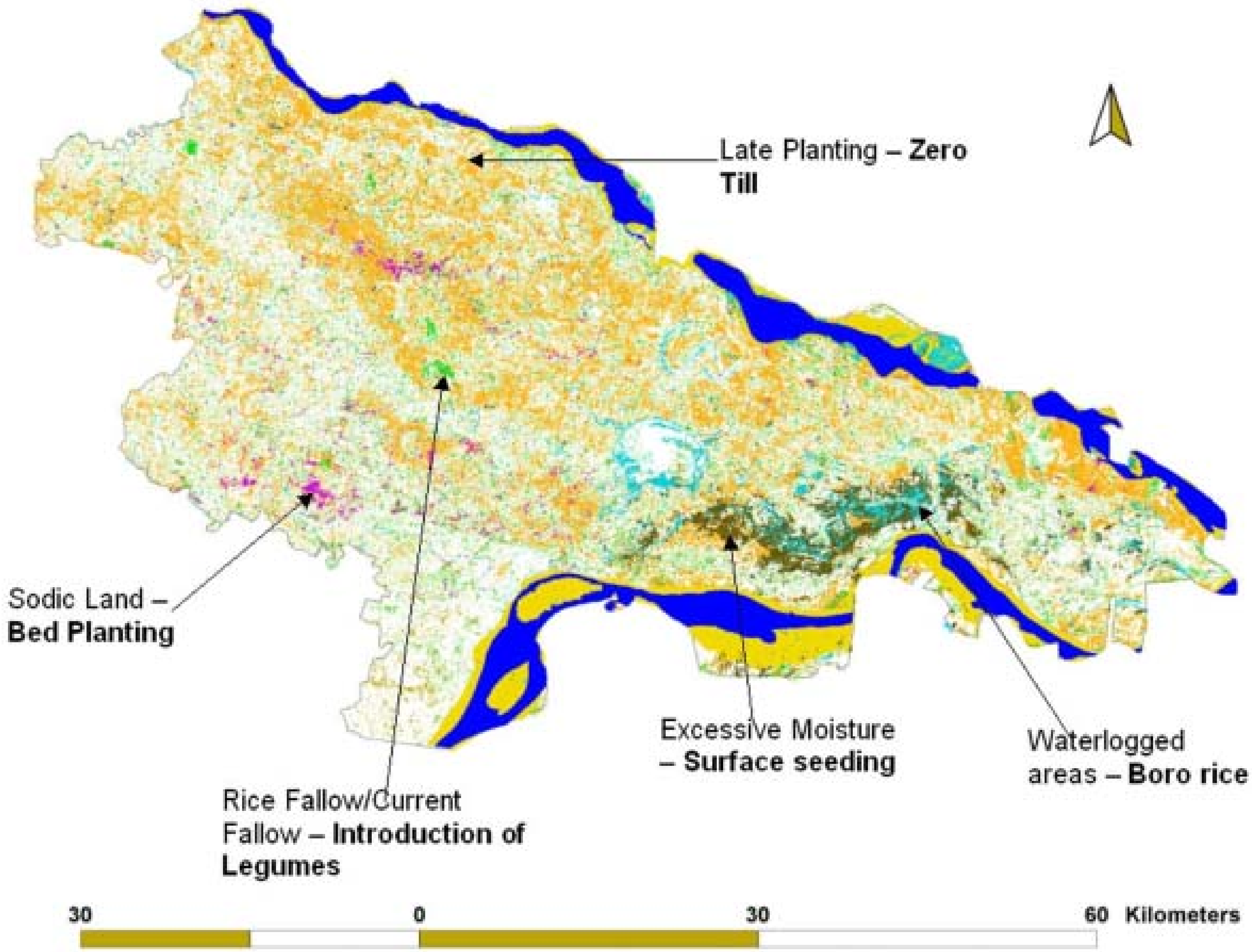


Plate 10. Potential technology targeting options for underutilized lands within Ballia

Glossary of Terms

Accuracy: The closeness or nearness of the measurements to the true or actual value of the quantity being measured. Usually represented as a percentile.

Accuracy assessments: These determine the quality of the information derived from remotely sensed data.

Chaur: A type of low land depression where water accumulates during rainy season.

Coordinates: X,Y input to denote a space on earth.

Diara lands: The land that lies in between the river bed and levees.

Datum: A datum is a mathematical surface on which a mapping and coordinate system is based.

Geographic Information System (GIS): A computerized information system for storing, manipulating and analyzing spatially indexed information or geo referenced information.

Geo-referencing: The process of establishing the relationship between page coordinates on a planar map and real-world coordinates.

Groundtruth: Observations or measurements made at or near the surface of the earth in support of an air or space-based remote sensing survey. It may also be referred to as ancillary data or reference data. Groundtruth may consist of several types of data acquired before, during, and after an image acquisition.

Global Positioning System (GPS): Method for identifying locations on earth using triangulation calculations of satellite positions. Originally created by the United States Military, it has since found numerous commercial applications as well as agricultural application.

Kharif: An Indian term used to indicate summer agricultural season, comprising the months of June to October.

Latitude: An angular measurement north and south of the equator.

Levee: Naturally formed raised bank along the side of a river channel.

Longitude: Angular measurement east and west from the prime meridian.

Lowlands: Land with the lowest elevations in the landscape.

Master image: The geo-referenced image to which all other images of the same area are aligned.

Maximum livelihood: A method embodying probability theory for fitting a mathematical model to a set of data.

Midlands: The areas that lie in between the lowland and upland.

Multispectral imagery: The process of using combinations of imagery taken at different wavelengths to generate a product (e.g., vegetation classification, vertical temperature, moisture sounding, etc).

Image classification: The process of arranging image pixels into categories based on their spectral values. There are two major types of image classifications unsupervised and supervised classification.

Projection: A mathematical calculation transforming the three-dimensional surface of the earth to a two-dimension plane.

Rabi: An Indian term used to indicate winter agricultural season comprising the months of November to March.

Remote sensing: Remote sensing means acquiring information about a phenomenon, object or surface while at a distance from it. The process of measuring a parameter (such as temperature, moisture, or rainfall) from a distance (such as from space, or by using a radar). This is done by measuring natural emission of radiation or backscattered radiation (i.e., radiation that was reflected or bounced back to the observing instrument) from an emission source.

Resolution: The degree to which small objects are distinguishable; the smallest spacing between two displayed or processed elements, the smallest feature that can be mapped or sampled.

Scale: The relationship between the size of the map and the corresponding size of the real world. For example with a 1:50,000 scale map, 1 cm on the map would represent 500 m in the real world.

Spectral signatures: The reflected/scattered/emitted energy of an object can be measured using various kinds of remote sensing instruments in terms of graphs and trends. These trends are spectral signatures.

Swath: The total ground area covered by a sensor in one scene.

Tal: An Indian term for a water body found in lowlands or depressions where water accumulates. Following the monsoon rains, water recedes very slowly from these areas.

Total cultivable land: This consists of net area sown, current fallows, fallow lands other than current fallows, cultivable waste and land under miscellaneous tree crops (Directorate of Economics and Statistics, India).

Thematic layers: A spatial dataset containing a common feature type. Themes are also referred to as layers or coverages.

Training sites: Areas representing each known land cover category that appear fairly homogeneous on the image (as determined by similarity in tone or color within shapes delineating the category).

Upland: Land with the highest elevations in the landscape.

Zaid: An Indian term used to indicate the agricultural season which falls in between kharif and rabi season, comprising the months of April, May, and mid-June.

References

Abrol, I.P., K.F. Bronson, J.M. Duxbury, and R.K. Gupta. 2000. Long Term Soil Fertility Experiments in Rice Wheat Cropping Systems. RWC Paper Series 6. Rice Wheat Consortium for Indo Gangetic Plains, New Delhi India.

Agricultural Statistics at a Glance, 1999, MOA, DAC, Govt. Of India.

Aslam, M., A. Majid, N.I. Hashmi, and P.R. Hobbs. 1993. Improving wheat yield in the rice-wheat cropping system of the Punjab through zero tillage. *Pakistan Journal of Agricultural Research* 14: 8-11.

Chandna, P., B.S Sokhi, and A. Kumar. 2002. Analysis of Existing wireless communication system using geo-spatial data – A case study of Dehradun City. A project report submitted to Indian Institute of Remote Sensing, Dehradun, Dept. of Space, Govt. of India. Page 16-18.

Census of India. 2001. Provisional Population Totals – 2001. Data Product No. PPT002. Office of the Registrar General India, New Delhi, India. CD-ROM.

Evans, L.T. 1993. *Crop evaluation, adaptation and yield*. Cambridge University Press, Cambridge, UK.

FAO. 1999. FAO production book, vol. 53, FAO, Rome Italy.

Gangwar, B. 1974. *Diara Land Farming – An Agricultural Review 1974*. Indian Council of Agricultural Research. p 71-80.

Gupta, R.K. 2002. 11th Regional Technical Coordination Committee Meeting – Rice wheat consortium for Indo Gangetic Plains. P. 9-10.

Gupta, R.K., and I.P. Abrol. 1990. Salt-affected soils: Their reclamation and management for crop production. *Adv. Soil Sci*. 11: 223-288.

Hobbs, P.R. 2001. Tillage and crop establishment in South Asian rice-wheat systems: present and future options. In Kataki, P.K. (ed.). The Rice-Wheat Cropping System of South Asia: Efficient Production Management. *Journal of Crop Production, Volume* 4 (1):1-23.

Hobbs, P.R., and R.K. Gupta. 2001a. Resource conserving technologies for wheat in rice-wheat systems. NRG web publication 2001. CIMMYT, Mexico D.F.

http://www.cimmyt.org/Research/NRG/map/developing_world/res_con/res_cons.htm

Hobbs, P. R., and R. K. Gupta. 2001b. Rice-Wheat Cropping Systems in the Indo-Gangetic Plains: Issues of Water Productivity in Relation to New Resource Conserving Technologies. In Proceedings of water productivity workshop held at IWMI, Colombo, Sri Lanka from 15-16th November 2001.

Hobbs, P.R., and M.L. Morris. 1996. *Meeting South Asia's Future Food Requirements from Rice Wheat Cropping Systems; Priority issues facing researchers in post green revolution era*. NRG Working Paper 96-01. CIMMYT, Mexico D.F.

Kumar, M. and B.K. Singh. 2002. Yearly report submitted to Rice Wheat Consortium for Patna site under ADB project.

Ladha, J.K., H. Pathak, A.T. Padre, D. Dawe, and R.K. Gupta. 2003. Productivity trends in intensive rice–wheat cropping systems in Asia. In *Improving the productivity and sustainability of rice wheat systems; issues and impacts*. ASA Spec. Publ. 65. ASA. CSSA. SSSA, Madison. WI. P 45-76

Mann, R.A., and C.A. Meisner. 2003. Proceedings of the national workshop on rice-wheat systems in Pakistan, 11-12th December, 2002. Islamabad, Pakistan. A Rice Wheat Consortium Paper Series 15. P. 2-3

Mishra, A., A.K. Ghorai, and S.R. Singh. 1997. *Effect of dike height on water, soil, and nutrient conservation and rice yield*. Publication No.5, WTCER, Bhubaneswar.

NAEB. 2003. Waste land vs geographical area break up 2003 – A report by National Afforestation and Eco-Development Board, (NAEB) Ministry of Environment & Forests, Government of India, Paryawaran Bhawan CGO Complex, Lodi road New Delhi - 110 003.

National Commission on Agriculture. 1976. A report by Govt. of India. P. 9-10.

NIRD. 2001. Rural Development Statistics. National Institute of Rural Development, Hyderabad, India.

Ortiz-Monasterio, J.I., S.S. Dhillon, and R.A. Fischer. 1994. Date of sowing effects on grain yield and yield components of irrigated spring wheat cultivars and relationships with radiation and temperature in Ludhiana, India. *Field Crops Research* 37: 169-184.

Paroda, R.S., T. Woodhead, and R.B. Singh. 1994. *Sustainability of rice–wheat production system in Asia*. RAPA Publication 1994/11. FAO, Bangkok, Thailand.

Paris, T.R., A. Singh, M. Hossain, J. Luis, H.N Singh, O.N. Singh, S. Singh, and R.K. Singh. 1999. Eliciting male and female farmers perceptions of rice varieties – A paper in IRRI program Report on Rainfed Lowland Rice Ecosystem.

Rai, M. 2002. A perspective for developing action program for sustaining productivity – Developing an Action program for farm level impact in Rice–wheat systems of the Indo Gangetic plains. Rice Wheat Consortium Paper Series 14. Rice Wheat Consortium for Indo Gangetic Plains, New Delhi India. P. 4-5.

Razzaque, M.A., Badarudin, M., and Meisner, C.A. 1995. Sustainability of rice–wheat systems in Bangladesh. Proc. National Workshop Dhaka, Bangladesh, 14- 15 Nov. 1994. Bangladesh and Australia Wheat Research Centre.

RWC. 2003. Agenda notes of the 11th Regional Technical Coordination Committee meeting. Kathmandu Nepal 4-6th March 2003. Rice Wheat Consortium for the Indo-Gangetic Plains, New Delhi.

RASC. 2001. A report on land use/ land cover mapping of priority watershed of Ballia district using IRS-IC data. Remote Sensing Application Centre, Lucknow and Natural Resource Information Consultants.

Sampei, S. 1997. Application of digital wireless technologies to global wireless communications. A project report submitted to Indian institute of Remote sensing Dehradun , Dept. of Space, Govt. of India. page 20-22.

Sheikh, A.D., M.A. Khan, M. Aslam, Z. Ahmad, and M. Ahmad. 1993. *Zero tillage wheat cultivation technology in the rice-wheat areas of the Punjab*. Pakistan, Islamabad: National Agricultural Research Council (NARC).

Subbarao, G.V., J.V.D.K. Kumar Rao, J. Kumar, C. Johansen, U.K. Deb, I. Ahmed, M.V. Krishna Rao, L. Venkatratnam, K.R. Hebbar, M.V.R.S. Sai, and D. Harris. 2001. *Spatial distribution and quantification of rice-fallows in South Asia – potential for legumes. International Crops Research Institute for Semi arid Tropics*, National Remote Sensing Agency and DFID plant Sciences Research Programme. ICRISAT, Patancheru, Andhra Pradesh, India.

Thakur, J., M.L., Bose, M. Hossain, and A. Janaiah. 2000. Rural income distribution and poverty in Bihar: Insights from village studies. *Economic and Political Weekly*.

Timsina, J., and D.J. Connor. 2001. The productivity and sustainability of rice wheat cropping systems; issues and challenges. *Field Crops Res*. 69: 93-132.

UN Disaster Management Team. 2002. *India Bihar Flood Situation Report* Sept. 06, 2002.

World Bank. 1991. India irrigation sector review Vol. I. Main document. World Bank Report No. 9518-IN, 1991. P. 61

World Bank. 2000. Leaching the salts to reclaim the land. India's Uttar Pradesh Sodic Lands Reclamation Project I. World Bank web document. June 28, 2000.

http://wbln1018.worldbank.org/sar/sa.nsf/0/f5f5dae81cc5ef348525690c0050dda2?OpenDocument

http://lnweb18.worldbank.org/sar/sa.nsf/Attachments/UPPov-toc/$File/Contents.pdf

World Development Indicator Database. 2000. Sustainable Networking Programme Bangladesh July 2000.

Yadav, R.L., K. Prasad, and K.S. Gangwar. 1998. Analysis of ecoregional production constraints in rice-wheat cropping systems. PDCSR Bull 98-2. PDCSR, Modipuram, India. 68p.